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Crop performance as affected by three opening configurations for no-till seeder in annual double cropping regions of northern China

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Abstract. The furrow opening configuration used by no-till seeders can have a major effect on crop emergence in conservation tillage systems. This is particularly important in annual double-cropping regions (winter wheat and summer maize) of northern China where large volumes of residue remain on the soil surface after maize harvesting. This problem has been investigated using 3 different opening configurations for no-till wheat seeding near Beijing in 2004–05 and 2005–06, and assessing performance in terms of soil disturbance, residue cover index, soil cone index, fuel consumption, winter wheat emergence, plant growth, and subsequent yield.

In this cropping system, the single-disc opening configuration significantly decreased mean soil disturbance and increased residue cover index compared with the combined strip-chop and strip-till opening configurations, but winter wheat emergence was 6–9% less, probably due to greater levels of residue cover and greater seed zone soil cone index. Winter wheat growth after seeding in combined strip-chop and strip-till seeded plots was faster than that in single-disc seeded plots and mean yield was greater. The most suitable furrow opening configuration in heavy residue cover conditions appeared to be the strip-chop one, which can provide similar crop performance with marginally better fuel economy than the strip-till opening configuration. These results should be seen as preliminary, but they are still valuable for the design and selection of no-till wheat seeders for double cropping in this region of China.

Additional keywords: conservation tillage, opening configuration, no-till seeder, winter wheat, crop emergence.

Introduction

Conservation tillage can reduce soil degradation and water erosion (Packer *et al.* 1992; Li *et al.* 2007) and improve water use efficiency (Chan and Heenan 1996) and crop yield (Schmidt *et al.* 1994). It can also reduce the problem of dust storms by reducing wind erosion and improving the sustainability of agriculture (Chan and Heenan 2007). The technology of conservation tillage has been demonstrated and extended by the Ministry of Agriculture (MOA) of China (Gao *et al.* 2000, 2003) in the annual double-cropping (winter wheat and summer maize) regions of northern China since 1997. Conservation tillage studies in these regions have demonstrated that yields of winter wheat and summer maize can increase by 7–12%, costs can be reduced by up to 20% (Li *et al.* 2000; Gao *et al.* 2003), and greenhouse gas (carbon) emission from agriculture slowed by the elimination of residue burning (Gao *et al.* 1999; Chan *et al.* 2003). Further, compared with traditional tillage, conservation tillage can increase water use efficiency by 12–16% and reduce water erosion by 52% (Liu *et al.* 2007).

No-till seeding of maize after wheat harvesting has been achieved with increasing success in these regions after several years of research and the development of several small–medium-sized, no-till maize seeders for these conditions (Li *et al.* 2000). No-till seeding of wheat after maize harvesting is, however, still a problem, and improvements are needed in residue handling ability and crop emergence when working in maize residues of 15–30 t/ha and 30–50 mm depth (Gao *et al.* 2003; Liao *et al.* 2004).

In no-tillage practices, the characteristics of the seedbeds play an important role in crop performance. Many authors have indicated that the abilities of residue handling and opening for no-till seeders are the most significant factors for the creation of suitable seedbeds (e.g. Mead and Chan 1988; Wang *et al.* 2008). Residue handling and seedling emergence after no-till seeding usually depend on the design of opening configuration and the quantity of surface residue (Siemens *et al.* 2006; Sun *et al.* 2008). Furrow openers, as the main opening configuration, are widely used by no-till seeders to open a furrow in the soil and place both seed and fertiliser; it may also incorporate the seed delivery system and/or the residue-cleaning system in heavy residue cover fields. The functional requirements and attributes of openers have been classified and described by Murray *et al.* (2006). Two main types of furrow openers—tine and disc—may lead to great differences in seedbeds (Chaudhuri 2001). Disc openers broadly classified as single- and double-disc types cut residue well, disturb little soil, and do not easily clog (Tajuddin and Balasubramanium

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1995). Single-disc openers employing a large diameter, plain or notched disc are currently adopted widely by no-till seeders, largely because the soil penetration and residue cutting ability enable effective operation over a wide range of soil types and residue conditions (Murray *et al*. 2006). Compared with single-disc openers, the double-disc openers need greater down-pressure to penetrate the soil and cut crop residues, but they can form more comfortable V-shaped furrows for seed germination and crop growth (Wang *et al*. 2008). However, under certain conditions surface residue can be pushed into the groove by inappropriately designed single- and double-disc openers, where it contacts the seed and reduces emergence (Payton *et al*. 1985; Chaudhry and Baker 1988). Disc openers, particularly double-disc openers, also require a large vertical force to penetrate hard soils depending on the depth of penetration and the amount of residue present (Kushwaha and Foster 1993). The consequence is that seeders using disc openers are usually too large, heavy, and expensive to be widely used in China.

Typically, tine openers require a lower vertical force for soil penetration and cause more soil disturbance than disc openers. Some investigations have also shown that tine openers reduce bulk density and soil penetration resistance in the top 50 mm soil layer compared with disc-type openers (Vamerali *et al*. 2006). These advantages have led to the adoption of small, inexpensive, no-till wheat seeders with tine-type openers in the single-cropping regions of northern China (Du 1999).

However, in the heavy crop residue of annual double-cropping regions, seeders equipped with tine openers are prone to blockages between adjacent openers (Wilkins *et al*. 1983; Liao *et al*. 2004). Consequently, tines must be widely spaced or equipped with cleaning attachments. These new types of combined opening configurations have included placing residue cutting coulters ahead of each opener (Ma 2006) and/or using row cleaning devices to move residue away from the furrow (Zhang and Gao 2000; Siemens *et al*. 2004).

After several years' development, no-till wheat seeder opening configurations with low susceptibility to blocking have been developed for the double-cropping regions (Yao 2005) and some have been manufactured commercially (Gao *et al*. 2007). These opening configurations have encouraged the development and extension of conservation tillage in these regions (Gao 2006) but the literature contains little information about their impact on crop performance.

This paper reports a comparison of opening configurations for no-till wheat seeders in terms of crop emergence, early growth, and subsequent yield in annual double-cropping regions of northern China. The units tested included 2 combined opening configurations, powered strip-chopping rotary coulter + tine opener (strip-chop) and powered strip-till rotary hoe + tine opener (strip-till), and one well known proprietary single-disc opening configuration (single-disc).

Materials and methods

Description of equipment

The strip-chop, no-till seeder (Fig. 1*a*) designed by the Conservation Tillage Research Centre of MOA sets 2 powered strip-chopping rotary coulters ahead of each opener to keep the above-ground section of the fertiliser tine type opener free from residue blockage (Fig. 1*b*). This complete machine was 2.4 m wide with 12 openers at 0.2-m spacing. It is equipped with tine openers to provide a groove 30–50 mm wide and 80–120 mm deep for fertiliser placement and a double-disc opener with individual-row depth control mechanisms to place seed 40–50 mm above the fertiliser. The groove is typically U-shaped (Fig. 2*a*).

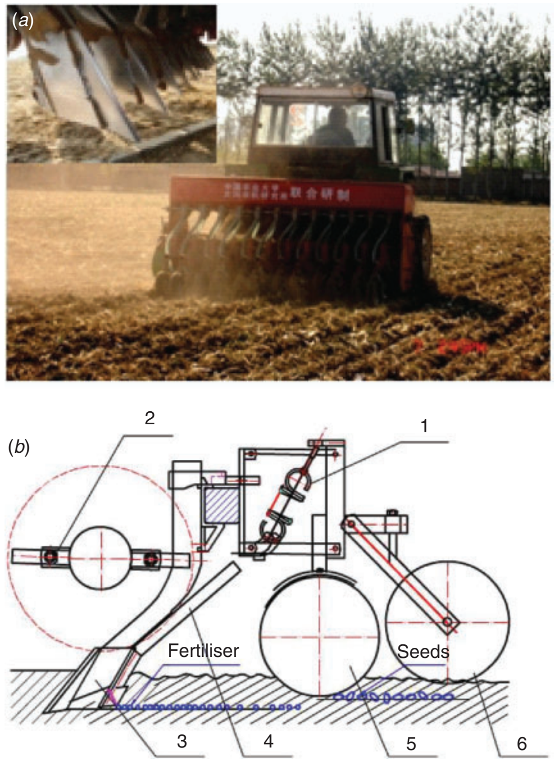

Fig. 1. (*a*) Strip-chop no-till wheat seeder, (*b*) schematic diagram of strip-chop seeding unit: 1, floating unit support; 2, strip-chopping rotary coulter unit; 3, tine opener; 4, fertiliser tube; 5, double-disc opener; 6, press wheel.

The strip-till, no-till seeder (Fig. 3*a*) is equipped with 5 powered strip-till rotary hoes (Fig. 3*b*) at 0.38-m spacing, to chop the maize stubble and till strips of seedbed (Fig. 2*b*) to create a 0.12-m-wide, 0.10-m-deep tilled zone. Behind a single narrow tine-type opener, a pair of offset delivery tubes place 2 rows of seed at 0.10-m spacing and a single, centred, delivery tube places fertiliser, 30–40 mm lower than the seed, within the tilled zone. Overall seeding width is 2.28 m.

The single-disc seeder (JD1590, John Deere Machinery Co., Ltd) (Fig. 4) has 18 single-disc openers at 0.19-m spacing to give a total width of 3.42 m. An adjustable gauge wheel (410 mm diameter, 100 mm wide) is beside, and a firming wheel (360 mm diameter, 13 mm wide) behind, each disc opener (Fig. 4*b*). The 460-mm-diameter single-discs are mounted at a compound angle of ~7° to the direction of travel. The resultant groove is V-shaped (Fig. 2*c*), 20–30 mm wide and 40–50 mm deep. Seed and fertiliser are placed together via a single dropper tube.

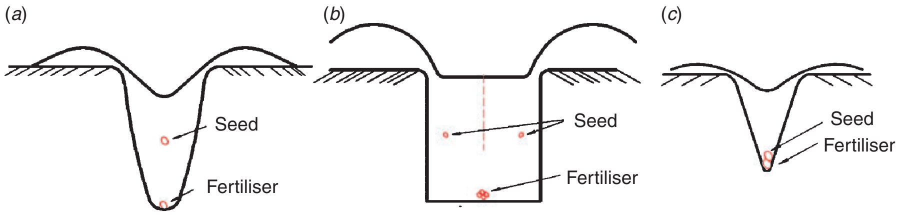

Fig. 2. Schematic of the groove shape produced by opener configurations: (*a*) the strip-chop opening configuration, (*b*) the strip-till opening configuration, (*c*) the single-disc opening configuration.

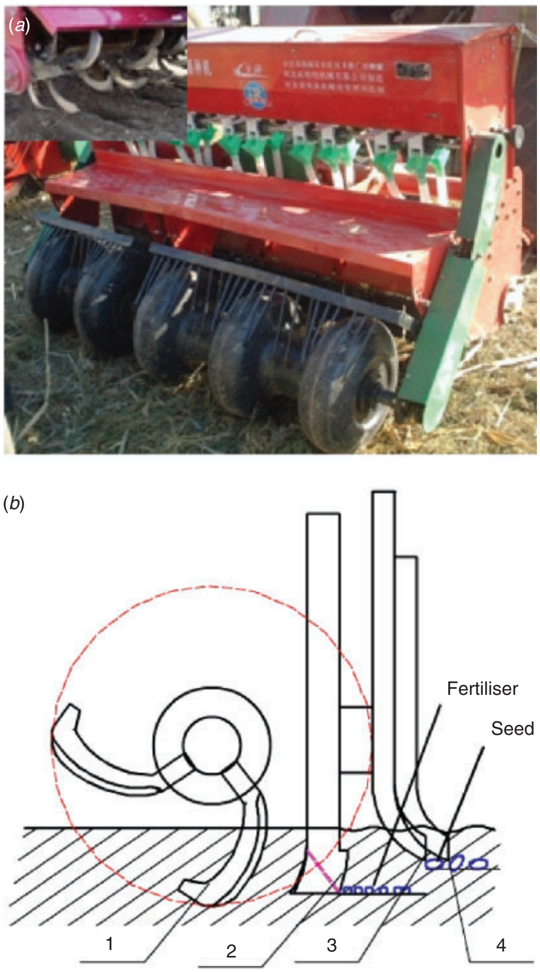

Fig. 3. (*a*) Strip-till no-till wheat seeder, (*b*) schematic of the strip-till opening configuration: 1, rotary hoe; 2, tine opener; 3, 4, seed tube.

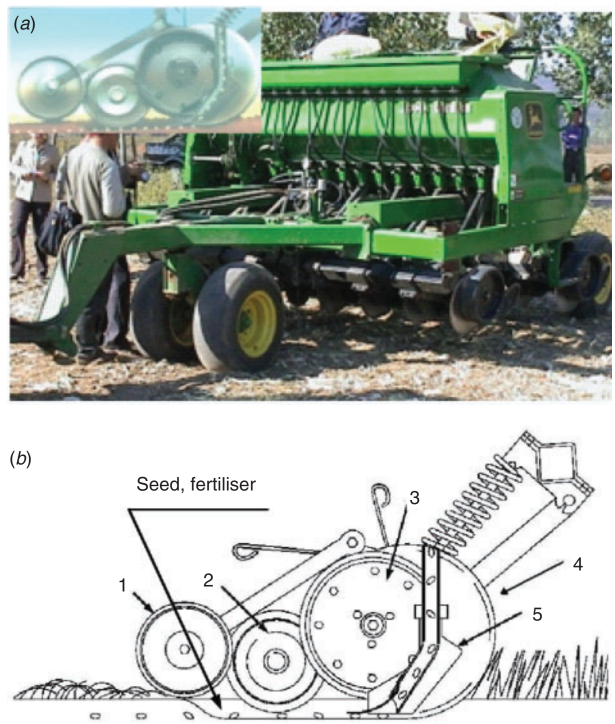

Fig. 4. (*a*) Single-disc no-till wheat seeder, (*b*) schematic diagram of single-disc opening configuration: 1, press wheel; 2, seed firming wheel; 3, depth control wheel; 4, single-disc opener; 5, seed tube.

Site description

Field trials were conducted over 2 years (2004–05, 2005–06) at Shaziying farm in the Daxing district of Beijing. The site is ~15 km south of Beijing city (39°7′N, 116°3′E) and has a 5-year history of no-till cropping. Average annual rainfall is 600 mm, 80% occurring in summer, and the average annual temperature 11.6°C with 190 frost-free days. The soil type is silt loam, clay 141 g/kg, silt 743 g/kg, and sand 116 g/kg, on average. In the top 0.20 m layer, soil bulk density was 1.28 Mg/m^3 and total porosity ~40%.

Cropping operations on the experimental area were typical of those used in the annual double-cropping regions of northern China, i.e. harvesting summer maize (end of September); no-till seeding winter wheat (beginning of October); spraying (middle of October); irrigating (end of November, then March and May in the following year); harvesting wheat (beginning of June); no-till seeding and spraying summer maize (middle of June); harvesting summer maize (end of September).

Seeders with 3 different opening configurations were assessed using 9 plots in 3 complete, randomised blocks (i.e. 3 replications). Each plot was 18 m wide and 100 m long with an access pathway and guard strip between each plot. Detailed operation schedules for winter wheat in 2004–05 and 2005–06 are shown in Table 1.

Table 1. Operation schedules for winter wheat in 2004–05 and 2005–06

Cropping season	Schedules
2004–05	No-till seeding winter wheat (7 Oct. 2004), spraying (13 Oct. 2004), irrigating (25 Nov. 2004, 20 Mar. 2005, 10 May 2005), harvesting wheat (10 June 2005)
2005–06	No-till seeding winter wheat (1 Oct. 2005), spraying (15 Oct. 2005), irrigating (20 Nov. 2005, 25 Mar. 2006, 8 May 2006), harvesting wheat (5 June 2006)

The wheat variety 'Jing 9428' was used in both the 2004–05 and 2005–06 cropping seasons. The seeding rate for each no-till seeder was calibrated following the standard procedure (JB/T6274.1-2001) using plastic bags to collect seed from each delivery tube for 15 m forward travel. Individual seed meters were then adjusted as necessary to achieve uniform seeding rate of 300 kg wheat seeds/ha. The same method was used to calibrate fertiliser rates. In this experiment, 100 kg/ha of fertiliser [$CO(NH_2)_2$, $(NH_4)_2HPO_4$, and KCl] was applied as the basal fertiliser at sowing and 125 kg/ha as a broadcast application before the first irrigation. Seeding was carried out with a 48 kW tractor operating at 3 km/h with the strip-chop and strip till seeding units and at 6 km/h with the single-disc seeding unit. Gauge wheels were adjusted on each seeding unit to provide soil cover of ~40 mm over seeds, but soil disturbance extended to a depth of 0.10 m with the strip-chop and strip till seeding units.

In all the experimental plots, the previous crop was maize harvested in October of 2004 and 2005, so the seeding condition was maize residue, with a fresh weight of 20–28 t/ha in both years. The mean soil gravimetric water contents to 0.10 m depth for 2004 and 2005 were 11.7% and 12.2%, respectively (mean of 50 randomised sites).

Soil disturbance

The maximum width of the seeding slot was measured using a ruler after sowing across 12 rows, taking 3 replicate sets of measurements per plot. Soil disturbance caused by opening configurations was taken as the proportion of surface disturbed (GB/T 20865–2007):

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

where η is soil disturbance, d is width of the furrow groove, and D is row space.

Covering index

A 100-m-long cord with knots at 0.2-m intervals was used to estimate residue cover before and after seeding. The cord was randomly placed on the surface (not parallel to the seed row), then the knots in contact with residue were counted. This procedure was carried out at 5 random locations per plot. The covering index was counted using the equation (GB/T 20865-2007):

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

where F is covering index, N_1 is total knots in 100-m-long cord, and N_2 is total knots in contact with residue.

Soil cone index

Soil cone index was measured using a cone penetrometer with a 13-mm-diameter cone base, a cone angle of 30°, and a 10-mm-diameter rod. Cone index was measured at different wheat growth stages before irrigation, by noting the maximum force as the penetrometer was pushed in by hand at constant speed to a depth of 100 mm. Ten measurements per plot were taken randomly in the seeded rows.

Seeding depth and plant population

Sowing depths were measured on 27 October 2004 and 21 October 2005 by noting the length of chlorophyll-free stem above the coleoptiles (i.e. from the seed remnants to green stem) (Tessier *et al.* 1991*a*). The standard deviation of mean seeding depth was used as the seed scattering index, as it represents the vertical scattering of seeds around the mean depth (Chen *et al.* 2005). Plant population was taken as the mean of final seedling counts after seedling counts stabilised, ~30 days after seeding.

Plant growth

Crop growth parameters including adventitious root, tiller counts, plant height, root dry weight, and plant dry weight were measured in 2005–06. In each plot, roots were carefully dug out to 0.20 m soil depth in 3 random 1 m lengths of seeding row during the winter dormancy (20 November 2005), re-greening (15 March 2006), and jointing (20 April 2006) stages. Roots were directly immersed into water to remove soil, measure adventitious roots, and do tiller counts. Plant dry weight and root dry weight were noted after drying to constant weight at 80°C.

Yield

Wheat samples were collected by hand from 5 random 1-m^2 quadrats per plot before harvest on 10 June 2005 and 5 June 2006. Samples were brought to the laboratory and yield parameters including grains per spike, kernel weight, and spike length measured before threshing. Grain samples were oven-dried at 60°C for 72 h to determine dry matter yield.

Fuel consumption

The tractor was fitted with a proprietary fuel sensor (Ma 2006), which was used to indicate fuel consumption during seeder operation.

Data analysis

Mean values were calculated for each of the measurements, and ANOVA was used to assess the effects of opening configuration on the measured variables. When this indicated a significant F-value (at $P = 0.05$), multiple comparisons of annual mean values were made on the basis of the least significant difference (l.s.d.). The SPSS analytical software package (v.13.0) was used for all statistical analyses.

Results

Soil disturbance and residue cover index

The soil disturbance and residue cover index for each of the 3 opening configurations were similar in both 2004 and 2005 (Table 2), which was consistent with the findings of Tajuddin and Balasubramanium (1995). For all 3 treatments, the experimental plots had complete residue cover before seeding, but afterwards the mean residue cover index for 2004 and 2005 was 82%, 53%, and 96% in strip-chop, strip-till, and single-disc seeded plots, respectively. Differences in residue cover and soil disturbance between strip-till and single-disc treatments were significantly in both years ($P < 0.05$). Strip-till and single-disc opening configurations provided the maximum and minimum soil disturbance, respectively, in both years.

Table 2. Soil disturbance (%) and residue cover index (%) for 3 opening configurations before and after seeding in 2004–05 and 2005–06
Means within a column followed by the same letters are not significantly different at $P = 0.05$

Cropping season	Treatments	Soil disturbance	Residue cover index	
			Before seeding	After seeding
2004–05	Strip-chop	24a	100	83a
	Strip-till	51b	100	52b
	Single-disc	15a	100	96a
2005–06	Strip-chop	26a	100	80a
	Strip-till	50b	100	54b
	Single-disc	16a	100	95a

Soil cone index

Soil cone index measured in the seeding row for the 3 opening configurations at different stages of winter wheat growth in 2005–06 are illustrated in Fig. 5, showing that the type of opening configuration had significant effect on soil cone index. At the seedling stage, the strip-chop, strip-till, and single-disc treatments decreased soil cone index in the seeding row at 0–0.10 m soil depth by 83%, 89%, and 26%, respectively, compared with the cone index before seeding; a significantly ($P < 0.05$) smaller cone index value was founded in the strip-chop and strip-till seeded plots. Soil cone index in the winter dormancy, re-green, and jointing stages of winter wheat showed the same trend as that in seedling stage.

Crop emergence and plant population

Despite attempts made to provide ~40 mm soil coverage, the mean chlorophyll-free length for all treatments varied from 35 to 40 mm but the differences were not significant ($P > 0.05$) (Fig. 6). Mean values of seed scattering index in strip-chop (5.3 mm) and single-disc (6.9 mm) seeded plots were significantly less than that of strip-till (4.1 mm) seeded plots in both years (Fig. 7), indicating that the strip-chop and single-disc opening configurations could provide a more uniform seeding depth.

The type of opening configuration had a significant effect on wheat emergence (Table 3) in both cropping seasons. Mean plant population for strip-chop, strip-till, and single-disc treatments was 498, 505, and 466 plants/m^2, respectively; the strip-chop and strip-till treatments significantly ($P < 0.05$) improved plant populations by 6.8% and 8.4% compared with the single-disc treatment.

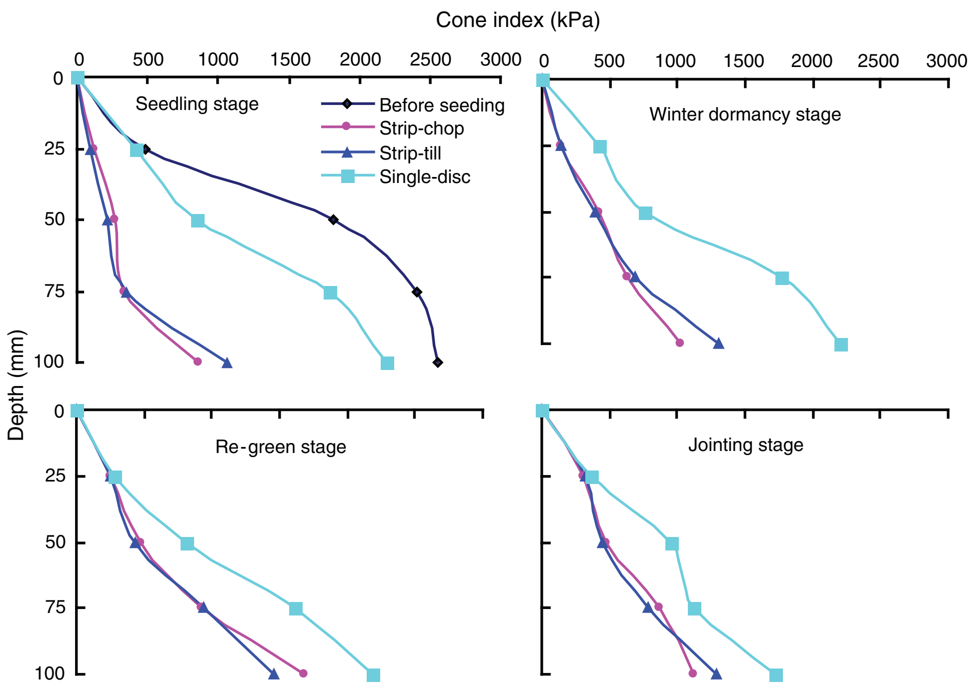

Fig. 5. Soil cone index in seeding row for 3 opening configurations in 2005–06.

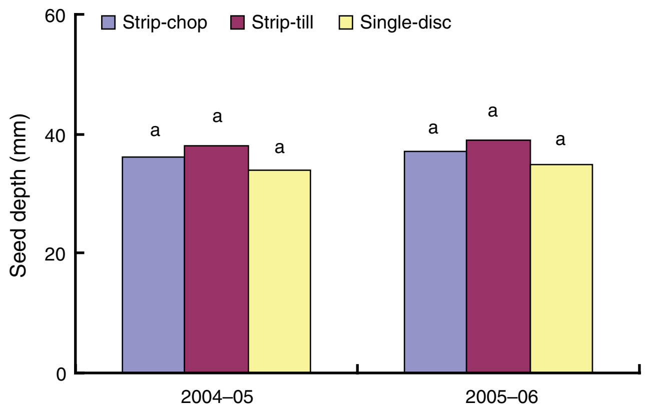

Fig. 6. Seed depth after seeding by 3 opening configurations in 2004–05 and 2005–06. Values with the same letters within each cropping cycle are not significantly different at $P=0.05$.

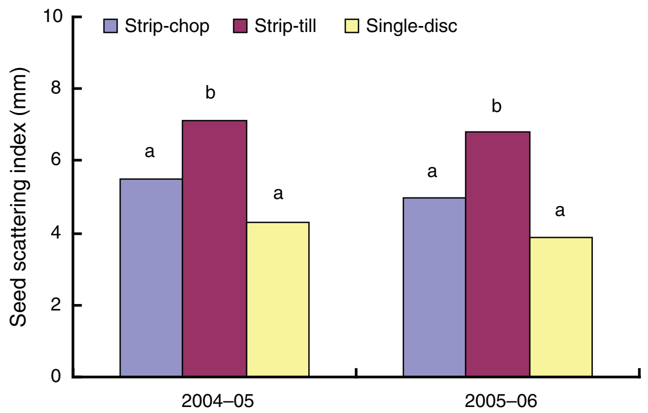

Fig. 7. Seeding scattering index after seeding by with 3 opening configurations in 2004–05 and 2005–06. Values with the same letters within each cropping cycle are not significantly different at $P=0.05$.

Table 3. Plant population (plant/m^2) for 3 opening configurations in 2004–05 and 2005–06

Means within a row followed by the same letters are not significantly different at $P=0.05$

Cropping season	Strip-chop	Strip-till	Single-disc
2004–05	483a	490a	449b
2005–06	513a	520a	483b

Growth

Winter wheat growth on strip-chop and strip-till seeded plots was faster than that of single-disc seeded plots in both cropping seasons (Table 4). In 2004–05, plant and root dry weights of strip-chop and strip-till seeded wheat were 23–79% ($P<0.05$) greater than single-disc seeded wheat in the dormancy and re-green stages, but this effect was negligible by the jointing stage. Similar results were found in the following cropping season. In 2005–06, strip-chop and strip-till treatments increased plant and root dry weight by 35% and 39% ($P<0.05$) compared with single-disc treatment in early growth stages, but the improvements were only 5% and 10%, respectively, by the jointing stage. Differences between the strip-chop and strip-till results were consistently small and non-significant.

Yield

The mean winter wheat yield for strip-chop, strip-till, and single-disc treatments were 6110, 6210, 5930 kg/ha, respectively, for the 2004–05 cropping season, and results were similar in 2005–06, with strip-till and single-disc associated with the greatest and least yields, respectively (Table 5).

Fuel consumption

Fuel consumption for the 3 treatments ranged from 10.2 to 17.5 L/ha, with strip-chop and strip-till seeders requiring 32.4% and 71.6% ($P<0.05$) more fuel, respectively, than the single-disc seeder (Fig. 8).

Discussion

The single disc opening configuration provided the least soil disturbance (Table 2), which is an accepted characteristic of this type compared with the combined opening configurations (coulter/hoe + tine opener) (Tessier *et al.* 1991*b*; Tajuddin and Balasubramanium 1995) and was expected here given the sequence of soil-engaging components on each opening configuration. It also provided the greatest residue cover (>95%), because the single-disc opening configuration disturbed less soil and formed a much smaller groove than the other opening configurations. Nevertheless the residue coverage following the strip-chop and strip-till treatments was >50%, and therefore provided excellent protection from water and wind erosion in double-cropping regions of northern China (Liu 2004). All the opening configurations satisfied the conservation tillage requirement of leaving >30% residue cover on the soil surface after seeding (Gao *et al.* 2000).

Seedling emergence after seeding with the single disc treatment was 6–8% less than that from the other treatments (Table 3). This could be a consequence of the greater level of residue cover over the seedling trench produced by the single-disc opening configuration. Residue over the seed zone can have a significant negative effect on wheat establishment and crop production, according to Siemens and Wilkins (2006). The single-disc opening configuration has been shown to force some residues down into the seed trench and move dry topsoils into the seed zone rather than moving it laterally, thereby affecting wheat emergence (Wilkins *et al.* 1983). Despite careful attention to settings, the single-disc opening configuration provided a shallower, but (on average) more uniform seeding depth than strip-chop and strip-till opening configurations under the full residue cover fields.

The data indicate more vigorous growth of wheat seeded via the strip-chop and strip-till seeding configurations, which provide greater soil disturbance and reduce cone index in the seed zone. The designs of opening configurations that provide greater soil shatter around the seed groove can promote root growth, and seedling development, as shown by Swan *et al.* (1996) and Zhang *et al.* (2006). The data on adventitious root, tillering counts, plant height, root dry weight, and plant dry

Table 4. Adventitious root, tillering counts, plant height (cm), and root and plant dry weight (mg/plant) of winter wheat for 3 opening configurations in 2004–05 and 2005–06

Means within a column followed by the same letters are not significantly different at $P = 0.05$

Cropping season	Growth stage	Treatments	Adventitious root	Tillering counts	Plant height	Root dry wt	Plant dry wt
2004–05	Winter dormancy (25 Nov. 04)	Strip-chop	5.5ab	2.0a	17.1ab	33.1a	106.0a
		Strip-till	6.0a	2.1a	17.9a	26.1ab	116.2b
		Single-disc	5.0b	1.3b	16.2b	20.2b	64.8c
	Re-green (21 Mar. 05)	Strip-chop	6.7a	2.6a	20.6a	66.2a	180.5a
		Strip-till	6.2ab	2.4a	20.5a	57.8b	183.0a
		Single-disc	5.7b	1.4b	18.4b	43.2c	146.8b
	Jointing (24 Apr. 05)	Strip-chop	7.2a	–	38.8a	219.2a	662.5a
		Strip-till	7.6a	–	39.1a	210.5ab	654.8a
		Single-disc	7.4a	–	38.1a	207.1b	649.2a
2005–06	Winter dormancy (20 Nov. 05)	Strip-chop	5.9a	2.2a	17.5a	30.1a	129.8a
		Strip-till	6.2a	2.2a	18.6a	32.2a	131.6a
		Single-disc	3.6b	1.2b	14.3b	15.9b	66.2b
	Re-green (15 Mar. 06)	Strip-chop	6.4ab	2.5a	21.5a	69.7a	192.1a
		Strip-till	6.7a	2.8a	23.6a	65.6a	196.5a
		Single-disc	6.0b	1.5b	19.8b	57.1b	168.2b
	Jointing (20 Apr. 06)	Strip-chop	7.8a	–	41.2a	225.6a	688.7a
		Strip-till	7.6a	–	40.3a	230.4a	698.2a
		Single-disc	7.8a	–	37.5b	217.8a	630.5b

Table 5. Grains per spike, kernel weight (g), spike length (cm), and yield (kg/ha) for 3 opening configurations in maturing stage in 2004–05 and 2005–06

Means within a column followed by the same letters are not significantly different at $P = 0.05$

Cropping season	Treatments	Grains per spike	Kernel wt	Spike length	Yields
2004–05	Strip-chop	32.4a	40.8a	6.9a	6110ab
	Strip-till	32.3a	41.2a	7.1a	6210a
	Single-disc	31.6a	40.1a	6.6b	5930b
2005–06	Strip-chop	33.5a	41.2a	7.1a	6238a
	Strip-till	33.1a	41.6a	7.0a	6274a
	Single-disc	32.5a	39.8b	6.8a	6051b

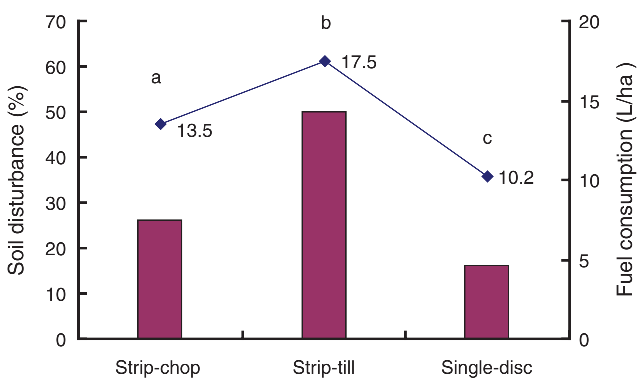

Fig. 8. Fuel consumption (♦) and soil disturbance (■) for 3 opening configurations. Means within fuel consumption followed by the same letter were not significantly different at $P = 0.05$. Data were measured at seeding on 1 October 2005.

weight all confirm this improvement in early growth compared with the single-disc opening configuration.

Soil cone index has been shown to affect wheat early growth (Doan *et al.* 2005; Vamerali *et al.* 2006). All 3 opening configurations reduced soil cone index in the seed zone (Fig. 5), but soil cone index decreased significantly after both strip-chop and strip-till seeding, compared with single-disc. Average soil cone index (0–50 mm) at the seedling stage was decreased by 85% after strip-chop and strip-till seeding, but by only 26% after single-disc seeding, and soil disturbance has an inverse relationship with soil cone index. Murray *et al.* (2006) provided evidence that the single disc opening configuration produces slight compaction beneath the disturbed layer, which might account for less vigorous growth.

Crop growth can be improved in some circumstances by subsurface seedbed shatter (Chaudhry and Baker 1988; Mead *et al.* 1992), so the limited disturbance and greater soil cone index produced by the single-disc opening configuration is likely to have disadvantaged early growth of wheat. Later in the season, after irrigations and soil freezing/thawing (Halvorson *et al.* 2003), there was no significant treatment difference ($P > 0.05$) in soil cone index, or wheat growth after jointing. This suggests that the difference in wheat emergence and early growth was the major factor affecting final yield in this trial. Yang (2002) has also concluded that greater plant population and faster crop growth were the important factors influencing wheat yield in northern China.

While soil disturbance might have been a positive factor in terms of crop development in these conditions, it is clearly a more energy-intensive process than chopping residue, or cutting a slit with a sharp disc opening configuration. Strip-chop and strip-till seeders required 23% and 42% more fuel, respectively, per unit area seeded compared with the single-disc seeder, when powered by the same tractor. This is only an approximation of seeding energy requirement, because values would also be influenced by other variables such as tractor engine characteristics and tractive efficiency.

Many factors influence the effectiveness of seeding, particularly in no-till situations, according to Murray *et al.* (2006), who observed that powered opening configurations have demonstrated exceptional ability to operate over a wide range of soil types and conditions, but their adoption has been restricted by high capital and operating costs. Anecdotal evidence suggests that the gradual improvement in soil structure observed under low-disturbance cropping systems will slowly reduce the need for soil disturbance at seeding.

This study showed that, in these conditions at least, winter wheat emergence, early growth, and yield of wheat seeded using the powered strip-chop and strip-till no-till seeders was significantly better than that seeded with a single-disc no-till seeder in heavy residue conditions. In this context, the immediate outcome of this work is a recommendation that the strip-chop, no-till seeder is more suitable for work in no-till conditions in annual doubling-cropping regions of northern China, on the basis of improved crop performance, and marginally better fuel economy than the strip-till no-till seeder.

Conclusions

Comparative field tests of no-till wheat seeders fitted with combined strip-chop and strip-till, and single-disc opening configurations in heavy residue conditions following maize harvest in double-cropping systems of northern China have demonstrated that:

(1) Although with less residue cover index after seeding, the combined opening configurations reduced soil cone index and produced more shattered soils in seeding rows due to greater soil disturbance, thereby providing better seedbeds.
(2) The improvement in seedbed conditions following seeding with the combined opening configurations resulted in a significant improvement in emergence and early growth of wheat. Consequently, wheat yields for strip-chop and strip-till seeded plots were 3.0–4.7% greater than for single-disc seeded plots.
(3) The combined opening configurations, particularly the powered strip-chop type, satisfied the requirements of conservation tillage farming, at the cost of a small increase in fuel cost per hectare seeded.

These conclusions might not apply in every situation, and further research is needed over more seasons, encompassing factors such as press-wheel settings, soil temperature, and soil moisture in the seed zone. This data are, however, useful in supporting decisions on the production of no-till seeding equipment to support the adoption of better cropping systems. In this case, the data generally support the use of the combined strip-chop opening configuration on the basis of crop performance and fuel economy.

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