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Field performance of a pneumatic row crop planter equipped with active toothed coulter for direct planting of corn in wheat residue

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Abstract

In this research effects of active toothed coulter on planter penetration in semi-dried soils covered with previous wheat (*Triticum aestivum)* residue was studied. Therefore, effects of three levels of speed ratio (coulter peripheral speed/tractor forward speed; 1.22, 2, 3) at two previous residue levels (baled and non-baled) and two modes of planter attachment (with and without row cleaner) on the corn (*Zea mays*) planting depth and its uniformity, amount of surface residue, emergence rate index and seed spacings indices were investigated. Results showed that planting depth and its uniformity increased significantly with increasing speed ratio, so that desired planting depth was obtained at speed ratio of 2. The emergence rate index decreased with increase in speed ratio mainly due to increase in seeding depth at higher speed ratios. Miss and precision indices decreased in a significant manner with increase in the speed ratio. Other results showed that planting with row cleaner attachment into baled-out residue plots at speed ratio of 2 resulted in 31% decrease in miss and 30% decrease in precision indices as compared to control (inactive coulter). Quality of feed index at same conditions was 72%, the increase was up to 11% as compared to control. No significant difference was found between speed ratios of 2 and 3 for all the parameters studied. The results suggest that the row crop planter equipped with active toothed coulter and row cleaner attachment can be satisfactorily used for direct corn planting in hard soils covered with previous crop residues.

Additional key words: active coulter; speed ratio; seed placement; seed spacing; *Triticum aestivum*; *Zea mays.*

Introduction

No-tillage or zero tillage is a farming system in which seeds are directly deposited into untilled soil retaining previous crop residues. Special no-till seeding equipment with discs (low disturbance) or narrow tine coulters (high disturbance) open a narrow slot into the soil covered residue which is only wide enough to put the seeds into the ground and cover them with soil. No other soil tillage operation is required. The residues from the previous crops will remain largely undisturbed at the soil surface as mulch (CTIC, 2011). The fact that the soil is not tilled and remains permanently covered with crop residues leads to efficient erosion control, to sequestration of atmospheric carbon in the soil, to increase biological activity in the soil, to better conservation of water and to higher economic returns through time (Derpsch *et al.*, 2010).

Planting depth is a factor that needs to be optimized for successful no-till or reduced tillage systems. Tanaka *et al*. (1997) concluded that seeding depths common in tilled seed beds are not appropriate for no-till. They found that increasing seeding depth from 25 to 75 mm could delay emergence by 3 days and subsequently reduce yield. They concluded that seeding depth with no-till should be 25-50 mm because that planting depth promotes quick emergence and allows the crop to get a head start on weeds. Soil and weather conditions will modify these recommendations, and although 50 mm is often ideal for average conditions, the ideal depth in early April when soils are cool may be slightly less. However, planting depth for corn (*Zea mays* L.) should never be less than 35 mm (Farnham, 2001).

Rolling cutting coulters are extensively used to cut plant residues left on the soil surface, and also as to facilitate the work of tillage tools in reduced tillage or direct drilling practices. Four basic patterns of these

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Abbreviations used: B (baled-out residue); DAP (number of days after planting); EMG (percentage of seeds emerged on the day); ERI (emergence rate index); NA (inactive coulter); NB (non-baled residue); NRC (without row cleaner attachment); QFI (quality of feed index); RC (with row cleaner attachment).

coulters are available in the market; smooth, notched, ripple, and wave. These coulters have operational problems and usually do not cut the residue efficiently. When the soil is dry, they demand high vertical load to penetrate and when the soil is wet, they push the residue into the soil without cutting it. This work presents a new geometry for cutting coulters, making them capable of cutting through residue under any soil condition, eliminating build-up and reducing implement draught. Magalhaes *et al.* (2007) presented a toothed coulter which was designed using a computer simulation program. In this program, soil resistance to the action of the coulter teeth could be calculated using the theory for narrow tools described by McKyes (1985), assuming that a tooth penetrating the soil behaves as a narrow tine with a variable rake angle and depth. After laboratory tests in a soil bin, the best disc performance was obtained using a 610 mm diameter coulter.

According to Tice & Hendrick (1992), the interaction between the coulter and soil is poorly understood. A peripheral disc speed greater than forward speed is essential to ensure a positive sliding cut action at the disc edge, which results in better cutting of the residue.

Bianchini & Magalhaes (2007) conducted experiments in a soil bin to evaluate the performance of toothed coulters in comparison with notched and smooth coulters, in cutting sugar cane residue in two working depths (80 and 100 mm). Their results showed that toothed coulter performed best, since that was more efficient than smooth and notched coulters in cutting crop residue. It required smaller torque, and lower vertical and draught forces requirements.

Raoufat & Matbooei (2007) indicated that surface residue decrease planting depth and uniformity of seed spacing. In order to overcome the seed placement, they suggested equipping row-crop planter with row cleaner attachments. The row cleaner improved seed placement uniformity through clearing surface residue on the rows.

This study attempts to evaluate the performance of a row crop planter with active coulter as compared to a conventional row crop planter. Planting depth and its uniformity, emergence rate index, amount of retained residue after planting and seed spacing indices will be considered in evaluation.

Material and methods

According to Bianchini & Magalhaes (2007) smooth and notched coulters usually do not cut the residue efficiently. When soil is dry and hard, they demand higher vertical load to penetrate as compared to toothed coulter. First a toothed coulter was designed and fabricated from a smooth coulter according to design guidelines presented by Magalhas *et al.* (2007) (Fig. 1a). The physical dimensions of the coulter are presented in Table 1.

Power could be transmitted from hydro motor shaft to the coulter assembly by a chain drive. Components of this hydrostatic system included a gear pump, a rotary hydro motor, a relief valve, a flow control valve and a reservoir (Fig. 1b). Considering the fact that both hydro motor and pump were fixed-displacement type, a compensated flow control was used to adjust speed of the hydro motor. A four bar linkage mechanism with spring loaded link was used to promote double disk

a)

b)

c)

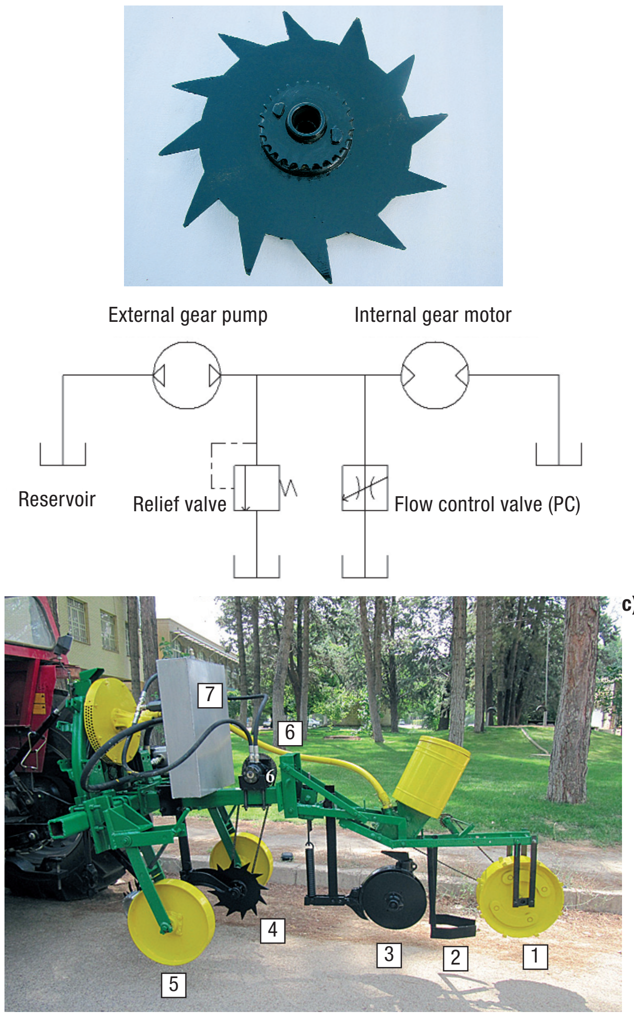

Figure 1. The fabricated toothed coulter (a), layout of the hydrostatic system (b) and row crop planters (c) used in this study: 1) drive wheel of the seed metering; 2) furrow filler; 3) double disk furrow opener; 4) toothed coulter; 5) gauge wheel; 6) hydro motor; 7) reservoir.

Table 1. Dimensions of the toothed coulter used in this study

External diameter	380 mm
Coulter thickness	4 mm
Number of teeth	12
Tooth height	60 mm
Tooth tip angle	30°
Tooth cutting edge length	70 mm

furrow opener penetration in the soil (Fig. 1c). Down force pressure was adjusted using spring. The row cleaner attachment was similar to that used by Raoufat & Matbooei (2007). The seed metering was ground driven. Finally all of the attachments were assembled on a single unit row crop planter to accomplish the treatment envisaged in this study. Fig. 1c shows the developed row crop planter in this study.

The row crop planter was adjusted for planting at 50 mm depth at theoretical seed spacing of 90 mm. Field experiments were conducted in summer 2011 at the Badjgah Research Station, Shiraz University located in NW Shiraz, Iran. The soil was classified as clay-loam at an average moisture content of 6% db covered with previous wheat (*Triticum aestivum* L.) crop residue at depth range of 0-100 mm. The soil con index was 1.9 Mpa at above moisture content. The study was arranged in a randomized complete block design as a $4 \times 2 \times 2$ factorial with 16 treatments and three replications. The variables were three levels of speed ratio (1.22, 2 and 3) plus control (inactive control, NA) and two levels of residue (non- baled, NB and baled- out, B) and two modes of attachment (with-RC/ without row cleaner-NRC). Corn hybrid SC-704, with 1000-kernel weight of 250 g, emergence of 87% and purity of 93% was planted. Plot dimensions were 5 m × 20 m and the measurements taken in each plot were (i) weight of the residue after planting operations, (ii) depth of seed placement, (iii) number of seeds emerged per day and (iv) distance between seedlings.

Residue management

A relatively uniform stubble was left after harvesting the wheat with a combine, the amount of wheat residue was measured immediately after harvest by collecting and drying at 105°C for 24 h and weighting all surface residue from 0.5 m^2 quadrant using 10 samples for each plot. The averages of wheat residue at this experimental site were 5.65 and 3.52 t ha^{-1} for non- baled and baled- out plots.

After planting, residue samples were measured an each row and regarded as flat surface cover. Eq. [1] introduced by Papendick (2002) was used to convert flat surface cover to percent residue cover:

$$y = (1 - e^{-0.000644x}) \times 100 \qquad [1]$$

where y is the percentage of residue cover, and x is the dried weight of residue per unit surface area.

Considering the threshold for adopting conservation farming that at least 30% of the soil surface should be covered with crop residue (McCarthy *et al.*, 1993), the equation was solved for 30% surface residue cover and x was found to be 621 kg ha^{-1}.

Speed ratio

Speed ratio was calculated using the following equation:

$$\text{speed ratio} = \frac{s_p}{s_f} = \frac{2\pi rn}{60\, s_f} \qquad [2]$$

where s_p is the coulter peripheral speed (m s^{-1}), s_f is the tractor forward speed (m s^{-1}), r is the radius of coulter (m) and n is revolutions min^{-1} (rpm) of the coulter. For three levels of rotational speeds of coulter (120, 200, 300 rpm) at 0.19 m coulter radius moving at 7 km h^{-1} forward tractor speed, three speed ratios could be established (1.22, 2 and 3).

The rotational speed of hydro motor could be recorded by an incremental shaft encoder mounted on the output shaft. Considering the coefficient of increase in coulter speed in chain drive transmission for driving coulter, the coulter speed could be calculated as:

$$\text{rpm of coulter} = \text{recorded rpm by encoder} \times 1.66 \qquad [3]$$

where 1.66 is the coefficient of increase in coulter speed in chain drive transmission

Emergence rate index

Emergence rate index (ERI) – (Erbach, 1982) – was calculated using Eq. [4] by counting the number of plants that emerged for several days after planting (DAP):

$$ERI = \sum_{n=1}^{x} \frac{EMG_n - EMG_{n-1}}{DAP_n} \qquad [4]$$

where n is the nth emergence observation, EMG_n and EMG_{n-1} the percentage of seeds planted that have emerged on the day of the nth and (n-1)th emergence observation, respectively, $EMG_{n-1} = 0$ when $n = 1$ and DAP_n is the number of days after planting when the n^{th} emergence observation was taken. In this study, counts were made on 7, 9, 11, 13, 15, 18 and 21 days after planting, and stopped when no further increase in emerged counts was observed.

Seed placement depth

A special tool was developed to help pull seedlings out of the soil to measure placement depth. The seedlings were washed and the length of the mesocotyl was measured. An extra 20 mm was added to obtain seed placement depth since nodal roots typically grow approx. 20 mm below the soil surface (Ritchie *et al.,* 1993). Measurements were made at several randomly selected locations within each plot and averaged for statistical analysis.

Uniformity of seed spacing

The uniformity of seed spacing was determined as outlined by Katchman & Smith (1995). The theoretical spacing for the plants used in this study was considered to be 90 mm. This value was therefore used as a reference spacing (x_{ref}) to divide the observed plant spacings into several categories which correspond to the following classifications: (1) $0 - 0.5x_{ref}$, a multiple, closer to the previous plant than the theoretical spacing; (2) $0.5x_{ref} - 1.5x_{ref}$, a single, closer to the theoretical spacing than either the previous plant or a single skip; (3) $1.5x_{ref} - 2.5x_{ref}$, a single skip, closer to a single skip than either the theoretical spacing or a double skip, (4) $2.5x_{ref} - 3.5x_{ref}$, as a double skip, and (5) $> 3.5x_{ref}$. as a triple or more skips. The seeds that fall in the second classification of regions are considered as planted with correct spacing. These measures are defined as:

— Multiple index: percentage of plant spacings that are less than or equal to half the theoretical spacing. Smaller values of multiple index indicate better planter performance than larger values.

— Miss index: percentage of plant spacings that are 1.5 times larger than the theoretical spacing. Similarly smaller values of miss index indicate better planter performance than larger values.

— Quality of feed index (QFI): percentage of plant spacings that are more than half and less than or equal to 1.5 times theoretical spacing. Greater values of this index indicate better planter performance than smaller values. In other words, quality of feed index is a measure of how often the spacings are close to the theoretical spacing (Kachman & Smith, 1995).

— Precision is a measure of the variability in spacing between plants after accounting for variability due to both multiples and skips. Smaller values of precision mean better performance than larger values. The theoretical upper limit for precision is 50%, which indicates that the theoretical spacing is incorrectly specified and, therefore, this level of theoretical spacing is unfavorable. A practical upper limit on the value of precision is 29%, while there is a theoretical upper limit of 50 % on the precision, and values consistently larger than 29% should be viewed with suspicion (Kachman & Smith, 1995).

Statistical analyses

All experiments were carried out in triplicate and the data were analyzed using the ANOVA procedure of SPSS (vers. 17.0, 2010) followed by the comparison of means using the Duncan multiple range test ($p \leq 0.05$).

Results and discussion

Evaluation of amount of residue retained

Comparison of the data means on residue retained after planting operation (Table 2) showed that increase in speed ratio resulted in lower amount of residue retained which is mainly due to throwing of surface residue to both sides by the active coulter. Minimum amount of residue retained after planting operation was observed at speed ratio of 3. The amount of residue retained decreased significantly at speed ratios of 2 and 3 as compared to the control. Nonetheless, significant difference was not found between speed ratios of 2 and 3. Table 3 shows that the row cleaner attachment decreased the amount of residue retained up to 34% as compared to NRC treatment. For the B and NB residue plots, the residues are 2.12 and 2.59 t ha^{-1}, amount equivalent to removal averages of 40% and 55% of those present before planting, respectively. This suggests that the row cleaner works effectively at high residue conditions (Table 3). The 3/B/RC and 1.2/NB/NRC treatments resulted in minimum and maximum amounts of residue retained.

Table 2. Overall speed ratio effects on in-row residue retained, seeding depth, standard deviation (SD) of seeding depth, emergence rate and planter performance indices

Speed ratio	Residue retained (t ha^{-1})	Seeding depth (mm)	SD of seeding depth (mm)	Emergence rate (% d^{-1})	Miss index (%)	QFI[1] (%)	Precision (%)
NA[2]	3.42^{a}	31^{a}	4.1^{a}	24.26^{a}	43.17^{a}	41.23^{b}	14.69^{a}
1.22	3.39^{a}	41^{b}	3.9^{a}	20.00^{b}	44.10^{a}	40.70^{b}	14.65^{a}
2	2.57^{b}	50^{c}	2.2^{b}	15.30^{c}	31.25^{b}	53.00^{a}	11.60^{b}
3	2.47^{b}	51^{c}	2.1^{b}	14.24^{c}	30.17^{b}	53.9^{a}	11.02^{b}

[1] QFI: quality of feed index. [2] NA: inactive coulter (control). Means followed by the same letter within a column are not significantly different at $p < 0.05$.

Table 3. Initial crop residue and row cleaner attachment effects on in-row residue retained and removed, seeding depth, standard deviation (SD) of seeding depth, emergence rate and planter performance indices

	Residue retained (t ha^{-1})		Seeding depth (mm)	SD of seeding depth (mm)	Emergence rate (% d^{-1})	Miss index (%)	QFI[3] (%)	Precision (%)
	RC[1]	NRC[2]						
Residue treatment								
B[4]	2.12^{d}	2.92^{c}	43^{a}	3.0^{a}	21.75^{a}	33.84^{b}	50.81^{a}	11.78^{b}
NB[5]	2.59^{b}	4.22^{a}	43^{a}	3.1^{a}	15.15^{b}	40.76^{a}	43.61^{b}	14.20^{a}
Row cleaner								
NRC	2.36^{b}		43^{a}	3.0^{a}	20.38^{a}	20.31^{b}	64.18^{a}	15.20^{a}
RC	3.56^{a}		44^{a}	3.2^{a}	16.52^{b}	54.30^{a}	30.23^{b}	30.50^{b}

[1] RC: with row cleaner. [2] NRC: without row cleaner. [3] QFI: quality of feed index. [4] B: residue removed by baling. [5] NB: non baled residue. Means followed by the same letter within a column have not significant difference at $p < 0.05$.

Evaluation of depth of seed placement

Comparison of average seeding depth as affected by speed ratio (Table 2) indicated that seeding depth increased significantly as speed ratio increased. The seeding depth was equal to recommended value of 50 mm at speed ratio of 2. The seeding depth in control treatment was 38% lower than the desired planting depth (50 mm). The row cleaner attachment and amount of previous surface residue had no significant effects on seeding depth (Table 3). This is in contrary to findings of Sanavi & Matbooei (2006), Fallahi & Raoufat (2007) and Raoufat & Matbooei (2007) who reported that row cleaner attachment and removing surface residue by baling increased the seeding depth mainly due to decrease in the amount of surface residue. The reason for this conflict in the present study might be perfect residue cutting by active coulter paving the way for subsequent furrow opener operation. It can be concluded that the seeding depth is independent of levels of previous residue on the soil, which is desirable. The seeding depth near to target depth pertained to the 2/B/NRC treatment (Fig. 2a).

Evaluation of uniformity of seed placement depth

Levels of surface residue had no significant effect on the uniformity of seeding depth (Table 3), however the SD of seeding depth decreased with increasing of speed ratio. The active toothed coulter cut the root and stem residue in wheat perfectly, creating a good seed placement at uniform depth. The SDs of seeding depth at speed ratios of 2 and 3 were lower as compared to the control a reduction of 48% (Table 2). No significant difference was found between speed ratios of 2 and 3. Table 3 reveals that level of previous surface residue and row cleaner attachment had no significant effect on this factor. The maximum uniformity of seeding depth (minimum standard deviation) was observed for baled residue plots at speed ratio of 3 in the presence of row cleaner attachment (3/B/RC).

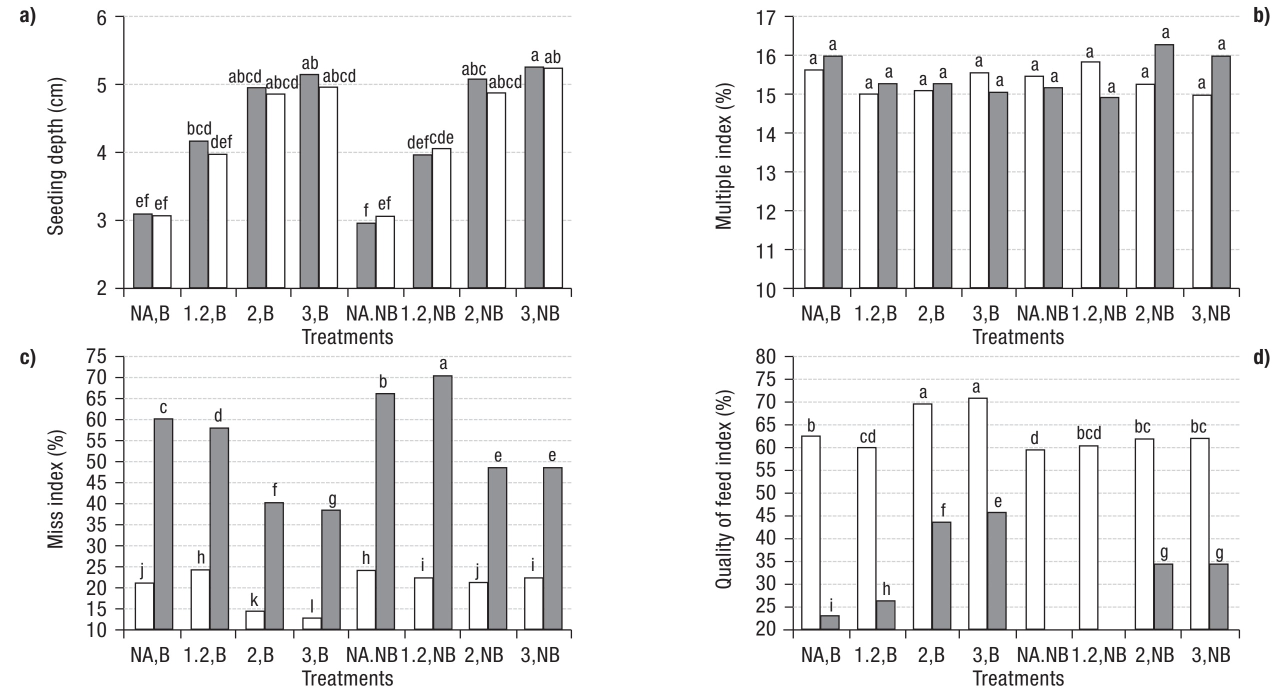

Figure 2. Comparison of means of (a) seeding depth, (b) multiple index (c) miss index, and (d) quality of feed index at various residue conditions, speed ratios and attachment modes. NB, non-baled residue; B, residue removed by baling; NA, inactive coulter (control); 1, 2 and 3, speed ratios; RC, with raw cleaner; NRC, without row cleaner. Columns with same letters are not significantly different at $p < 0.05$. Grey histograms: RC. White histograms: NRC.

Evaluation of emergence rate index

ERI decreased significantly at higher speed ratios. The reason was increase in seeding depth caused by higher speed ratios (Table 2). Addition of row cleaner attachment resulted in higher emergence rate as compared to the planter without row cleaner (Table3). Other findings show that planting at baled residue plots results in highest emergence rate (Table 3). This is in agreement with findings of Cochran *et al*. (1982) who declared that allelopathic effects of incorporation of high residue in the soil may reduce the grain yield and hence emergence rate index. Furthermore high residue might provide cooler conditions and retard early plant growth (Wicks *et al*., 1994). Raoufat & Matbooei (2007) also reported that planting with planter equipped with row cleaner attachment at reduced surface residue result in higher emergence rate. The maximum and minimum emergence rate in this study pertained to NA/B/RC and 3/NB/NRC treatments, respectively.

Evaluation of seeding indices

Data on seedling spacings were used to calculate the following four indices of spacing. During field trials, it was observed that amount of residue cover affects seed spacing. Higher surface residue would result in more hampering of press wheel rotation which would finally result in unsatisfactory performance of seed metering system for common planters in local farms.

Analysis of variance of the data on average multiple index as affected by various treatments and their interactions showed that none of the treatments have significantly affected this index ($p < 0.05$). Fig. 2b shows comparison of data means of multiple index for various treatments.

Comparison of data means indicated that miss index decreased significantly in speed ratios of 2 and 3 up to 27% and 30% as compared to control (Table 2). The reason might be higher surface residue that cause increase in planter press wheel slippage. No significant difference was observed in speed ratio of 1.2 as compared to inactive coulter (control). No significant difference was found between speed ratios of 2 and 3 (Table 2). Table 3 also reveals that this index has decreased as a result of row cleaner attachment. Moreover, reduction in surface residue resulted in sharp decrease in miss index which is desirable (Table 3). This is in agreement with findings of Raoufat & Matbooei (2007). The lowest (12.5%) and the highest (71%) values of miss index among residue plots were obtained for the 3/B/RC and 1.2/NB/NRC treatments, respectively (Fig. 2c).

Mean comparison of values of QFI as affected by speed ratio revealed that QFI has increased significantly for speed ratios of 2 and 3 up to 28% and 30% as compared to the control (Table 2). Nonetheless, no significant difference was found between speed ratios of 2 and 3 (Table 2). Similarly, the QFI for speed ratio of 1.2 was not significantly different as compared to control (Table 2). Moreover, QFI increased as the surface residue reduced from NB to B residue level which is desirable (Table 3). Further analysis indicated that the row cleaner attachment increased QFI significantly (Table 3). The lowest (14%) and the highest (72%) values for QFI were observed for the 1.2/NB/NRC and 3/B/RC treatments, respectively (Fig. 2d). Similar results have been reported by Kaspar & Erbakh (1998), who stated that crop residues interfere with planter performance, resulting in poor seed placement and reduced final stand.

Comparison of data means on precision index as affected by speed ratio indicated that significant differences exist among treatments (Table 2). Minimum value of precision was obtained in speed ratio of 3 which is desirable. Furthermore, the lower values of precision index were obtained for plots planted in presence of row cleaner attachment (Table 3). Table 3 also shows that as the surface residue increases, the precision index tends to increase which is undesirable. Other data showed the lowest (7%) and the highest (18%) precision index values occurred for 3/B/RC and NA/NB/NRC treatments, respectively.

For all the parameters studied, no significant difference was found between speed ratios of 2 and 3 (Table 2) and hence in the present study, the speed ratio of 2 is recommended for direct planting of corn.

As conclusions, this study suggests that the row crop planter equipped with active toothed coulter and row cleaner attachment can be used satisfactorily for direct planting of corn in hard soils covered with previous crop residue. Adoption of active toothed coulter and row cleaner attachment to planters can successfully achieve the desired seeding depths and plants spacing uniformity. The active toothed coulter could significantly establish deeper seed placement and also, improve uniformity of seeding depth. Level of previous surface residue and row cleaner attachment had no significant effect on seeding depth and its uniformity. This is the advantage of the active toothed coulter introduced in this study. Moreover, the row cleaner attachment improved the seeding indices and emergence rate index significantly. Removing surface residue by bailing comprised similar results.

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