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Residue management practices and planter attachments for corn production in a conservation agriculture system

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Abstract

Seed placement and failure to establish a uniform plant stand are critical problems associated with production of corn (*Zea mays*) following wheat (*Triticum aestivum*) in a conservation agriculture system in Iran. Our objectives were to evaluate the performance of a corn row- crop planter equipped with two planter attachments (smooth/toothed coulters) at six wheat residue management systems (three tillage systems and two levels of surface residue) at two forward speeds of 5 and 7 km h^{-1}. Residue retained after planting, seeding depth, emergence rate index (ERI) and seed spacing indices were determined. The baled residue plots tilled by chisel plow followed by disc harrow (BRCD) resulted in minimum residue after planting as compared to other residue treatments. Furthermore, the maximum values of the ERI and uniformity of plant spacing pertained to this treatment. Other results showed that the ERI increased up to 18% for the toothed coulter as compared to the smooth coulter. The toothed coulter also established a deeper seed placement as compared to the smooth coulter. Planting at forward speed of 5 km h^{-1} resulted in deeper seeding depth as compared to a forward speed of 7 km h^{-1}. However, lower values of miss and precision indices were obtained at forward speed of 7 km h^{-1}, indicating a more uniformity of plant spacing. Results of this study showed that equipping the conventional planter with toothed coulter and planting in soil prepared under the BRCD residue management system can result in a satisfactory conservation crop production system.

Additional key words: *Zea mays;* corn planter; toothed coulter; smooth coulter; plant spacing; conservation farming.

Introduction

Conservation tillage has been defined as a tillage system that retains at least 30% of cover crop residues on the soil surface after planting operation is completed (McCarthy *et al.,* 1993; Han & Simmons, 2001). One of the important concerns encountering in conservation agriculture systems is non-uniformity in plant spacing and amount of residue retained when using conventional crop production systems in fields with previous residue. Swan *et al.* (1994) observed that surface residues decrease planting depth and uniformity of the plant spacing and increase the number of seeds placed closer to the surface. In order to overcome the seed placement problems in conservation tillage systems, Erbach (1982) suggested equipping row-crop planters with rolling coulters. Rolling coulters cut the soil and trash, helping correct seed placement. Four basic patterns of these 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.

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

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Abbreviations used: BRC (baled residue and single pass of chisel plow); BRCD (baled residue and single pass of chisel plow followed by disc harrowing); BRD (baled residue and single pass of disc harrow); ERI (emergence rate index); NBRC (untouched residue and single pass of chisel plow); NBRCD (untouched residue and single pass of chisel plow followed by disc harrowing); NBRD (untouched residue and single pass of disc harrow); QFI (quality of feed index); RMS (residue management system); SC (smooth coulter); TC (toothed coulter).

obtained using a 610 mm diameter coulter. 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 the toothed coulter performed best because it was more efficient than smooth and notched coulters in cutting crop residue. It required smaller torque and lower vertical and draught forces.

Raoufat & Mahmoodieh (2005) evaluated the effects of planter coulter attachments, previous crop residue levels and tillage systems on plant establishment and uniformity of plant spacing. They concluded that chisel plowing followed by coulter-planting provides a suitable alternative to conventional systems, offering the advantages of conservation farming and improving plant establishment.

Raoufat & Matbooei (2007) developed a star wheel row cleaner for residue management and cleaning crop residue on seed rows. They reported that the row cleaner removed 70% of wheat (*Triticum aestivum*) straw residue on the row band which resulted in a significant improvement in soil-seed contact. Straw residue with adequate amount of organic material has an important function in terms of improvement in soil structure and stability (Morris *et al.,* 2010). Fallahi & Raoufat (2008) evaluated the field performance of a conventional row-crop planter with three types of planter attachments (plain rolling coulter, row cleaner and row cleaner followed by plain rolling coulter) in three tillage systems (single pass of disc harrow, three passes of disc harrow and single pass of disc harrow followed by chisel plowing). They reported that a row-crop planter equipped with row cleaner followed by rolling coulter increased the quality of feed index up to 37.7%.

Iran is one of the major wheat producing countries in the world with the production of 14,000,000 t from an area of 7,000,000 ha. After wheat and rice (*Oryza sativa*), corn (*Zea mays*) is the third largest planted crop in Iran with the production of 1,730,000 t from an area of 240,000 ha (USDA, 2012). In Iran, corn is most commonly grown as the second crop in tight annual rotations with wheat. Iranian farmers cultivate corn after harvesting wheat. The farmers use crop residue burning practice to facilitate land clearing from previous crop residue. The crop residue burning practice has become a concern in Iran due to its adverse impact on human health, the environment, and soil quality. Several factors, ranging from the lack of management decisions for handling previous crop residues to the inability of the conventional planters to drill corn into soils covered with residue, are contributing to the problems. Therefore, presenting an appropriate residue management system and modification of existing planters are envisaged to ensure successful planting operation.

The specific objective of this research was to evaluate the effects of two types of corn planter attachment in six previous wheat residue management systems at two forward speeds on the amount of surface residues after planting operation, emergence rate index, seeding depth and plant spacing.

Material and methods

Considering the results and recommendations of previous studies (Bianchini & Magalhaes, 2007; Magalhaes *et al.,* 2007), a toothed and a smooth coulter were designed and fabricated from a high carbon steel plate 4 mm thick (Fig. 1). The physical dimensions of the coulters are presented in Table 1. The edges of both coulters were sharpened to 14°. Each coulter was mounted on the tool-bar in the space between the row cleaners and the furrow opener of a pneumatic row-crop corn planter (Fig. 2). The planter was a single unit row-crop planter and was equipped with appropriate conservation farming tools to accomplish the treatments envisaged in this study. The seed metering unit was of pneumatic type (vacuum metering disk) with press-wheel drive. Furrow openers can play an important role in providing proper seed placement depth, especially in conservation agriculture systems. For better cutting of surface residue a double disk furrow opener was used. A four- bar linkage mechanism with spring-loaded link was used to facilitate the penetration of the double disk furrow opener in the soil. The down force pressure was adjusted using the spring.

In conservation agriculture systems, row cleaners clean trash and residue on the row and are believed to

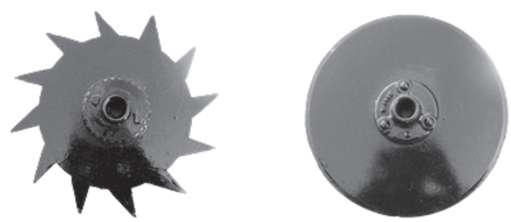

Figure 1. Toothed (left) and smooth (right) coulters used in this study.

Table 1. Dimensions of the toothed and smooth coulters used in this study

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

improve seed spacing indices significantly. Each row cleaner unit was made up of two 25 cm diameter free rotating thin wheels placed at a 45° angle against each other. The row cleaner attachment was installed in front of the coulter to clean rows from previous crop residue. The row cleaner assembly comprised of a pivot joint and spring loaded link, providing suitable floatation.

Field experiments were established in summer 2011 at the Badjgah Research Station, Shiraz University, located in NW Shiraz, Iran. The soil composed of 35% sand, 30% coarse silt, 5% fine silt and 30% clay, was classified as clay loam. The soil was covered with previous wheat crop residue. Average moisture content of the soil was 13.0% (dry basis) at the depth range of 0-20 cm. The wheat was harvested by a combine leaving relatively uniform stubble.

The residue management systems (RMSs) were defined as follows: baled-out residue and merely a single pass of disc harrow (BRD), baled-out residue and a single pass of chisel plow (BRC), baled-out residue and a single pass of chisel plow followed by disc harrowing (BRCD), untouched residue and merely a single pass of disc harrow (NBRD), untouched residue and a single pass of chisel plow (NBRC) and untouched residue and a single pass of chisel plow followed by disc harrowing (NBRCD).

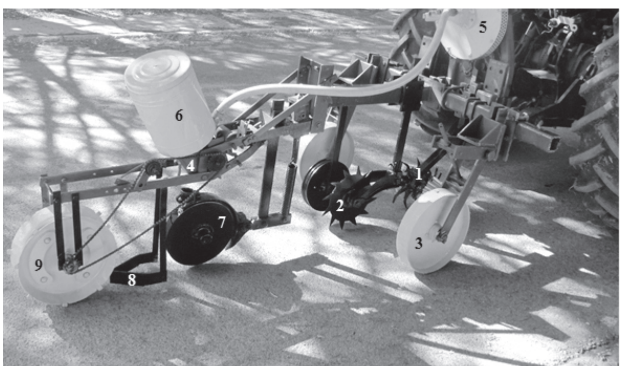

Figure 2. Mounted pneumatic row- crop planter used in this study: 1, row cleaner attachment; 2, toothed coulter; 3, gauge wheel; 4, pneumatic seed metering unit; 5, vacuum fan; 6, seed hopper; 7, double disk furrow opener; 8, furrow filler; 9, press-wheel drive.

A split-split-plot experiment arranged as a randomized complete block design was conducted with three replications. The planter attachments consisted of smooth coulter (SC) and toothed coulters (TC). The split-level was the residue management method (*i.e.,* BRD, BRC, BRCD, NBRD, NBRC and NBRCD). The sub-split-level was planter forward speed at two levels: 5 km h^{-1} and 7 km h^{-1}.

Maize hybrid SC-704, with 1000-kernel weight of 250 g, an average seed emergence rate of 85% and purity of 93% was used. The plot dimensions were 5 m × 20 m and the measurements taken in each plot were: weight of the residue before tillage and after planting operations, depth of seed placement, number of seed emergence per day and spacing between adjacent plants in the row. In each plot, the measurements were taken along central 14 m length of each row to avoid marginal effects. The measurements in each plot were used to calculate the indices introduced in the following sections. The target depth of seed placement and theoretical plant spacing were 5 cm and 10 cm, respectively.

Residue management practice

Previous wheat residue biomass in t ha^{-1} was determined before tillage operations in the untouched (non-baled) and baled-out residue plots immediately after harvesting by collection and weighing all surface wheat residues from two 0.5 m^2 quadrants per plot. Moreover the amount of surface residue after tillage operations in the BRD, BRC, BRCD, NBRD, NBRC and NBRCD residue management plots was measured in the same way. After planting, however, all measurements were made in the row area.

Emergence rate index (ERI)

The ERI is an indication of how fast and uniform in time the crop emerges from the soil (Staggenborg *et al.,* 2004). Erbach (1982) suggested Eq. [1] for computing ERI index:

$$ERI = \sum_{n-1}^{X} \frac{EMG_n - EMG_{n-1}}{DAP_n} \quad [1]$$

where n is the n^{th} emergence observation; EMG_n and EMG_{n-1} are the percentage of seeds planted that have emerged on the day of the n^{th} and $n-1^{th}$ emergence observation, respectively, being $EMG_n = 0$ when $n = 1$; and DPA_n is the number of days after planting when the n^{th} emergence observation was taken. The number of plants emerged in each row was counted after 3, 4, 5, 7, 9, 12, 14, 17, 20 and 25 days after planting and stopped when no further increase in emerged plant counts was observed.

Seed placement depth

In order to measure seeding depth, a special tube was developed with one edge sharpened according to Raoufat & Matbooei (2007) guidelines to help pull seedlings out of the soil. The seedlings were washed and the length of the mesocotyl was measured by a digital caliper. Since nodal roots typically grow approximately 2 cm below the soil surface, an extra 2 cm was added to obtain seed placement depth (Ritchie *et al.,* 1993).

Uniformity of plant spacing

For determining the uniformity of plant spacing an ISO standard (ISO, 1984) as suggested by Kachman & Smith (1995), was adopted. The distance between seedlings X_{ref} in cm is the theoretical spacing which is used to divide the observed spacings into five regions: $[0, 0.5x_{ref}]$, $[0.5x_{ref}, 1.5x_{ref}]$, $[1.5x_{ref}, 2.5x_{ref}]$, $[2.5x_{ref}, 3.5x_{ref}]$, and $[3.5x_{ref}, \infty]$. The five regions correspond to the following classification of regions: (1) a multiple, closer to the previous plant than the theoretical spacing; (2) a single, closer to the theoretical spacing than either the previous plant or a single skip; (3) a single skip, closer to a single skip than either the theoretical spacing or a double skip; (4) a double skip; and (5) a triple or more skips. The plant spacings which fall in the second region are considered as planted with correct spacings. These five regions are the basis for a series of indices measuring the accuracy in plant spacing. Thus, the multiple index is the percentage of plant spacings that are less than or equal to half the theoretical spacing. Smaller values of the multiple index indicate better planter performance than larger values.

The miss index is the percentage of plant spacings greater than 1.5 times the theoretical spacing. Similarly, smaller values of miss index indicate better planter performance than larger values.

The quality of feed index (QFI) is the percentage of plant spacings that are more than half but less than or equal to 1.5 times the theoretical spacing. Larger values of the QFI indicate better planter performance than smaller values. In other words, the QFI is a measure of how often the spacings are close to the theoretical spacing (Kachman & Smith, 1995). For example, a QFI of 70% means that 70% of the spacings are not classified either as multiples or skips.

Finally, the precision index is a measure of the variability in spacings between plants after accounting for variability due to both multiples and skips. Smaller values of precision indicate better performance than larger values. The theoretical upper limit for precision is 50% and this distribution of spacing would indicate that the theoretical spacing was incorrectly specified and, therefore, this theoretical level 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, values consistently greater than 29% should be viewed with suspicion (Kachman & Smith, 1995).

In this research, the theoretical plant spacing was considered to be 10 cm. Therefore the multiple index is the percentage of spacings that are ≤ 5 cm, the miss index is the percentage of spacings that are > 15 cm and the QFI is the percentage of spacings that are > 5 cm and ≤ 15 cm.

Statistical analyses

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

Results and discussion

Surface residue after planting operation

The average amount of crop residues remaining on the soil surface before tillage operation in the untouched (non-baled) and baled-out residue plots were 5.83 t ha^{-1} and 3.75 t h^{-1}, respectively. Moreover, the amount of surface residue after tillage operations for the BRD, BRC, BRCD, NBRD, NBRC and NBRCD residue management systems was measured in relevant

Table 2. Analysis of variance of the effects of planter attachment, residue management system (RMS) and forward speed on the residue retained after planting, emergence rate index (ERI), seeding depth and seed spacing indices

		Mean squares for variables studied		
Source of variation	**Degrees of freedom**	**Residue retained after planting**	**ERI**	**Seeding depth**
Block	2	0.301^{ns}	18.112^{ns}	19.291**
Planter attachment (main factor)	1	0.287^{ns}	0.95**	840.500**
Error-main	2	0.290^{ns}	4.597^{ns}	0.291^{ns}
RMS (subplot factor)	5	6.043**	421.588**	46.400**
Planter attachment × RMS	5	0.005^{ns}	5.955^{ns}	32.000**
Error-subplot	20	0.072^{ns}	5.872^{ns}	1.891^{ns}
Forward speed (sub-subplot factor)	1	2.000**	329.388**	450.000**
Planter attachment × Forward speed	1	0.008^{ns}	0.222^{ns}	0.000^{ns}
RMS × Forward speed	5	0.048^{ns}	0.688^{ns}	2.855^{ns}
Planter attachmen × RMS × Forward speed	5	0.003^{ns}	0.722^{ns}	2.780^{ns}
Error-(sub-subplot)	24	0.090	5.513	1.791
Total	71	0.530	39.529	25.783

	Degrees of freedom	**Multiple index**	**Miss index**	**Quality of feed index**	**Precision**
Block	2	3.12^{ns}	11.166^{ns}	10.680^{ns}	6.112^{ns}
Planter attachment (main factor)	1	0.420^{ns}	14.531^{n}s	11.680^{ns}	4.511^{ns}
Error-main	2	1.021^{ns}	1.166^{ns}	4.254^{ns}	7.593^{ns}
RMS (subplot factor)	5	0.946^{ns}	373.53**	375.402**	483.612**
Planter attachment × RMS	5	1.835^{ns}	8.881^{n}s	9.512^{ns}	2.111^{ns}
Error-subplot	20	1.046^{ns}	7.866^{ns}	6.970^{ns}	1.402^{ns}
Forward speed (sub-subplot factor)	1	0.82^{3ns}	344.531**	379.042**	242.113**
Planter attachment × Forward speed	1	4.450^{ns}	0.281^{ns}	6.968^{ns}	4.501ns
RMS × Forward speed	5	2.064^{ns}	4.181^{ns}	5.951^{ns}	3.211^{ns}
Planter attachment × RMS × Forward speed	5	1.139^{ns}	5.231^{ns}	4.625^{ns}	2.134^{ns}
Error-(sub-subplot)	24	1.112	3.512	3.721	1.961
Total	71	1.288	36.404	37.080	39.563

** Significant at $p < 0.01$. ns: non-significant at $p < 0.05$.

plots and found to be, on average, 1.73, 2.92, 1.36, 2.32, 4.06 and 1.74 t ha^{-1}, respectively.

The analyses of variance of data of residue retained after planting as affected by various treatments and their interactions indicated that only the RMS and forward speed significantly affected this index (Table 2). No interaction was found between planter attachment, RMS and forward speed.

According to McCarthy *et al.* (1993), at least 621 kg ha^{-1} of residue, equal to 30% surface coverage, are needed for small grain crops such as wheat to establish a soil conservation tillage system. In the present study, the amounts of residue retained before and after tillage operations and after planting for all the treatments (Table 3) were higher than 621 kg ha^{-1}. It can be concluded that treatments envisaged for the present study fall within the residue cover limits defined for conservation farming practices.

A comparison of mean values residue retained after planting operation in the different residue management systems showed that the BRCD system retained the lowest amount of surface residue (Table 3). Disc harrowing in both baled and non-baled residue plots (BRD and NBRD systems) retained significantly less amount of surface residue as compared to chisel plowed plots (BRC and NBRC). Other results indicated that the smooth coulter left less surface residue on rows as compared to the toothed coulter but not in a significant manner, which is the result of pushing surface residues into tilled soil. In a previous study, Raoufat & Mahmoodieh (2005) concluded that the smooth coulter retained less surface residue as compared to a notched coulter. A

Table 3. Effects of residue management system, planter attachment and forward speed on the amount of residue retained after planting, the emergence rate index (ERI), the seeding depth and the seed spacing indices

	Residue retained after planting ($t\ ha^{-1}$)	ERI ($\%\ day^{-1}$)	Seeding depth (mm)	Miss index (%)	Quality of feed index (%)	Precision (%)
Residue management system[1]						
BRD	1.19^{d}*	32.25^{b}	43.03^{c}	18.25^{b}	66.77^{ab}	25.12^{b}
BRC	2.06^{b}	27.51^{cd}	42.55^{c}	20.76^{b}	61.15^{b}	24.23^{b}
BRCD	0.92^{e}	35.08^{a}	46.05^{a}	16.02^{b}	70.95^{a}	23.02^{b}
NBRD	1.62^{c}	25.53^{d}	42.04^{c}	20.74^{b}	61.55^{b}	25.33^{b}
NBRC	2.84^{a}	18.00^{e}	40.07^{d}	27.53^{a}	54.52^{c}	27.08^{b}
NBRCD	1.20^{d}	29.01^{c}	44.27^{b}	20.37^{b}	64.32^{ab}	24.29^{b}
Planter attachment[2]						
TC	1.70^{a}	33.91^{a}	46.47^{a}	22.08^{a}	62.81^{a}	24.75^{a}
SC	1.58^{a}	27.86^{b}	39.53^{b}	21.12^{a}	63.62^{a}	22.27^{a}
Forward speeds						
5 $km\ h^{-1}$	1.80^{a}	30.03^{a}	45.41^{a}	23.79^{a}	60.92^{b}	25.33^{a}
7 $km\ h^{-1}$	1.47^{b}	25.75^{b}	40.41^{a}	19.42^{b}	65.51^{a}	21.86^{b}

[1] BRD, baled residue and single pass of disc harrow; BRC, baled residue and single pass of chisel plow; BRCD, baled residue and single pass of chisel plow followed by disc harrowing; NBRD, untouched residue and single pass of disc harrow; NBRC, untouched residue and single pass of chisel plow; NBRCD, untouched residue and single pass of chisel plow followed by disc harrowing. [2] TC, toothed coulter; SC, smooth coulter. For each parameter, means within each column followed by the same letters are not significantly different at $p < 0.05$.

comparison of the overall mean values of residue retained for different forward speeds indicate a trend to increase residue retained as forward speed increases (Table 3). The reason for this finding is that the cleaner wheels are ground driven and hence perform best at higher forward speeds. A close observation of the cleaner wheels performance showed that cleaner wheels tend to skid over residues at low forward speeds.

Table 4 shows the amounts of residue retained on the row area for the various treatments compared. As expected, among baled residue plots (BR), the lowest value (770 $kg\ ha^{-1}$) of residue retained corresponded to BRCD/SC/7 treatment, whereas for non-baled residue plots (NBR), the lowest value (1,000 $kg\ ha^{-1}$) pertained to NBRCD/SC/7 treatment. These are equivalent to 20% and 17% of amount of residues before tillage operations for BR and NBR plots, respectively.

Evaluation of emergence rate index

The analysis of variance of ERI data indicated that planter attachment, RMS and forward speed have significant effects on this index (Table 2). There was no significant interaction between planter attachment, RMS and forward speed.

A comparison of mean values of the ERI indicates that the BRCD resulted in the highest ERI (Table 3). The reason might be the lowest amount of residue retained after planting in BRCD plots as compared to the other residue management systems. As concluded by Wicks *et al.* (1994), a high amount of surface residue causes further reduction in soil temperature and thus slow seed emergence. In a previous study, Raoufat & Mahmoodieh (2005) concluded that the ERI is higher in moldboard tilled plots as compared to the chisel plowed plots. They indicated that the reason for this higher ERI is a lower surface residue left in moldboard plowed plots as compared to chisel plots. Other results showed that the use of smooth coulter decreased the ERI significantly (up to 18%) as compared to the toothed coulter, which is undesirable. The reason might be more subsurface residue as the result of using the smooth coulter. The smooth coulter pushes the surface residue into the soil and decreases the seed-to-soil contact, which results in a slow emergence (Kushwaha *et al.,* 1986). The ERI increased up to 16% at forward speed of 5 $km\ h^{-1}$ as compared to forward speed of 7 $km\ h^{-1}$. The reason might be better seed placement

Table 4. Mean values of variables studied for various treatments used in this study

Treatment[1]	Residue retained after planting (t ha^{-1})	ERI (% day^{-1})	Seeding depth (mm)	Multiple index (%)	Miss index (%)	Quality of feed index (%)	Precision (%)
BRD/TC/5	1.38^{fghi}	35^{ab}	48^{b}	15.03^{a}	21.05^{abcdef}	65.05^{defg}	21.03^{g}
BRD/TC/7	1.12^{hijk}	30^{cdef}	45^{cd}	14.08^{a}	17.00^{def}	71.03^{bc}	16.98^{ij}
BRC/TC/5	2.34^{c}	29d^{efg}	49^{ab}	15.95^{a}	20.66^{cdef}	58.01^{h}i	26.95^{cde}
BRC/TC/7	1.89^{de}	25g^{hij}	44^{de}	13.59^{a}	23.33^{abcde}	64.53d^{efg}	25.00^{ef}
BRCD/TC/5	1.08^{hijk}	38^{a}	51^{a}	15.57^{a}	20.03^{cdef}	67.53^{cde}	15.97^{ijk}
BRCD/TC/7	0.88^{jk}	33^{bcd}	43^{def}	14.45^{a}	14.33^{ef}	72.53^{a}b	14.05^{k}
NBRD/TC/5	1.85^{def}	27f^{ghi}	48^{b}	16.00^{a}	21.07^{abcdef}	56.95^{i}	28.95^{bc}
NBRD/TC/7	1.50^{efgh}	24^{hij}	45^{cd}	16.49^{a}	23.61^{abcde}	61.53^{ghi}	26.13^{def}
NBRC/TC/5	3.25^{a}	21^{kl}	48^{b}	15.37^{a}	29.11^{abc}	51.73^{j}	34.11^{a}
NBRC/TC/7	2.63^{bc}	17^{lm}	43^{def}	14.12^{a}	30.03^{a}	58.0^{3hi}	30.21^{b}
NBRCD/TC/5	1.39^{fghi}	30^{cdef}	49^{ab}	15.00^{a}	25.02^{abcd}	62.05^{fgh}	24.95^{ef}
NBRCD/TC/7	1.13^{hijk}	26^{fghi}	43^{def}	15.98^{a}	20.05^{cdef}	65.03^{defg}	21.03^{g}
BRD/SC/5	1.27^{ghij}	34^{abc}	42^{efg}	14.90^{a}	20.33^{cdef}	64.13^{defg}	20.05^{gh}
BRD/SC/7	1.02^{hijk}	30^{cdef}	37^{h}	15.48^{a}	18.32^{def}	67.04^{cde}	18.09^{hi}
BRC/SC/5	2.22^{cd}	30^{cdef}	41^{fg}	15.31^{a}	23.03^{abcde}	58.73^{hi}	28.01^{bcd}
BRC/SC/7	1.79^{def}	26^{fghi}	36^{h}	15.63^{a}	22.64^{abcde}	63.42^{efg}	24.04^{f}
BRCD/SC/5	0.95^{jik}	37.33^{a}	47^{bc}	15.49	17.65^{def}	68.55^{bcd}	16.10^{jk}
BRCD/SC/7	0.77^{k}	32^{bcde}	42^{efg}	14.74^{a}	12.02^{f}	75.33^{a}	11.13^{l}
NBRD/SC/5	1.74^{ef}	28^{efgh}	40^{g}	15.08^{a}	18.65^{def}	64.05^{defg}	28.05^{bcd}
NBRD/SC/7	1.40^{fghi}	23^{ijk}	35^{h}	15.33^{a}	19.67^{def}	63.71^{efg}	25.09^{ef}
NBRC/SC/5	2.95^{ab}	19^{klm}	37^{h}	15.40^{a}	29.63^{ab}	50.58^{j}	34.97^{a}
NBRC/SC/7	2.52^{bc}	15^{m}	32^{i}	15.23^{a}	29.11^{abc}	57.83^{hi}	29.08^{bc}
NBRCD/SC/5	1.27^{ghij}	32^{bcde}	45^{cd}	14.64^{a}	25.02^{abcd}	63.90^{defg}	26.06^{def}
NBRCD/SC/7	1.03^{hijk}	28^{efgh}	40^{g}	15.59^{a}	19.16^{def}	66.44^{def}	20.05^{gh}

[1] Residue management systems: see Table 3. Planter attachments: see Table 3. Forward speeds: 5 km ha^{-1} and 7 km ha^{-1}. For each parameter, means within each column followed by the same letters are not significantly different at $p < 0.05$.

in soil at low planting speed. The highest and lowest ERI values corresponded to BRCD/TC/4 and NBRC/SC/7 treatments and were equal to 38% day^{-1} and 15% day^{-1}, respectively (Table 4).

Evaluation of seeding depth

The analysis of variance of seeding depth data indicated that planter attachment, residue management system, forward speed and interaction between RMS and planter attachment have significant effects on this index (Table 2).

Comparison of average seeding depth for residue management systems indicated that the seeding depth increases when the tillage operation increases as result of changing the RMS (Table 3). As expected, the BRCD resulted in a deeper seeding depth (46 mm) as compared to the other residue management systems (Table 3). Tillage operations improve the seeding depth in two ways: loosening the soil, and decreasing the surface residue. The looser soil with lower surface residue allows the furrow opener to work at a more depth. Other results show that the toothed coulter resulted in deeper seeding depth as compared to the smooth coulter in a significant manner (Table 3). The forward speed of 7 km h^{-1} decreased the average seeding depth significantly as compared to forward speed of 5 km h^{-1}.

Fig. 3 shows the average seeding depth as affected by the interaction between RMS and planter attachment. As Fig. 3 shows, the seeding depth changes in two different manners: when the planter was equipped with the toothed coulter, the RMS did not have any significant effect on seeding depth, whereas when the planter was equipped with the smooth coulter, the RMS had a significant effect on the seeding depth. The reason might be related to the ability of the two coulters to cut the surface residue. When the surface residue increases, the toothed coulter cut the surface residue well and paves the way for subsequent furrow opener

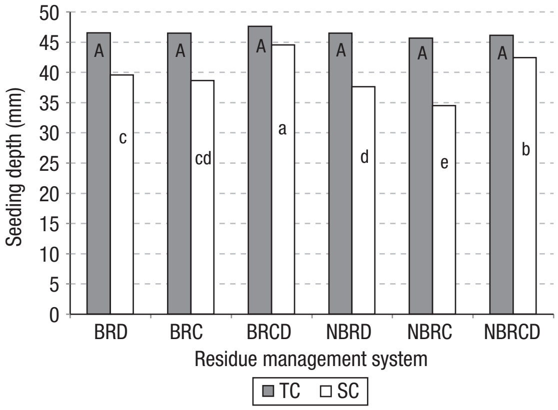

Figure 3. Average seeding depth (mm) for various residue management systems and planter attachments. Residue management systems: BRD, baled residue and single pass of disc harrow; BRC, baled residue and single pass of chisel plow; BRCD, baled residue and single pass of chisel plow followed by disc harrowing; NBRD, untouched residue and single pass of disc harrow; NBRC, untouched residue and single pass of chisel plow; NBRCD, untouched residue and single pass of chisel plow followed by disc harrowing. Planter attachments: TC, toothed coulter; SC, smooth coulter. Columns with same lower and upper case letters are not statistically different at $p = 0.05$.

operation, whereas the smooth coulter push the surface residue in the soil and the furrow opener fail to penetrate in the soil, resulting in a shallow seed placement. Therefore it can be concluded that the seeding depth is independent of levels of previous surface residue on the soil when the planter is equipped with a toothed coulter.

The maximum and minimum seeding depths corresponded to BRCD/TC/5 and NBRC/SC/7, with mean values of 51 and 32 mm, respectively (Table 4). It should be noted that the target seeding depth considered in this study was 50 mm.

Evaluation of seeding indices

During the field tests, it was observed that the amount of residue cover and the disturbed width affected plant spacing. Higher surface residue and less soil disturbance width would result in more hampering press wheel rotation, which would finally result in unsatisfactory performance of the seed metering system for common planters in local farms.

The analyses of variance of the multiple index data as affected by various treatments and their interactions showed that none of the treatments significantly affected this index (Table 2). Other results for miss index, QFI and precision index showed that only the RMS and forward speed had significant effects on these indices ($p < 0.01$).

Multiple index

Table 4 shows mean values of the multiple index for various treatments considered in this study. As the Table 4 shows, no significant difference was observed between the treatments.

Miss index

A comparison of means values of this index indicated that the BRCD resulted in a better miss index and, therefore, a more acceptable seed spacing (Table 3). In other words, the BRCD decreased miss index up to 22% and 12% as compared to BRC and BRD residue management systems, respectively, although not in significant manner. The NBRC resulted in the highest miss index value as compared to the other residue management systems. The reason of this significant difference might be the highest surface residues observed in the NBRC plots that caused an increase in planter press wheel slippage. The planter attachment did not have significant effect on the index. Other results showed that a forward speed of 7 km h^{-1} significantly improved this index (up to 18%) as compared to the 5 km h^{-1} forward speed in significant manner. In a similar study, Raoufat & Matbooei (2007) found that the miss index decreased significantly (up to 22%) when the forward speed increases from 4 to 7 km h^{-1}. As expected, the minimum and maximum miss index values pertained to BRCD/SC/7 and NBRC/TC/7 treatments, respectively (Table 4).

Quality of feed index (QFI)

The BRCD resulted in the highest QFI which increased significantly up to 16% as compared to BRC (Table 3). The lowest QFI pertained to NBRC, which decreased significantly up to 11% and 15% as compared to NBRD and NBRCD treatments, respectively. The reason might be again the surface residue for the NBRC plots which caused an increase in planter press wheel slippage. The planter attachment did not have significant effect on the QFI. Further analysis indicated that planting at a forward speed of 7 km h^{-1} increased significantly QFI (up to 8%) as compared to planting at a forward speed 5 km h^{-1}. In a previous work, Raoufat & Matbooei (2007) reported that planting at a forward speed of 7 km h^{-1} increased the QFI significantly as compared to planting at a forward speed of 4 km h^{-1}. The highest and lowest QFI corresponded to BRCD/TC/7 and NBRC/SC/5 treatments, which were equal to 75% and 50% respectively (Table 4).

Precision of plant spacing

A comparison of the mean values of the precision of plant spacing for the different residue management systems, planter attachments and forward speed (Table 3) firstly indicates that the RMS did not have a significant effect on this index. However, the BRCD system resulted in the lowest precision of plant spacing, which is desirable. Table 3 also indicates that the planter attachment did not have a significant effect on the precision index. Other results showed that planting at a forward speed of 7 km h^{-1} decreased the precision index up to 13% as compared to planting at a forward speed of 5 km h^{-1}, thus indicating a more uniformity of the plant spacing. This result is in agreement with a previous finding by Raoufat & Matbooei (2007) who indicated that planting at a forward speed of 7 km h^{-1} decreased the precision index significantly up to 8% as compared to planting at a forward speed of 4 km h^{-1}. The maximum and minimum values of precision corresponded to the NBRC/TC/5 and BRCD/SC/7 treatments, respectively (Table 4).

In summary, the six residue management techniques tested in the present study resulted in a residue cover greater than the threshold value defined for establishing conservation farming practices. Nonetheless, the BRCD technique left a lower amount of residue after planting as compared to the other methods. This treatment also resulted in maximum ERI and uniformity of plant spacing. As the planting unit was equipped with toothed coulter, constant seeding depth was achieved irrespective of the RMS used. However, the toothed coulter established a deeper seed placement. Moreover, the toothed coulter resulted in higher ERI as compared to the smooth coulter. Planting at a forward speed of 7 km h^{-1} resulted in lower values of miss and precision indices and maximum value of QFI. As final conclusions, the study suggests installing a toothed coulter on the conventional row-crop planter and planting of corn in soils prepared under the BRCD system, *i.e.,* baled wheat residue and single pass of chisel plow followed by disc harrowing, can result in a suitable corn production system for soil conservation.

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