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RESEARCH ARTICLE

# Seed Zone Properties and Crop Performance as Affected by Three No-Till Seeders for Permanent Raised Beds in Arid Northwest China

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## Abstract

The no-till seeders of various soil opener configurations have been shown to produce various soil physical responses in relation to soil and climate conditions, thus affecting crop performance in permanent raised beds (PRB) systems. This is particularly important in arid Northwest China where large volumes of residue are retained on the soil surface after harvest. In Zhangye, Gansu Province, China, a field trial assessed the effects of three typical (powered-chopper, powered-cutter and powered-disc) PRB no-till seeders and one traditional seeder on soil disturbance, residue cover index, bulk density, fuel consumption, plant growth, and subsequent yield. In general, seedbed conditions and crop performance for PRB no-till seeders seeded plots were better than for traditional seeded plots. In PRB cropping system, the powered-chopper seeder decreased mean soil disturbance and increased residue cover index compared to powered-disc and -cutter seeders. However, the results indicated that soil bulk density was 2.3-4.8% higher, soil temperature was 0.2-0.6°C lower, and spring wheat emergence was 3.2-4.7% less. This was attributed to greater levels of residue cover and firmer seedbeds. Spring maize and wheat performance in the powered-cutter and -disc treatments was better (non-significant) than powered-chopper treatment. So powered disc no-till seeder, which generally provided the best planting condition and the highest yield, appeared to be the suitable seeder in heavy residue cover conditions. Considering the precision requirements for soil disturbance and residue cover, the powered strip-chopping no-till seeder could be a suitable option for PRB cropping system in Northwest China. Although these results are preliminary, they are still valuable for the design and selection of no-till seeders for PRB cropping systems in arid Northwest China.

Key words: no-till seeder, permanent raised beds, crop growth, seedbed, yield

## INTRODUCTION

In arid Northwest China, especially in Hexi Corridor, the mean precipitation varies from 40-200 mm yr$^{-1}$, but the annual potential evaporation exceeds 1 500 mm, making water shortage one of the major constraints to the agricultural production (Xie *et al*. 2005). In this region, maize and wheat seasonal water requirement is greater than 600 mm, and therefore crop production is largely dependent on irrigation. Maintenance or improvement of water use efficiency (WUE) is extremely important in the region, particularly when glaciers are in rapid retreat and groundwater supplies are decreasing (Kang *et al*. 2000).

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Permanent raised beds (PRB), as an advanced water-saving technique, has been adopted to ensure the sustainable development of agriculture in arid areas of Northwest China. PRB, combines the concepts of zero-till bed planting, furrow irrigation, and controlled traffic farming, which ensures the beds and furrows are permanently in the same position and repaired only once a year before the next crop is seeded (Singh 2003). The positive effects of PRB on soil moisture and WUE (Connor *et al*. 2003; Choudhury *et al*. 2007), crops yields (Kukal *et al*. 2005) and cost (He *et al*. 2008) have been broadly demonstrated in many environments. Furthermore, PRB has also been shown to improve soil physical and chemical properties (Holland *et al*. 2007; McHugh *et al*. 2009).

In current PRB cropping system in Hexi Corridor of Northwest China, 1 m wide beds systems for maize and wheat planting are the most common due to the dimensions of small-size tractor and harvester wheel spacing (He *et al*. 2007). In this farming system, in order to maximize crops yields, two rows maize and five rows wheat are generally planted on 1 m bed (bed surface width: ~75 cm). Furthermore, the high annual crop yield (maize: >10 t $ha^{-1}$; spring wheat: >6 t $ha^{-1}$) results in heavy crop residues. Consequently, no-till seeding, particularly for maize after wheat, raises a considerable issue for PRB farming systems in Northwest China (Zhu 2008). For small landholders significant modifications are required so that no-till seeders cope with heavy residue and enhance crop emergence.

Furrow openers, which incorporate a residue cleaning system, is widely used by no-till seeder to produce suitable seedbeds for crop growing (Sun *et al*. 2008; Yao *et al*. 2009). The disc and tine based furrow opener systems may lead to greatly different levels of soil disturbance on seedbeds. Disc openers broadly classified as single, double and triple disc types cut residue well, disturb little soil, and do not easily clog. Single disc openers, which generally employ plain or notched disc are widely used by no-till seeders, largely because of their penetration and residue-cutting ability in wide range of soil types and residue conditions (Murray *et al*. 2006). However, all type disc openers, particularly double and triple disc openers, need a large vertical force to penetrate hard soils depending on disc settings and the amount of residue present (Kushwaha *et al*. 1993). Therefore, disc seeders are usually too large, heavy, and expensive to be widely used in China. Consequently, there is large-scale use of the tine based, small, inexpensive no-till wheat seeders in the single cropping regions of northern China (Du 1999). In general, tine openers have rake angles of <90° and require lower vertical force to form "U", "V", or "T" shaped furrows as compared with disc openers.

In PRB cropping of Northwest China, where beds are covered by heavy crop residues, seeders are prone to blockage, therefore, tines are set with wide spacing or equipped with cleaning attachments (Zhu *et al*. 2008). Presently, wide space settings of tines are broadly used by PRB no-till seeder to avoid blockage in Northwest China. Although space between the tines has been increased to enhance residue flow, the problem still persists while conducting smooth field operations. There are limitations in increasing this dimension, such as narrow bed width, planting density rewired small and low powered tractors, field obstructions which limited turning within field operations. Consequently, the need for residue cleaning mechanism attached with implements is felt to avoid the residue blockage. Residue cleaning mechanism is the most important for conservation farming in case of sustainability. These new types of attachments have included mounting powered residue-cutting devices ahead of each opener to move residue away from the seeding zone (Ma 2006; Zhu *et al*. 2008). After several years' development, no-till seeders with low susceptibility to blocking have been developed for PRB cropping system (Li *et al*. 2008; He *et al*. 2009) and some have been manufactured commercially. These seeders have encouraged the development and extension of PRB in Northwest China but the literature contains little information about their impact on seedbed properties and crop performance. This paper compared three most widely used PRB no-till seeders (powered-chopper, -cutter, and -disc) and one local traditional seeder, and investigated their effects on soil physical properties in the seed zone, crop emergence, early growth, and subsequent yield in a 2-yr period in Hexi Corridor of Northwest China.

## RESULTS

### Soil disturbance and residue cover index

Soil disturbance and residue cover index for four treatments after seeding in 2008 and 2009 are shown in Table 1. There were no residues cover in CK plots after seeding, but the mean residue cover index for powered-chopper, -cutter, and -disc seeded plots was 90, 53, and 85% after spring maize seeding and 80, 53, and 69% after spring wheat seeding, respectively. The residue cover index in powered-cutter seeded plots were significantly ($P$=0.05) lower than that in powered-chopper and -disc treatments. Similar results were found for soil disturbance after seeding. In CK treatment, the soil disturbance was 100% after seeding due to intensive tillage for seedbed preparation. In PRB treatments, powered-cutter increased soil disturbance significantly ($P$=0.05) by over 60% after spring maize and spring wheat seeding, respectively, as compared with powered-chopper and -disc treatments. Among the treatments, powered strip-chopping no-till seeder provided the highest residue cover index and the minimum soil disturbance after seeding in both experimental years.

## Soil bulk density and water-stable aggregates

Soil bulk density measured in the seedbed for all treatments after seeding in 2008 and 2009 is illustrated in Table 2. CK treatment decreased bulk density after seeding by 1.0-6.2% compared with powered-chopper and -cutter treatments, but the difference of bulk density between CK and powered-disc treatments after seeding was negligible in both experimental years. In PRB treatments, after seeding bulk density at 0-10 cm soil depth in powered-disc seeding system was 1.0-4.6% lower than that in powered-chopper and -cutter seeding systems, respectively.

In general, CK produced the highest micro-aggregates (<0.25 mm) and the lowest macro-aggregates (>2 mm) amongst four treatments after seeding in 2008 and 2009 (Table 3). Within PRB treatments, soils from powered-chopper plots contained 1.0-1.7% lower macro-aggregates (>0.25 mm) than those under powered-disc and -cutter in 0-10 cm layer. The percentage of micro-aggregates (<0.25 mm) was found 3.0% more in powered-chopper plots.

## Soil moisture

As indicated in Table 4, soil water content before the first irrigation in PRB treatments was 1.9-4.5% and 1.9-3.7% higher than that in CK treatment for spring maize and spring wheat, respectively. A similar trend was observed after 4 d of the first irrigation, and 3.7-6.9% and 4.7-7.8% soil water was found higher in PRB plots compared with CK plots, respectively. Amongst PRB treatments, mean soil water content before the first irrigation was similar, and powered-chopper increased 3.1 and 3.0% of soil moisture after 4 d of first irrigation for spring maize and spring wheat, respectively, compared with powered-cutter treatment. The difference between powered-chopper and -disc treatments was slight and can be neglected.

**Table 1** Soil disturbance and residue cover index for four treatments after seeding in 2008 and 2009

| Cropping season | Treatment | Soil disturbance (%) | Residue cover index (%) |
|---|---|---|---|
| Spring maize (2008) | Powered-chopper | 11 c | 90 b |
| | Powered-cutter | 55 b | 53 c |
| | Powered-disc | 15 c | 85 b |
| | CK | 100 a | 0 a |
| Spring wheat (2009) | Powered-chopper | 27 c | 80 b |
| | Powered-cutter | 55 b | 53 c |
| | Powered-disc | 35 c | 69 b |
| | CK | 100 a | Negligible a (less than zero) |

Means within a column followed by the same letters are not significantly different ($P$=0.05). The same as below.

**Table 2** Soil bulk density (g cm$^{-3}$) of 0-10 cm soil layer in the seedbeds for four treatments after seeding in 2008 and 2009

| Cropping season | Soil layer (cm) | Powered-chopper | Powered-cutter | Powered-disc | CK |
|---|---|---|---|---|---|
| Spring maize (2008) | 0-5 | 1.08 a | 1.04 a | 1.03 a | 1.03 a |
| | 5-10 | 1.12 a | 1.09 a | 1.07 a | 1.06 a |
| Spring wheat (2009) | 0-5 | 1.07 a | 1.05 a | 1.04 a | 1.03 a |
| | 5-10 | 1.13 a | 1.10 a | 1.09 a | 1.06 a |

## Soil temperature

Table 5 shows the mean of daily soil temperature for 8 d after seeding in the four different treatments at 5 and 10 cm depths. Mean soil temperature at 5 cm soil depth in PRB treatments was greater by 0.2-0.8°C than in CK. At 10 cm soil depth, the soil temperature difference between PRB and CK treatments declined but powered-disc and -cutter still produced 0.1-0.7°C higher soil temperature compared with CK. In PRB treatments, compared with powered-chopper treatment, powered-disc and -cutter increased soil temperature at 5 and 10 cm depths by 0.3-0.6°C in 2008. Similar result was found in 2009 and the soil temperature in powered-disc and -cutter was 0.2-0.6°C higher than that in powered-chopper treatment.

## Seeding depth and plant emergence

The seeding depth for four treatments in 2008 and 2009 was similar, but vertical seed scattering indicated by standard deviation (SD) in CK, powered-disc and -cutter treatments were significantly ($P$=0.05) less than that of powered-chopper (Table 6), the results indicated that the CK, powered-disc and powered-cutter could provide a more uniform seeding depth. The vertical seed scattering of powered-disc and powered-cutter treatments was comparable with that of CK treatment.

The difference in plant population of spring maize in the four treatments was negligible, but the type of seeder had a significant effect on spring wheat emergence (Table 6). Mean plant population for CK was 3.2-8.3% higher than for PRB treatments, but only the difference between CK and powered-chopper was significant at $P$=0.05 level. Amongst PRB treatments, mean plant population for powered-chopper, -cutter, and -disc were 665, 687, and 698 plant $m^{-2}$, respectively, and the powered-disc and -cutter treatments improved plant populations by 5.0 (significant at $P$=0.05) and 3.3% compared with the powered-chopper treatment.

## Crop growth and yield

Data in Table 7 indicated that spring maize performance for PRB treatments was found better than for CK, particularly when assessed by stem diameter and dry root

**Table 3** Soil water-stable aggregate size classes of 0-10 cm soil layer in the seedbeds for 4 treatments after seeding in 2008 and 2009

| Cropping season | Treatment | Aggregate size classes (%) | | | |
|---|---|---|---|---|---|
| | | Macro-aggregates (>0.25 mm) | | | Micro-aggregates (<0.25 mm) |
| | | >2 mm | 2-1 mm | 1-0.25 mm | <0.25 mm |
| Spring maize (2008) | Powered-chopper | 16.8 a | 21.2 a | 37.2 a | 24.8 a |
| | Powered-cutter | 15.5 a | 20.4 a | 40.4 a | 23.7 a |
| | Powered-disc | 14.9 a | 18.2 a | 42.9 a | 24.0 a |
| | CK | 14.4 a | 17.6 a | 43.0 a | 25.0 a |
| Spring wheat (2009) | Powered-chopper | 17.7 a | 20.9 a | 36.8 a | 24.6 a |
| | Powered-cutter | 16.6 a | 20.3 a | 39.3 a | 23.8 a |
| | Powered-disc | 16.2 a | 19.6 a | 40.9 a | 23.3 a |
| | CK | 15.7 a | 18.4 a | 41.1 a | 24.8 a |

**Table 4** Soil gravimetric water content (before and after first irrigation) to the depth of 30 cm for four treatments in 2008 and 2009

| Cropping season | Sampling time | Powered-chopper (%) | Powered-cutter (%) | Powered-disc (%) | CK (%) |
|---|---|---|---|---|---|
| Spring maize (2008) | Before irrigation | 16.3 a | 15.9 a | 16.2 a | 15.6 a |
| | After irrigation[1)] | 20.2 a | 19.6 a | 20.0 a | 18.9 a |
| Spring wheat (2009) | Before irrigation | 16.8 a | 16.5 a | 16.6 a | 16.2 a |
| | After irrigation[1)] | 20.7 a | 20.1 a | 20.4 a | 19.2 a |

[1)] The data were measured 4 d after irrigation.

**Table 5** Soil temperature (°C) at 5 and 10 cm soil depths for four treatments in 2008 and 2009

| Soil depth (cm) | 2008 (spring maize) | | | | 2009 (spring wheat) | | | |
|---|---|---|---|---|---|---|---|---|
| | Powered-chopper | Powered-cutter | Powered-disc | CK | Powered-chopper | Powered-cutter | Powered-disc | CK |
| 5 | 16.5 a | 17.0 a | 16.9 a | 16.3 a | 15.2 a | 15.5 a | 15.8 a | 15.0 a |
| 10 | 14.6 a | 14.9 a | 15.1 a | 14.4 a | 13.8 a | 14.1 a | 14.0 a | 13.9 a |

weight in 2008. Stem diameter and dry root weight were greater by approximately 6.8 and 6.3%, respectively, in PRB than CK. Within PRB treatments, powered-disc increased stem diameter by 8.2 (significant at $P$=0.05) and 2.9%, compared with powered-chopper and -cutter treatments, respectively. Furthermore, powered-disc produced higher dry root weight and the increase was 6.3 and 2.0% relative to powered-chopper and -cutter treatments, respectively. The spring wheat performance was also better in PRB plots than that in CK plots in 2009, and particularly the powered-disc treatment was found significantly compared with CK. Leaf area and dry root weight in powered-disc were 8.5 and 5.1% significantly ($P$=0.05) greater than those in CK. The difference of spring wheat performance between powered-cutter and -chopper was observed inconsiderable and could be neglected.

The mean spring maize yields in 2008 for powered-chopper, -cutter, -disc, and CK treatments were 11.51, 12.02, 12.30, and 11.39 t ha$^{-1}$, respectively, indicating the yield improvement of 1.1-8.0% for PRB treatments compared with CK. In PRB treatments, powered-disc increased spring maize yields by 6.9 and 2.3% compared with powered-chopper and -cutter treatments, respectively. For spring wheat, mean yields for powered-chopper, -cutter, and -disc were 2.9, 1.1, and 0.3% greater than for CK treatment and powered-disc, respectively and again produced the highest yield.

### Fuel consumption

Fuel consumption for seeding by three no-till seeders in PRB treatments, and tillage for seedbed preparation and seeding by traditional seeder in CK treatment are shown in Fig. 1. In CK treatment, fuel consumption for the seeding of traditional seeder was 11.7 L ha$^{-1}$, but considering the fuel consumption for the ploughing and leveling of seedbed preparation, the total fuel consumption for CK treatment was 32.8 L ha$^{-1}$, which was significantly higher than that in PRB treatments. Amongst PRB treatments, powered-disc and -cutter seeder was required 14.1 and 10.9% more fuel consumption than the powered-chopper, respectively.

## DISCUSSION

Field test results showed that crop performance and yield in PRB no-till seeders seeded plots can be improved compared to traditional seeded (CK) plots. The results contribute to other studies on the advantages of PRB system (Kukal *et al*. 2005; He *et al*. 2008). The advantage of PRB can be explained by improved seedbed conditions and increased soil moisture characteris-

**Table 6** Seeding depth (mm) and plant population (plant m$^{-2}$) for four treatments in 2008 and 2009

| | 2008 (spring maize) | | | | 2009 (spring wheat) | | | |
|---|---|---|---|---|---|---|---|---|
| | Powered-chopper | Powered-cutter | Powered-disc | CK | Powered-chopper | Powered-cutter | Powered-disc | CK |
| Seeding depth | | | | | | | | |
| Mean | 46 a | 46 a | 45 a | 45 a | 47 a | 46 a | 48 a | 47 a |
| SD | 6.7 a | 4.3 b | 3.4 b | 3.2 b | 7.9 a | 5.7 b | 4.8 b | 4.5 b |
| Plant population | | | | | | | | |
| Mean | 10 a | 11 a | 10 a | 10 a | 665 b | 687 a b | 698 a | 720 a |

**Table 7** Crop performance and yield for 4 treatments in 2008 and 2009[1)]

| Year | Treatment | Plant height (cm) | Stem diameter (cm) | Root dry weight (g/plant) | Yield (t ha$^{-1}$) |
|---|---|---|---|---|---|
| 2008 (spring maize) | Powered-chopper | 256 a | 2.32 b | 128.1 a | 11.51 a |
| | Powered-cutter | 259 a | 2.44 a b | 133.5 a | 12.02 a |
| | Powered-disc | 258 a | 2.51 a | 136.2 a | 12.30 a |
| | CK | 254 a | 2.27 b | 124.7 a | 11.39 a |

| Year | Treatment | Leaf area (cm$^2$/plant) | Plant height (cm) | Plant dry weight (g/plant) | Root dry weight (g/100 plants) | Yield (t ha$^{-1}$) |
|---|---|---|---|---|---|---|
| 2009 (spring wheat) | Powered-chopper | 64.8 b | 67.9 a | 33.7 a | 752 b | 6.15 a |
| | Powered-cutter | 66.1 a b | 67.2 a | 35.0 a | 769 a b | 6.20 a |
| | Powered-disc | 68.7 a | 68.0 a | 35.1 a | 783 a | 6.31 a |
| | CK | 63.3 b | 67.4 a | 33.0 a | 745 b | 6.13 a |

[1)] The data for maize and wheat growth were measured on the 3rd September in 2008 and the 25th May in 2009. Maize and wheat root dry weight were measured in 0-60 and 0-20 cm soil depth, respectively.

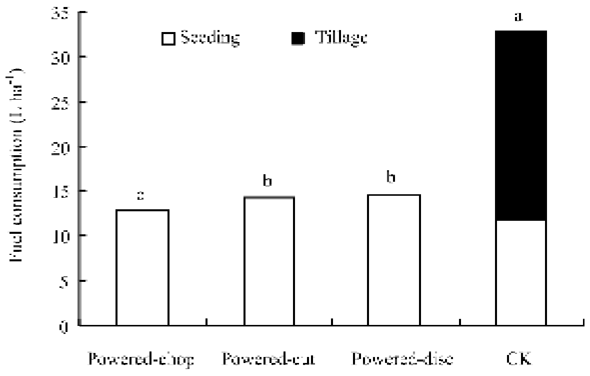


**Fig. 1** Fuel consumption for seeding by three no-till seeders in PRB treatments, and tillage for seedbed preparation and seeding by traditional seeder in CK treatment. Means followed by the same letters were not significantly different at $P$=0.05.

tics and soil temperature.

For three PRB no-till seeders, the powered strip-chopping no-till seeder provided the least soil disturbance, and it is an accepted characteristic of this type as compared with the powered-cutter and -disc no-till seeders, which use combination opening configurations of cutter/disc+tine opener to produce seedbeds (Yao *et al.* 2009). It also had the greatest residue cover index (≥80%), because the single tine opener in powered strip-chopping no-till seeder disturbed less soil and formed a smaller slot than the other two no-till seeders. However, the residue coverage following the powered-disc and -cutter treatments was greater than 50% in each case, and therefore provided excellent protection from water and wind erosion in arid Northwest China (He *et al.* 2008). All the three PRB no-till seeders met the conservation tillage requirement of leaving more than 30% residue cover on the soil surface after seeding (Uri *et al.* 1998).

The difference in soil water-stable aggregates was not significant. However, soil bulk density which has been shown to affect crop early growth (Vamerali *et al.* 2006) in seedbed was statistically reduced by over 17% by three PRB no-till seeders after seeding. For three PRB no-till seeders, the powered-disc strip-till for 10 cm depth uses a tine opener to form the U-shaped slot, thus produced the most loose soil in the disturbed soil layer relative to powered-cutter (strip cut to 2 cm depth+open 10 cm depth furrow by tine opener) and powered-chopper (open 10 cm depth furrow by tine opener). Consequently, soil bulk density in seedbed in powered-disc seeded plots was over 1.0% lower than that in powered-chopper and -cutter seeded plots.

The looser soils (fine tilth) in the seedbeds also help to produce better seeding conditions. Seeding depth was suitable for spring maize and wheat, but powered-disc produced more uniform seeding depth (Table 6) due to increased tilth and possibly more soil backfilled around the seeds. The improvement in soil tilth, especially below seeding depth tended to promote root growth and seedling development, as shown by Zhang *et al.* (2006).

Numerous researchers have shown that residue mulch helps to reduce soil water evaporation and increase soil moisture (Huang *et al.* 2005; He *et al.* 2011; Singh *et al.* 2011). This study generally confirmed the improvements of soil water content in the powered-chopper seeded plots, which had the highest residue cover index after seeding (spring maize: 90%, spring wheat: 80%) in three PRB no-till seeders. Although with less residue cover, in powered-disc seeded plots, the more loosening soils were associated with improved water holding pores which increased uniform lateral penetration of irrigation water into beds. This activity retained similar soil moisture as compared to powered-chopper treatment. Furthermore, powered-disc and -cutter treatments were associated with higher soil temperatures compared with powered-chopper. Mean maximum soil temperature was reported for powered-disc, and powered-cutter was 0.5-0.6°C greater than powered-chopper in the first 8 d after seeding during the consecutive two experimental years. In arid Northwest China, the air temperature is still very low after wheat and maize seeding in March and April, so the improvement in soil temperature in powered-disc and -cutter treatments is of considerable importance for the germination and growth of spring wheat and maize (He *et al.* 2008), and it can be explained by less residue cover and more loose soils in powered-disc and -cutter treatments, which allowed the soils to absorb solar energy directly, together with more porous soils that tended to promote soothing air flow resulting quick warming in the spring (He *et al.* 2007).

Plant emergence of spring maize in three PRB treatments was similar, but spring wheat emergence in powered-disc treatment was statistically higher than that in powered-chopper treatment (Table 6). This could be a consequence of less level of residue cover over the seedling trench produced by powered-disc. Residue over the seed zone can have a significant negative effect on wheat emergence (Yao *et al*. 2009). Furthermore, more uniform seeding depth in powered-disc seeded soils also promoted the germination of spring wheat.

In PRB cropping system, crop growth can be improved in some circumstances by subsurface seedbed shatter (Chaudhry *et al.* 1988), so together with lower soil bulk density, higher soil temperature and greater plant emergence by powered-disc and -cutter appear to have an advantage for spring maize and wheat growth. This advantage for crop growth was particularly significant in powered-disc treatment (Table 7). The powered-disc treatment generally had the highest stem diameter and root dry weight for spring maize, and leaf area and plant and dry root weight for spring wheat. All these improvements were probably responsible for the increased (over 1.8%) spring maize and wheat yield grown in the powered-disc soils as compared with that in powered-chopper and -cutter plots. Our results supported earlier findings of Yang (2002), who concluded that for spring wheat in cold and arid areas, better crop growth was an important factor to result in higher crop yield.

This study showed that, in these conditions, with 0.4-1.8 L $ha^{-1}$ greater fuel consumption result from higher soil disturbance, powered-disc PRB no-till seeder had better plant population, growth, and yield of crop than those of powered-cutter and -chopper PRB no-till seeders in heavy residue conditions. So in the areas without precise requirement of soil disturbance, the powered disc no-till seeder can be a suitable option for work in no-till conditions in PRB cropping system. However, in the context of soil disturbance, soil moisture retention, the maximum residue cover and the loss of nutrients, the powered strip-chopping no-till seeder can be considered in the PRB no-till seeding systems for small landholders in arid Northwest China.

## CONCLUSION

Results from this research indicated that in the regions of Northwest China without strict requirement of soil disturbance, the powered-disc no-till seeder satisfies the requirements of conservation tillage farming systems which is the suitable machine among three tested for PRB cropping system. Although with less residue cover index after seeding, the powered-disc no-till seeder reduced soil bulk density and produced better seedbeds, thereby promoting crop emergence and growth, and improved 1.8-6.9% of spring maize and wheat yields as compared to powered-chopper and -cutter. While in the areas with high standard for soil disturbance and residue cover, the powered strip-chopping no-till seeder can be a suitable option. Our findings, which are a rare example of an integrated approach applying mechanics, soil physical properties and crop performance, indicate that closer integration of several research topics should be taken into consideration for more insights into the functioning of PRB no-till seeders.

## MATERIALS AND METHODS

### Equipment description

**Powered strip-chopping no-till seeder** The powered strip-chopping no-till seeder is mainly comprised of alabama style furrow cleaners, L-type flail blades, drive shaft, knife type openers, seed and fertilizer bin, press wheels, etc. (Fig. 2-A). The fluted roller type seed metering system is used for wheat and maize seeding. Two L-type flail blades arranged as the "++"-form are set between two neighboring knife type openers. The flails rotate at 1 200-1 400 r/min. The flail shaft is chain driven from a gearbox connected to the tractor's power take-off (PTO) by a standard drive shaft. During seeding, the alabama reshape the bed shoulders and clean the furrows; the powered flails don't touch the soils as they chop the residue and keep the above-ground section of the knife type openers free of residue; the double shoot knife opener creates a groove 30-40 mm wide and 90-110 mm deep, then the metal press wheel closes the slot and firms the seed and fertilizer at depths of 50 and 100 mm, respectively. The planter was 1 m wide which can plant two rows maize or five rows wheat. The groove of seedbed for powered strip-chopping no-till seeder is typically U-shaped and the seedbed's surface is covered by the chopped residues after seeding.

**Powered cutter no-till seeder** The powered cutter no-till seeder consists of cutters, drive pulleys, knife type openers, fluted roller type seed meter, press wheels, furrow cleaners, etc. (Fig. 2-B). The drive pulleys are powered through V-belts (C-section) from the gearbox driven by the tractor's PTO shaft at the 340-360 r/min. The cutters (width, 90 mm) reciprocate vertical above the bed surface, sometimes intersecting the soil by 20 mm depth. The cutters are mounted ahead of the openers, so they can chop the residues and prevent the openers from blockage. Furthermore, the cut-

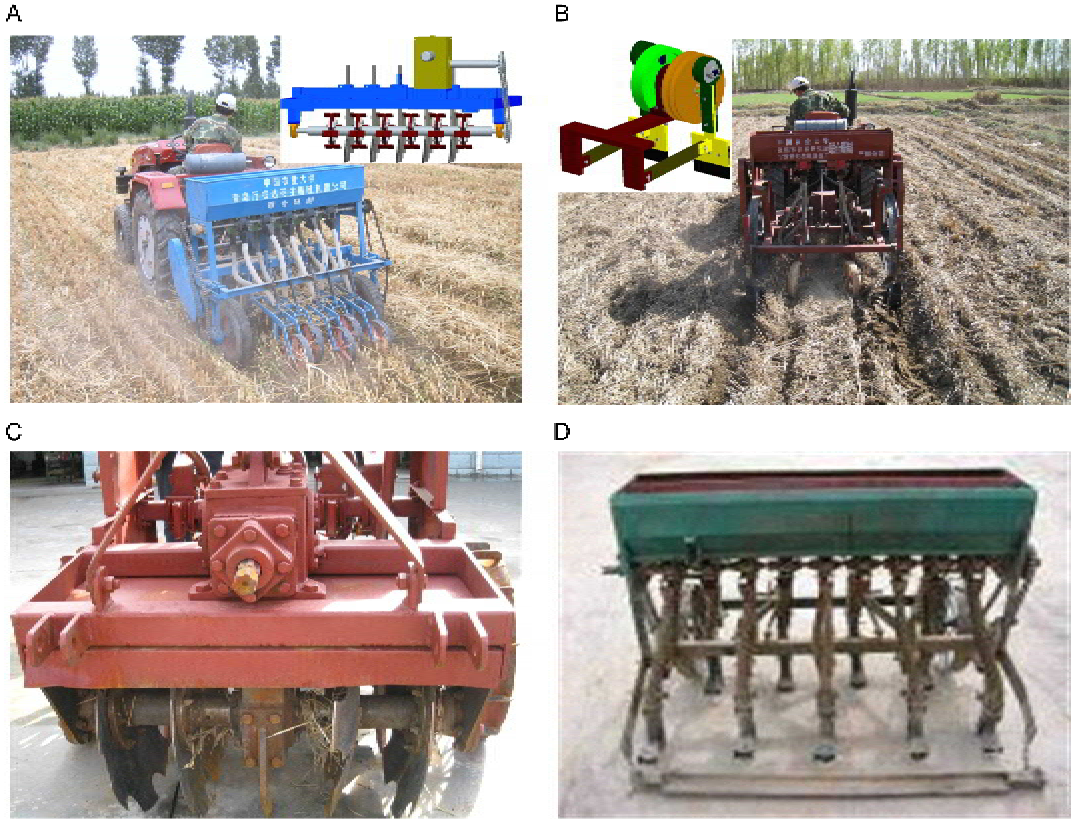


**Fig. 2** Four kinds of seeders used for the experiment: powered strip-chopping no-till seeder (A), powered cutter no-till seeder (B), powered disc no-till seeder (C), and traditional seeder (D).

ters often loosen the bed surface, which assists the double shoot knife opener to produce a U-shaped seeding slot (width, 30-40 mm; depth, 90-110 mm) for seed and fertilizer placement. The furrow cleaners also renovate the bed shoulders. With a working width of 1 m, the seeder can plant maize with two rows at 55 cm spacing or plant five rows of wheat at 15 cm spacing. After seeding, the seedbed remains covered with chopped residues.

**Powered disc no-till seeder** Powered disc no-till seeder includes cutting discs, knife type fertilizer openers, double-disc seed openers, fluted roller type seed meter, furrow cleaning and bed-reshaping tines, etc. (Fig. 2-C). The machine has four powered discs rotating at 260-320 r/min and one coulter ahead of knife openers to strip till the soils to about 10 cm depth and clear the residues from the seeding zone. The tine produces a U-shaped slot (width, 40-50 mm; depth, 90-110 mm) for fertilizer placement. A double-disc opener, behind the tine opener, with individual-row depth control mechanisms is used to place seed 40-50 mm above the fertilizer. The furrow cleaners also renovate the bed shoulders. After seeding, the seedbed is covered by chopped maize or wheat residues.

**Traditional seeder** Traditional seeder includes forward curved shoe openers, fluted roller type seed meter, roller, etc. (Fig. 2-D). The shoe opener creates a U-shaped seeding slot (width, 30-40 mm; depth, 50-60 mm) in ploughed soils, then the matched roller closes the slot and firms the seed at depths of 50 mm. For this experiment, the machine was set to plant two rows maize (row spacing, 55 cm) or six rows wheat (row spacing, 18 cm) by changing the numbers of openers. The key parameters of these four seeders are presented in Table 8.

## Site description

Field experiment was conducted at Zhangye (38°50′N, 100°10′E) situated in the Hexi Corridor of Northwest China, for the 2008 and 2009 cropping cycles. The site had three continuous years of PRB cropping prior to 2008, and is located in warm-temperate but arid region. The mean annual precipitation is 146 mm and the annual mean air temperature is about 7.3°C, with a maximum of 39°C (July) and a minimum of -27°C in January. Accumulated temperature of ≥10°C is about 3 088°C with 169 frost free days. In this single cropping area, it is either spring wheat or maize as the main cropping system used extensively in this area. The Loess soil in the experimental plots contains 16% clay, 33% silt, and 51% sand, on the average. In the top 20-cm layer, soil organic matter is 9.2 g $kg^{-1}$ and pH 7.9.

## Experimental design

In the experiment, three PRB no-till seeders were compared with one locally developed traditional seeder: powered strip-chopping no-till seeder (powered-chopper), powered cutter no-till seeder (powered-cutter), powered disc no-till seeder (powered-disc), and traditional seeder (CK). The experiment was designed as a randomized block with three replications. Each plot was 18 m wide and 25 m long with an access pathway and guard strip between each plot.

In three PRB treatments, cropping system operations are typical of those used in oasis farming areas in Northwest China, i.e., no-till seeding in March for spring wheat or April for spring maize, furrow irrigating in April, May, and June for spring wheat or May, June, July, and August for spring maize, harvesting in July for spring wheat or September for spring maize, fallowing till March for spring wheat and April for spring maize of the following year.

The CK treatment included ploughing to 20 cm depth and tillage for seedbed preparation. Seeding was done by traditional seeder in March for spring wheat or April for spring maize, flood irrigation in April, May and June for spring wheat or May, June, July, and August for spring maize, and harvesting in July for spring wheat or September for spring maize. All crop residues were removed following harvest. The detailed operation schedules for spring maize and spring wheat in 2008 and 2009 are shown in Table 9.

The spring maize variety Jinkai 1 and spring wheat variety Longfu 2 were used in 2008 and 2009 cropping seasons, respectively. In Hexi corridor, seed and fertilizer are commonly applied at very high rates as compared with the national common used level by farmers to maximize the chance of good yields. In 2008, spring maize was seeded with the district-recommended rate of 60 kg $ha^{-1}$, and the complete fertilizer ($N$-$P_2O_5$-$K_2O$) was applied at the rate of 205 kg N $ha^{-1}$ and 102.5 kg P $ha^{-1}$ at seeding. In 2009, spring wheat was seeded at the rate of 450 kg $ha^{-1}$, and the $CO(NH_2)_2$ and $(NH_4)_2HPO_4$ fertilizers were applied to provide 225 kg N and 180 kg P $ha^{-1}$ at seeding. The seeding rate for each of four seeders was calibrated following the standard procedure (JB/T6274.1-2001) using bags to collect seed from each delivery tube for 15 m of forward travel. Individual seed meters were then adjusted as necessary to achieve uniform seeding rate. During the experiment, seeding was carried out with a 20-hp tractor operating at 2.5 km $h^{-1}$.

Beds were formed in 2005 with an overall (furrow centre) width of 1.0 m for PRB treatments to fit the wheel track width of the tractor and harvester. Furrow depth was 15 cm, and the bed surface width was 75 cm, allowing two rows maize at 55 cm spacing and five rows wheat at 15 cm spacing. In all the experimental plots, the crop (spring wheat) in 2007 was harvested by combine harvester, leaving 20 cm-high standing stubble providing residue cover 100% equivalent to ~3.2 t $ha^{-1}$. In CK treatment, spring wheat and spring maize were seeded with the row space of 18 and 55 cm, respectively, which indicated that a 1.0-m width accommodated six rows of spring wheat or two rows of spring maize.

## Measurements

**Soil disturbance and residue cover index** Soil disturbance ($\eta$) on the bed surface was taken as the proportion of surface disturbed (GB/T 20865-2007) and calculated using the following eq.:

$$\eta = d/D \quad (1)$$

Where, $d$ is the disturbed soil width (cm) and $D$ is bed surface (cm).

Residue cover index ($F$) was measured using a 100-m long cord with knots at 0.2 m intervals on the bed surface. After seeding, the cord was randomly placed on the bed

**Table 8** The key parameters of three no-till seeders for PRB system and one traditional seeder

| Parameter | Powered strip-chopping no-till seeder | Powered cutterno-till seeder | Powered disc no-till seeder | Traditional seeder |
|---|---|---|---|---|
| Matched power | 18-30 hp | 18-30 hp | 18-30 hp | 18-30 hp |
| Working width | 1.0 m | 1.0 m | 1.0 m | 1.0 m |
| Residue-cutting/chopping part | Powered L type flail blade (rotating speed: 1 200-1 400 r/min) | Powered cutter (cutting speed: 340-360 r/min) | Powered disc (rotating speed: 260-320 r/min) | N/A |
| Number of furrow openers | Maize: two rows<br>Wheat: five rows | Maize: two rows<br>Wheat: five rows | Maize: two rows<br>Wheat: five rows | Maize: two rows<br>Wheat: six rows |
| Seed metering device | Fluted feed roller | Fluted feed roller | Fluted feed roller | Fluted feed roller |
| Productivity | 0.20-0.30 ha $h^{-1}$ | 0.20-0.30 ha $h^{-1}$ | 0.20-0.30 ha $h^{-1}$ | 0.20-0.30 ha $h^{-1}$ |

N/A, not applicable.

**Table 9** Operation schedules for spring maize and spring wheat in 2008 and 2009

| Cropping season | Treatment | Schedule |
|---|---|---|
| 2008 (spring maize) | PRB | No-till seeding (18 April)-furrow irrigation (13 May, 14 June, 16 July, 18 August)-harvesting (29 September) |
| | CK | Ploughing, leveling (17 April)-seeding (18 April)-flood irrigation (13 May, 14 June, 16 July, 18 August)-harvesting (29 September) |
| 2008 (spring maize) | PRB | No-till seeding (25 March)-furrow irrigation (16 April, 18 May, 15 June)-harvesting (26 July) |
| | CK | Ploughing, leveling (24 March)-seeding (25 March)-flood irrigation (16 April, 18 May, 15 June)-harvesting (26 July) |

PRB, permanent raised beds.

surface (not parallel to the seed row), then the number of knots in contact with the residue were counted. The residue cover index was counted using the eq. (GB/T 20865-2007):

$$F=\frac{\sum \frac{N_2}{N_1}}{5}\times 100 \quad (2)$$

Where, $N_1$ is total knots in 100 m long cord and $N_2$ is total knots in contact with residue. All the measurements for soil disturbance and residue cover index were replicated five times.

**Seeding depth** To calculate seeding depth of spring wheat, five seedlings were pulled out in each marked row. The chlorophyll-free stem and coleoptile length (from seed remnants to onset of green stem) was measured as effective seeding depth (Tessier *et al.* 1991). For maize, the chlorophyll-free stem lengths were not obvious and the seed location could not be clearly identified. A mark was made on the plant at the ground level. The plant was then dug out and the entire stem length below the mark was taken as the effective seeding depth.

**Bulk density, soil moisture and soil water-stable aggregates** For the determination of bulk density and soil moisture, randomly undisturbed soil samples were collected using a manual stainless steel core samplers (size: 50.4 mm diameter ×50 mm length), from all plots (four treatments × three replications). All the sampling soil cores were weighed wet and dried at 105°C for 48 h by oven dry method, and weighed again up to constant weight to determine bulk density at 0-5 and 5-10 cm, and gravimetric soil water content at 0-30 cm. In both 2008 and 2009, soil samples were collected again and bulk density was measured from the seedbeds (after seeding) at 0-5 and 5-10 cm depths, and soil moisture was measured before and after 4 d of the first irrigation.

The disturbed soil samples were collected from seedbeds (after seeding) at 0-10 cm depth for soil aggregate stability in 2008 and 2009. Each soil sample was first passed through an 8-mm sieve by gently breaking the soil clods, pebbles and stable clods larger than 8 mm were discarded. Before the analyses, soil samples were air-dried for 24 h in the laboratory at room temperature. Soil water-stable aggregate distribution was determined by placing the soil sample on a nest of sieves, immersing directly in water, and agitating the sieves up and down 35 mm at 30 cycles $min^{-1}$ for 15 min in water. Proportions of stable aggregates >2, 2-1, 1-0.25, and <0.25 mm were calculated by drying and weighing the soil remaining on the sieves. Micro-aggregates <0.25 mm are those formed by the material that passed through the stack of sieves (Oades and Waters 1991).

**Soil temperature, plant growth and crop yield** Soil temperature was recorded at 5 and 10 cm soil depths at 08:00 ($T_{08:00}$), 14:00 ($T_{14:00}$), and 20:00 ($T_{20:00}$). Mean daily soil temperature ($T$) for 8 d after seeding was estimated following the procedure described by Mao *et al.* (1998):

$$T=(2\times T_{08:00}+T_{14:00}+T_{20:00})/4 \quad (3)$$

Above ground (shoot) and root samples for spring maize and spring wheat were taken randomly from three areas (100 cm×100 cm) per plot on 3rd September in 2008 and 25th May in 2009, respectively. Roots were dug out and collected in 0-60 and 0-20-cm soil layers for spring maize and spring wheat, respectively. All samples were dried at 65°C to constant weight by oven dry method and weighed to determine shoot biomass and dry root weight.

Spring wheat and maize grain yields were determined at 12% moisture content by manually harvesting three 3-m row lengths taken randomly from each plot.

**Fuel consumption** Fuel consumption was measured directly by a 20-hp four-wheel tractor equipped with the CTM-2002B tractor performance monitor (Serrano *et al.* 2003).

## Data analysis

Mean values were calculated for each of the variables, an ANOVA was used to assess the effects of three PRB no-till seeders and one locally developed traditional row seeder on the measured seed zone properties and crop performance. When the ANOVA indicated a significant $F$-value, multiple comparisons of annual mean values were performed by the least significant difference method. In all analyses, a probability of error smaller than 5% ($P$=0.05) was considered statistically significant. The SPSS analytical software package (13.0) was used for all the statistical analyses.

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