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The effect of sowing depth and soil compaction on the growth and yield of rapeseed in rice straw returning field

Qingsong Zuo[a,b,1], Jie Kuai[a,1], Li Zhao[a], Zhan Hu[a], Jiangsheng Wu[a], Guangsheng Zhou[a,*]

[a] *C P S T , H A U , W 430070, H P , PR C*
[b] *K L C G P J P , Y U , Y 225009, J P , PR C*

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A B S T R A C T

The seed emergence and yield of rainfed rapeseed (*B* L.) are commonly limited by soil water availability during the growing season. The return of straw to the field helps maintain soil moisture status, but can cause long hypocotyls of

(Grzesiak et al., 2016). Post-sowing compaction can significantly increase rapeseed seedling emergence (Botta et al., 2013). Roath (1998) reported that soil packing increased seedling emergence by 14%, compared to non-packed treatments with a 13-mm sowing depth. Post-sowing compaction also benefited tall fescue and ryegrass with surface or very shallow sowing (Brock, 1973). This might be due to firmness of the seedbed, more accurate seed placement, and improved seed/soil contact resulting in greater seed hydration with the packed treatment. The great variability of responses to soil compaction is also dependent on the variable and the species studied (Alameda and Villar, 2009). Gomez et al. (2002a) found that the effect of soil compaction on growth of *P* saplings ranged from negative to positive, depending on the texture or water content of the soil. Therefore, it is very difficult to extrapolate compaction results to other soil conditions.

In the Yangtze Valley, in a rice-rapeseed cropping system, the optimal winter rapeseed sowing date often does not coincide with adequate soil conditions for field preparation and sowing. A delay in sowing beyond mid-October, however, is associated with continuous decreases in seed yield. Thus, farmers tend to prepare

Table 1
Air temperature and precipitation during the 2013–2104 and 2014–2015 rapeseed growing seasons.

Year	Item	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Sowing-harvest
2013–2014	Air temperature (°C)	19.0	12.5	6.3	6.4	6.3	12.8	17.5	21.9	12.8
	Precipitation (mm)	10.6	2.7	3.1	24.6	93.0	63.5	103.5	194.2	61.9
2014–2015	Air temperature (°C)	19.5	12.8	5.6	6.6	7.5	11.9	16.8	23.0	13.0
	Precipitation (mm)	57.0	13.8	61.0	21.2	94.1	65.1	124.5	106.9	68.0

2.3.4. W

The weed number and biomass was determined from an area of 1 m^2 at maturity as reported by Gronle et al., 2015. Weeds were cut 1 cm above the soil surface and dried in an oven for 30 min at 105 °C, and then dried again at 80 °C until constant weight. Each analysis was performed in three replicates.

2.4. S

Analysis of variance (ANOVA) was performed using SPSS Statistics 20 software (SPSS Inc., Chicago, IL, USA). Sowing depth and soil compaction were fixed factors, while year and block were random factors. Significant differences in means between the treatments were compared by the protected least significant difference (LSD) procedure at $P < 0.05$. Figures were prepared using the Origin 9.0 software program (OriginLab Corp.).

3. Results

3.1. P

No significant effects of sowing depth on BD, TP and water content were observed under both compacted and non-compacted soil. Soil compaction substantially increased BD and water content in 0–10 and 10–20 cm soil layers in both shallow and deep sowing, but TP decreased with a greater effect on the 0–10 cm soil layer (Table 2).

3.2. S , ,

The seedling emergence rate of the two seasons was in the range of 35.72%–42.01%. For shallow sowing, soil compaction substantially elevated the rate of emergence by 15.57% and 17.08% for 2013–2014 and 2014–2015, respectively; however, there was no significant difference between compacted and non-compacted soil for deep sowing. The seedling density of the two seasons ranged from 39.55×10^4 to 46.44×10^4 plants ha^{-1}, and the response to sowing depth and soil compaction was consistent with seedling emergence rate. With or without soil compaction, deeper sowing resulted in thinner stems. Soil compaction enhanced the rhizome diameter for both shallow and deep sowing, and the thickest stems among treatments were for shallow sowing with soil compaction. The ANOVA showed sowing depth had no great effect on seedling emergence rate and seedling density, but was extremely significant for rhizome diameter, and that the interaction of sowing depth and soil compaction had a significant effect on all three measures (Table 3).

3.3. D /

Without soil compaction, the overall dry weight and dry weight for different portions were substantially elevated with increased sowing depth, but were significantly reduced for increased sowing depth with soil compaction. Sowing depth had no effect on root/shoot ratio for both soil compaction treatments. With shallow sowing, the dry weight of root, aboveground tissue, whole plant, and root/shoot ratio were significantly higher for compacted than non-compacted soil, and the greatest increase was for root dry weight by 22.53% and 23.61% in 2013–2014 and 2014–2015, respectively. With deep sowing, no significant change in root dry weight was observed for compacted compared to non-compacted soil, but dry weight of aboveground tissue was reduced and root/shoot ratio increased by soil compaction with increases of 5.56% and 5.52% in 2013–2014 and 2014–2015, respectively. There were significant interactions between sowing depth and soil compaction on biomass of the root, shoot and the whole plant (Table 4).

3.4. Y

With no soil compaction, yield was significantly improved with increased sowing depth, with increases of 8.04% and 6.21% compared to shallow sowing for the two seasons, respectively. The effect of sowing depth on yield was not significant for compacted soil. For the same sowing depth, yield was significantly increased by soil compaction, with the greatest improvement for shallow sowing, showing increases of 19.02% and 18.17% in 2013–2014 and 2014–2015, respectively, compared to non-compacted soil. The increases with soil compaction were relatively small for both seasons for deep sowing, and were 8.57% and 8.75%, respectively (Table 5).

The effect of sowing depth and soil compaction on plant height was not substantial. Except for a slightly lower number for shallow sowing with soil compaction, there were no other significant differences in siliques per plant among treatments. There was no difference in population silique number for different sowing depths without soil compaction, but with soil compaction a significant reduction with increased sowing depth with the reduction amplitude of 4.77% and 5.10% in 2013–2014 and 2014–2015, respectively, for deep compared to shallow sowing. Shallow sowing with compacted soil significantly increased the population silique number compared to non-compacted soil by 9.66% and 8.77% in 2013–2014 and 2014–2015, respectively. There was little effect of soil compaction on population silique number under conditions of deep sowing. Silique number per plant was elevated with increased sowing depth, regardless of soil compaction; and was substantially increased for compacted compared to non-compacted soil at the same sowing depth. The lowest thousand-seed weight was for shallow sowing without soil compaction, while the highest was for deep sowing with soil compaction (Table 5).

3.5. L

Lodging was significantly affected by sowing depth and soil compaction. For non-compacted soil, the degrees of root and stem lodging with 3 cm sowing depth were significantly lower than for 2 cm depth, with a stronger effect on root lodging. For compacted soil, the degrees of root and stem lodging showed no substantial alteration with increased sowing depth. Soil compaction reduced the degrees of root and stem lodging, with greater reductions for shallow than deep sowing (Figs. 1 and 2).

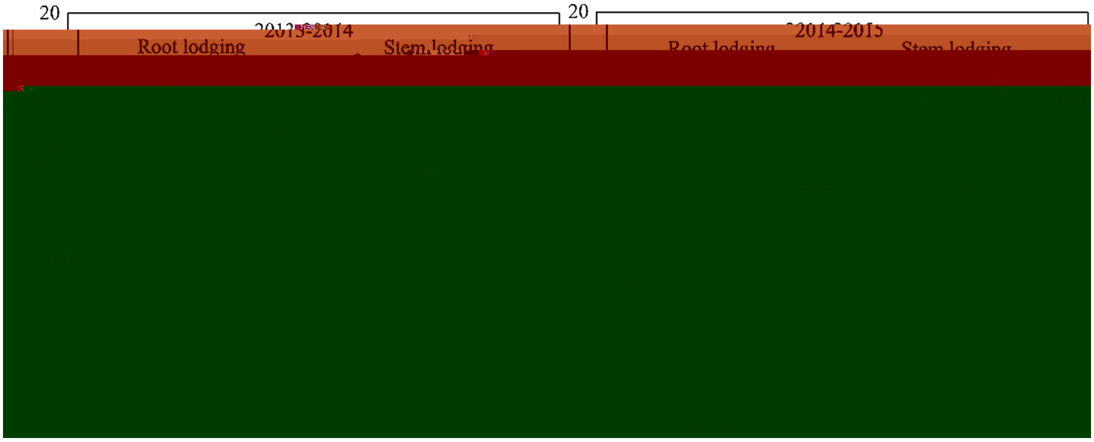

Fig. 1. Effect of sowing depth and soil compaction on lodging degree of rapeseed.

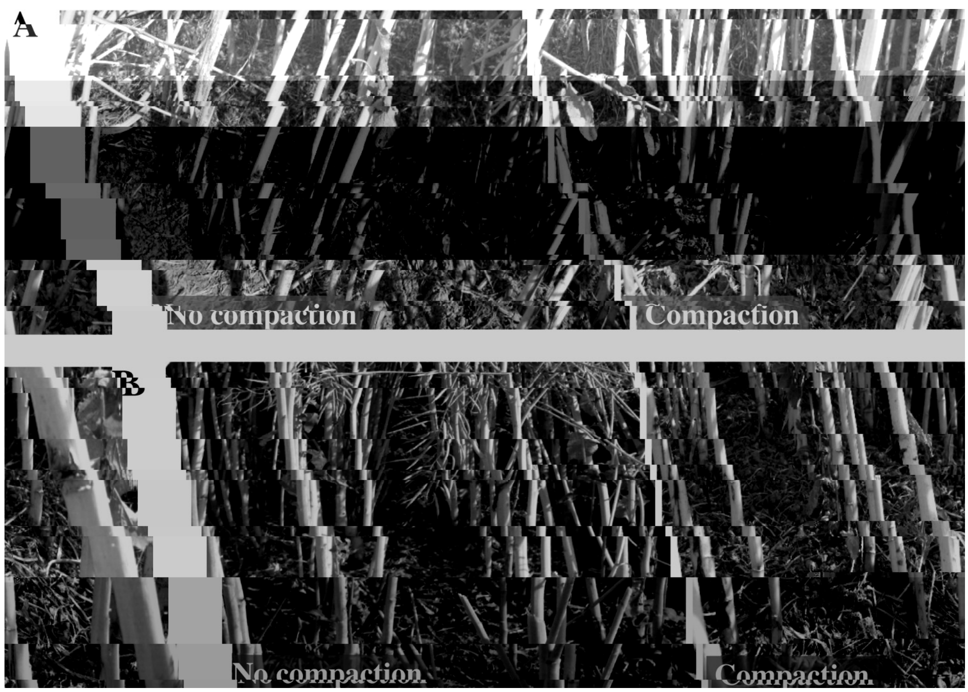

Fig. 2. Rapeseed growth at maturity under different sowing depth and soil compaction. A, sowing at 2 cm depth; B, sowing at 3 cm depth.

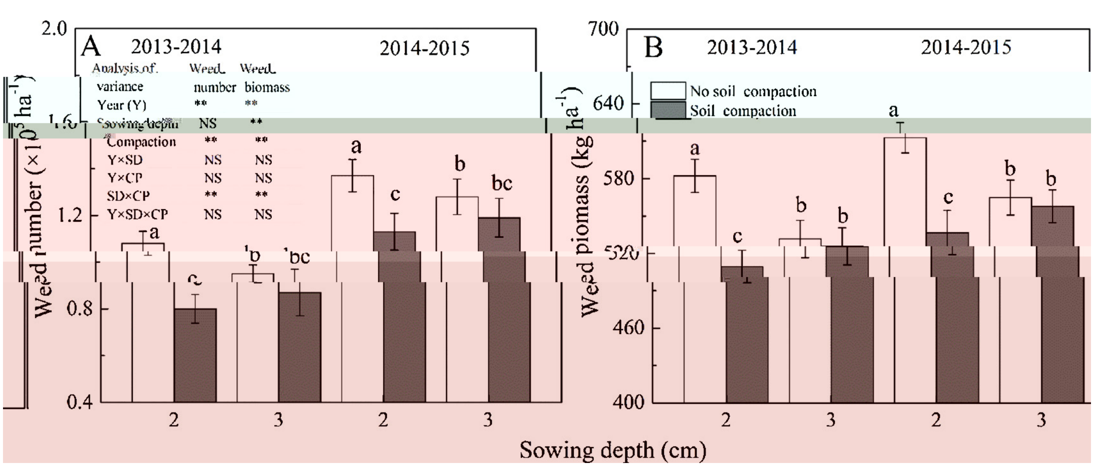

Fig. 3. Weed number (A) and weed shoot biomass (B) of rapeseed field as affected by soil compaction and sowing depth in 2013–2014 and 2014–2015.

Table 2
Bulk

and siliques. Shallow sowing with soil compaction had a positive effect on growth and development, and dramatically increased seedling density, siliques per plant and per hectare, leading to improved yield. However, seedling vigor was subsequently reduced as shown by reduced shoot growth with compacted soil and sowing at 3 cm. This was possibly due to resistance to lateral deformation of the soil by the expanding shoot, as compaction had no effect on seedlings sown at 2 cm. The growth of roots is closely related to the physiological metabolism and biomass accumulation of aboveground tissue, and a suitable ratio facilitates crop growth (Chen et al., 2015). The root/shoot ratio is an important indicator reflecting coordination of growth and biomass accumulation in roots and aboveground tissue. In the present study, the root/shoot ratio increased under the treatment of deep sowing or soil compaction and it had similar trends with the dry weight of underground and aboveground tissue and yield at maturity, revealing that an appropriate increase of root/shoot ratio was conducive to growth of rapeseed and high yield. Low seed yield after shallow sowing under organic and conventional conditions is often attributed to higher annual and perennial weed infestations, which are significantly influenced by soil compaction (Brandsæter et al., 2011). Weed number and biomass were obviously reduced with increased sowing depth for non-compacted soil (Fig. 2), as previously reported (Gronle et al., 2015). Soil compaction significantly restricted weed infestation for sowing at 2 cm depth. Weed infestation followed an opposite change pattern to seedling emergency rate and density (Table 3), indicating that strong rapeseed-weed competition existed. The greater biomass of shoots for plants in compacted soil when sown at 2 cm depth has previously been attributed to their ability to obtain more nutrients from soil as a result of reduced competition with weeds.

Lodging can occur by stem failure (stem lodging) (Neenan and Spencer-Smith, 1975) or anchorage failure (root lodging) (Crook and Ennos, 1993), and is a significant problem for farmers because it causes large reductions in seed yield and quality (Easson et al., 1993; Kuai et al., 2015). Plants next to wheel tracks caused by farm vehicles during application of agro-chemicals in commercial fields always remain standing, even when other plants in the field have lodged (Berry et al., 1998). Subsequent research has shown that reducing competition between plants can increase their resistance to both stem and root lodging by influencing their shoot and root growth, respectively (Easson et al., 1993, 1995; Berry et al., 1998). In addition to reduced competition, a further factor that may contribute to root lodging resistance of plants in compacted soil is the difference in soil physical conditions to non-compacted soil (Voorhees, 1992; Rowell, 1994). This may further influence their anchorage strength and hence resistance to root lodging. In the present study, rapeseed lodging had a similar trend with the root/shoot ratio. It was alleviated under the treatment of deep sowing or soil compaction, and the effect was greater for shallow sowing with soil compaction. Besides, root lodging of rapeseed was far more affected by sowing depth and soil compaction than stem lodging. An examination of the differences in soil and plant characteristics suggests that two main differences contributed to the increased root lodging resistance. These include (1) greater BD and reduced TP of the soil resulting from compaction. Depending on the mechanism of root lodging, soil strength affects either the resistance of the root–soil bond to failure by axial or shearing root movements, or the resistance of the soil matrix to failure by rotation of the root–soil cone (Easson et al., 1995) and (2) greater plant growth (increased root/shoot ratio and stem diameter) resulting from reduced competition with weeds and so greater water and nutrient absorption. Soil compaction affects root growth and thus the ability of root systems to provide anchorage to plants (Goodman and Ennos, 1999).

5. Conclusion

Sowing depth and soil compaction are two important agronomic measures for rapeseed in rice

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