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LODGING IN CORN VARIES WITH TILLAGE AND CROP ROTATION: A CASE STUDY AFTER TYPHOON BOLAVEN PUMMELING OVER THE BLACK SOIL ZEON IN NORTHEAST CHINA

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Corn lodging can damage corn growth and reduce corn yield, and the degrees of corn yield loss could vary with corn species, soil conditions, agronomic practices as well as the degrees of external forces from strong wind or heavy rain. In August, 2012, Jilin province, China suffered from Typhoon Bolaven and large areas of corn lodged. However, in some no-tillage (NT) fields of this area corn lodging is much less serious than in other fields. We assumed that NT led to less serious lodging. We conducted this study on a long-term tillage trial which was seriously hit by Typhoon Bolaven. The experiment consists of NT, moldboard plow (MP), ridge tillage (RT) with continuous corn (CC), corn-soybean (CS), and corn-corn-soybean (CCS) rotations. The most serious lodging occurred in MP-CC treatment, followed by NT-CCS, NT-CC, NT-CS, MP-CS, and RT-CS. The lower incidence of lodging occurred in CS rotation. Soil bulk density and penetration resistance were not major factors affecting corn lodging except for MP-CC plot where root lodging occurred. The ratio of 2012 to average of 2007-2011 corn yield took the order of MP-CC < NT-CCS < MP-CS ≈ NT-CS < NT-CC < RT-CS ≈ MP-CCS. It suggested that RT has more advantages than NT and MP in preventing yield loss from strong wind and heavy rain. Moreover, adoption of RT combined with CS rotation could be taken into consideration preferentially for lower lodging and higher yield in Black soils in Northeast China.
Keywords: Soil physical properties, lodging, yield, tillage practice, rotation.

INTRODUCTION

Root and stem lodging was defined as the permanent displacement of the stem from the vertical (Sposaro *et al.*, 2010; Acreche and Slafer, 2011). When the crop is close to maturity, it is prone to lodging and often lodging damage occurs during weather events with strong wind accompanied by heavy rains (Wu *et al.*, 2012). Lodging causes great losses in both quantity and quality of crops (Sposaro *et al.*, 2010; Wu *et al.*, 2012), leads to harvest difficulties, decreased yield and increased production cost (Wu *et al.*, 2012). Therefore, lodging is a significant problem for farmers. Some study concluded that crop lodging is a factor variable for the evaluation of the difference in crop yield (Caldicott and Nuttall, 1979), however some results are not in agreement due to differences in crop species and varieties (Vera *et al*., 2012), soil condition (Pinthus, 1973), or the stage of crop growth (Wu *et al*., 2012). On August 28, 2012, Typhoon Bolaven arrived in Jilin Province, northeast China with intense rainfall and strong winds. The storm caused extensive lodging damage of corn crops over large areas in this region. We observed that the lodging in corn in our 4.3 ha no-till demonstration plots, Jiutai County of Jilin Province (44°0′N, 125°38′E), was much less serious than that in some adjacent fields with the same corn variety and soil type but managed under conventional tillage. Hence, we hypothesized that corn might be more prone to lodging (wind and rain caused) under moldboard plough (MP) than under no tillage management. Our long-term tillage trial (44°12′N, 125°33′E) located in Dehui County, Jilin Province, was in the path of the typhoon and suffered varying degrees of lodging damage. This long-term tillage experiment has three tillage systems and three crop rotations and it provides a unique opportunity to study the impacts of long-term tillage and rotation on corn lodging and grain yield in a severe weather event.

MATERIALS AND METHODS

***Typhoon Bolaven*:** Bolaven, a massive tropical storm, was born over the weekend of August 18-19 in the western North Pacific. It slowly moved west-northwestward, and steadily intensified. Within less than a day it was soon upgraded to a tropical storm and further to a typhoon by August 24, 2012 (Source: NASA; Credit: Rob Gutro). The path of Typhoon Bolaven and the storm categories at different locations are given in Figure 1. Northeastern China did not experience the

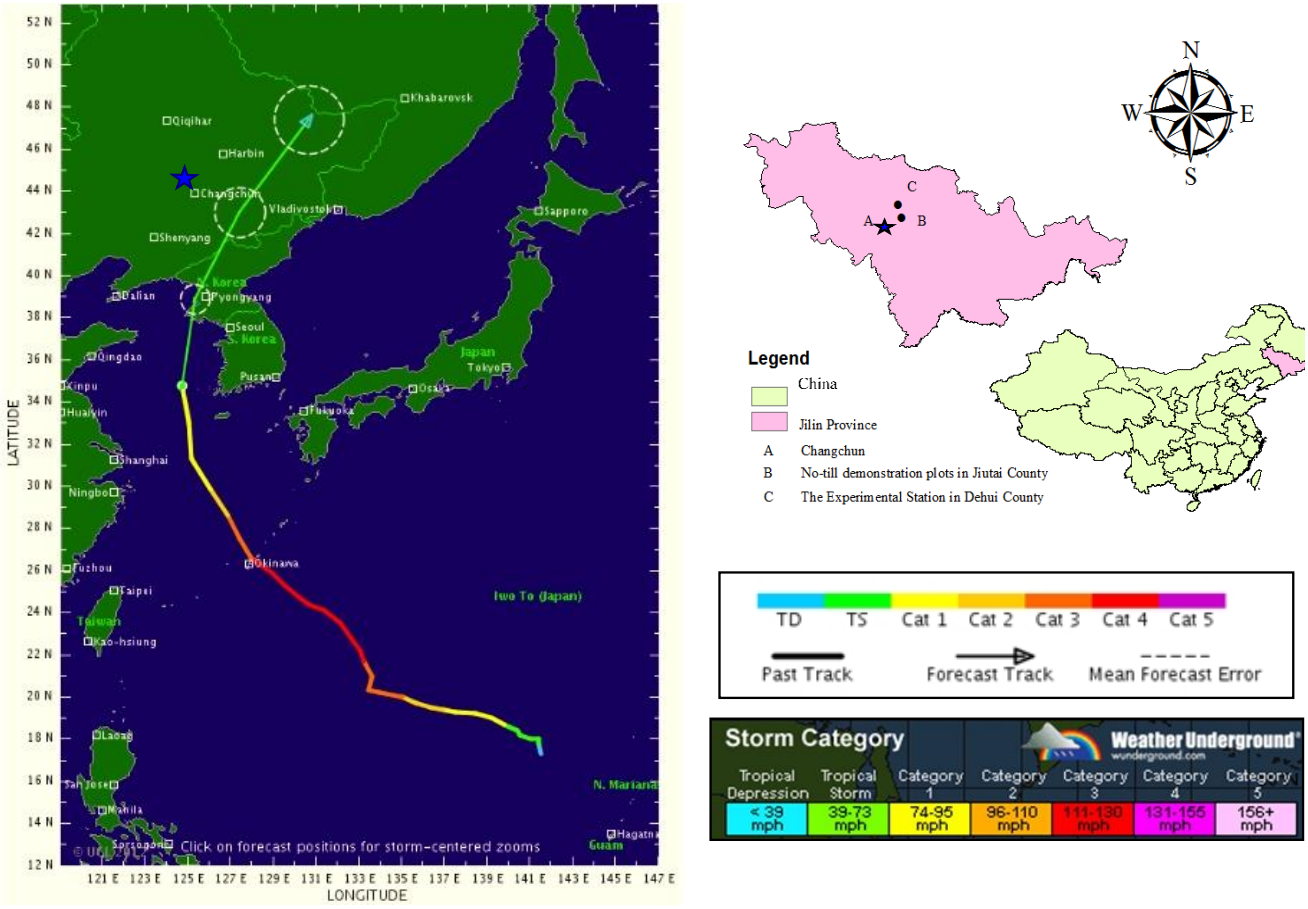

Figure 1. Typhoon Bolaven's moving path and the typhoon categories.
Source: http://tropicalstormrisk.com/tracker/dynamic/201216W.html

full-force of Typhoon Bolaven, but it did greatly impact this area. Typhoon Bolaven arrived in Jilin Province, northeast China on August 28, 2012 with intense rainfall and strong winds. Most of this area had rainstorm with the over 130 mm maximum rainfall. Yanji, in the east of Jilin Province had the maximum wind with instantaneous speed of 58.4 mph. Changchun, Jilin Province had 121.9 mm rainfall and winding at instantaneously 40.3 mph from 20:00 of August 28 to 14:00 of August 29, in 2012 (http://www.jl.chinanews.com.cn/news.aspx?id=53482). The storm in Jilin province caused extensive corn lodging over large areas and approximately 690,000 ha of crops were damaged (Qi, 2012). Figure 2 shows fields with the most seriously lodged corn close to our study site, when the corn was in the filling stage.

Figure 2. Image of fields near the study site after the Typhoon Bolaven.

***Study site description*:** Our tillage study site was in the area where the storm created extensive lodging damage in corn. The tillage experiment was initiated in fall 2001 at the Experimental Station (44°12′N, 125°33′E) of Northeast Institute of Geography and Agroecology (the Chinese Academy of Sciences) in Dehui County, Jilin Province of China. The study site lies in Temperate Zone with a continental monsoon climate. The mean annual temperature is 4.4°C and the mean annual precipitation is 520.3 mm with more than 70% occurring in June, July and August. Detailed monthly average temperature and precipitation from 2007 to 2012 was given in Table 1. The slope of the experimental plots is less than 1°**.** Soil named Black soils (Udolls, US Soil Taxonomy) is slightly acidic to neutral. It is a clay loam with an average of 36% clay, 24% silt and 40% sand. Averaged concentrations of soil organic carbon and total N in 0-30 cm layer were 15.1-18.6 g kg^{-1} and 1.33-1.71 g kg^{-1} in 2012. The land had been used for continuous corn production under conventional tillage for many years prior to establishing the tillage trial in 2001 (Liang *et al*., 2011). Under this tillage system, aboveground corn residue (including corn stubble) is removed from the field after harvest and stockpiled for fuel, feed, and / or home heating and cooking.

***Tillage experiment*:** The experiment was a split-plot randomized complete block design with four replications. The two factors were tillage consisting of moldboard plough (MP), ridge tillage (RT) and no-tillage (NT) as the main plot factor, and crop rotation as the subplot factor. The crop rotations included continuous corn (CC), corn-corn-soybean (CCS) and corn-soybean (CS) rotation. For the RT treatment, the crop rotation is only CS rotation. The NT or MP main plot was split into CC, CCS and CS rotations, respectively. Each sub-plot was 5.2 m × 20 m. The MP included one fall moldboard ploughing (about 20 cm deep) after corn harvest and disking (7.5 to 10 cm deep) and field cultivation in spring. The RT included ridging in June and smashing corn stalk/roots in fall (less than 1/3 row width). The NT had no soil disturbance except for planting using a KINZE-3000 NT planter (Williamsburg, Iowa). All crop residues were left on soil surface for all treatments after harvest. The maize stalks were chopped into about 30 cm pieces leaving 30-35 cm stubble stand, and then manually spread on the soil surface; soybean residues were directly returned to the soil surface (Zhang *et al*., 2013). The same variety of corn or soybean was planted in spring. Each year, 100 kg ha^{-1} N, 45.5 kg ha^{-1} P and 78 kg ha^{-1} K was applied to corn as starter fertilizer and 50 kg N ha^{-1} as top dressing at the V-6 stage for corn. For soybean, all fertilizers were applied as starter fertilizer, including 40 kg N ha^{-1}, 60 kg P ha^{-1}, and 80 kg K ha^{-1}. The starter fertilizers for all plots were applied concurrently during the planting.

***Lodging measurement*:** Lodging measurements for corn in above mentioned tillage plots (corn phase only) were done in September 21, 2012, 4 weeks after the typhoon event. The lodging damage of corn was evaluated following the methods of Caldicott and Nuttall (1979) and Vera *et al.* (2012) which assign a lodging score from 1 to 10 to corn where 1 is completely lodged (corn lying on the ground), 5 (corn tilted 45°), and 10 is assigned to corn which stands vertical with no lodging. Intermediate scores of lodging are given according to the angle of lodging as in Figure 3. We used five observers to independently assign the lodging scores for each corn plot. The observers were instructed not to talk to each other during the scoring so as not to be influenced by scores assigned by other observers. For each plot, the observer stood in the middle of the plot, assigned two scores, one for the north end, and one for the south end of the plot.

Table 1. Monthly average temperature and precipitation during the growing period from 2002 to 2012.

Item	Month	30-year average (1971-2000)	Year						
			2007	2008	2009	2010	2011	Average of 2007-2011	2012
Air Temperature	4	7.4	6.8	11.2	10.2	4.3	7.7	8.1	8.7
(°C)	5	15.1	15.1	14.4	18.2	16.0	15.3	15.8	17.2
	6	20.6	23.6	21.6	19.0	23.6	20.9	21.7	20.4
	7	23.1	22.1	23.2	22.3	23.1	24.3	23.0	23.5
	8	21.3	21.8	21.6	23.0	21.8	22.9	22.2	22.1
	9	14.8	16.1	15.1	16.2	16.8	15.5	15.9	17.0
	Average	17.0	17.6	17.9	18.2	17.6	17.8	17.8	18.5
Precipitation	4	17.4	22.0	28.0	55.0	42.0	17.0	33.0	35.0
(mm)	5	45.5	51.0	64.0	25.0	117.0	47.0	61.0	35.0
	6	84.8	24.0	780.0	118.0	16.0	72.0	62.0	111.0
	7	152.3	87.0	243.0.	60.0	191.0.	124.0	141.0	108.0
	8	115.3	118.0	74.0	39.0	92.0	135.0	92.0	168.0
	9	48.0	25.0	45.0	20.0	8.0	11.0	22.0	76.0
	Total	463.3	328.0	532.0	316.0	466.0	406.0	410.0	533.0

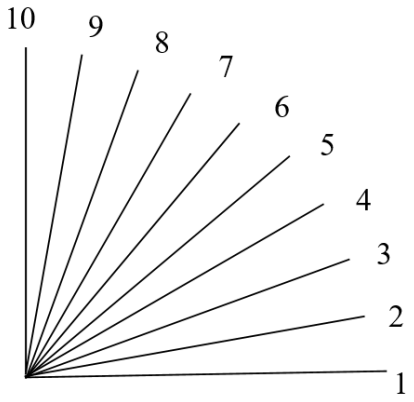

Figure 3. Lodging scores according to the angle of lodging.

***Soil physical properties measurements*:** Soil physical properties and yield measurements were done in October, 2012, approximately six weeks after the typhoon Bolaven. Soil samples were collected using a core sampler auger (2.64 cm diameter). The internal diameter of the sampler, segment depth and the oven-dry weight of soil were used to calculate soil bulk density (BD). Soil penetration resistance (PR) was measured in-situ down to 30 cm at intervals of 2.5 cm, using a handheld digital penetrometer (cone diameter = 1.27 cm, cone angle = 30°) (Field Scout, SC 900 Soil Compaction Meter; Spectrum Technologies, Inc., Plain-field, IL).

***Corn height and yield measurement*:** Corn height was measured from 3 rows in the center and 3 plants in each row two months after seedling emergence. Totally nine crops were measured for each plot. The height average of 9 plants was taken as the crop height of a given plot. In 2012, corn height was measured about 50 days before Typhoon Bolaven arrived in Jilin Province.

Because of serious lodging from the Typhoon Bolaven, it was much more difficult to harvest corn than usual. Corn harvest occurred at early October. Corn grain yield was determined by hand-harvesting 3 m lengths of 6 interior rows from each plot, and normalization to 14.0% grain moisture content (Fan *et al*., 2012) .

***Data analysis*:** The ANOVA followed by the LSD test were used to examine the differences in corn lodging under tillage and rotation management. Pearson correlation was used to evaluate the relationship between lodging and soil properties (BD and PR), crop yields. These procedures were performed using SAS (SAS Institute, Cary, NC, USA). Statistical significance was determined at the P=0.05 level except if indicated differently.

RESULTS AND DISCUSSION

***Lodging in corn under tillage practices*:** There are two types of crop lodging including root lodging and stem lodging. Root lodging refers to straight culms leaning from crown, sometimes being laid flat on the ground. Stem lodging involves bending or breakage of the lower culm internodes (Pinthus, 1973). Typhoon Bolaven induced both stem lodging and root lodging of corns in this area, but there were no roots pulled up by the storm. Most of our study plots mainly suffered from stem lodging except for plots with CC rotation under MP in which root lodging mainly occurred (Table 2).

Table 2. Lodging scores of corn in tillage and rotation systems in 2012.

Rotation	MP	NT	RT
CC	4.25†c B	5.93a A	-
CCS	5.25b A	5.28a A	-
CS	6.5a A	6.08a B	6.73 A

Note: The lower-case letters refer to means in the same column and the upper-case letters refer to means in the same row; there is no significant difference between the means followed by same letters in each column or row at 5% level.

† indicated that plots mainly suffered from root lodging, otherwise suffered from stem lodging.

The degree of lodging varied with tillage practices and crop rotation (Table 2). The lodging score in CC rotation was significantly higher under NT than under MP ($P<0.05$). It showed that the number of lodged corn was significantly higher in plots with intensive tillage than with reduced or no tillage management, which is like the study of Tyler and Ellis (1974). However, Pinthus (1973) concluded that stem lodging is restricted to plants that are held tightly by a dry and hard upper soil layer. Our present study was opposite to above conclusion. In the CC field the upper soil PR was greater and soil was drier due to greater soil water infiltration under NT than under MP (Chen, 2012; Fan *et al*., 2013), however, much severer stem lodging occurred in MP than in NT soils. The entire trial field was planted with the same corn variety so that there is no mixed impact on lodging resistance from corn inner characteristics, such as lignin content in stem (data not shown), except for crop height and stalk perimeter. We assumed that this disagreement might be due to significantly greater heights of corn plants under MP than under NT (Table 3). The stem perimeter of corn would be another factor influencing corn lodging; however, we did not make these measurements. Also, in this study, the higher infiltration rate under NT could have eased corn lodging from reduced soaking time in the root zone and less runoff compared with that under MP management (Fan *et al*., 2013).

Table 3. Corn heights (cm) in tillage and rotation systems.

Rotation	MP	NT	RT
CC	268.7a A	224.0bc B	-
CCS	279.1a A	231.9b B	-
CS	261.0a A	255.5a A	251.0 A

Note: The same column followed by the lower case; the same row followed by the upper case;

There is no significant difference between the same letters in each column or row at 5% level.

Serious corn lodging occurred in both CCS- and CS-NT fields. In both MP and NT plots, lower incidence of lodging occurred in CS than in CC and CCS rotations (P<0.05). These results agree with the study of Kontturi *et al*. (2011) that intercropping practice prevented crop from lodging, and soybean can improve soil physical properties in root zone which would benefit subsequent corn root systems.

***Effects of soil bulk density and soil penetration resistance on lodging*:** Soil PR and BD can influence crop resistance to lodging (Scott *et al*., 2005). In our 11-year tillage and rotation trail, tillage showed great impacts on BD and PR (P<0.01), however, rotation had no remarkable impacts on BD and PR. The same results were also observed by Chen *et al*. (2012, 2013) who found NT increased soil BD in 0-20 cm depth and soil PR of surface layer. Therefore, we speculate that soil BD and PR might thereby affect lodging under different tillage. However, our results showed that there were no obvious relationships between corn lodging and two soil physical properties (Table 4). It indicated that soil BD and PR did not affect corn lodging at this stage. The dominant damage mechanism was stem lodging which was closely related to plant property but not soil property. Root lodging only occurred in CC-MP plot which showed a significant relationship between soil BD or PR at 7.5 cm depth and the degree of lodging. It indicates that lower root lodging was associated with lower soil BD and greater soil PR at this depth. This result was somewhat in agreement with the study of Scott *et al*. (2005) that greater soil BD and soil compaction resulted in lower root lodging. The adverse relationships between soil BD and lodging in this and Scott *et al*.'s studies could be attributed to soil BD measured at different depths.

***Effects of lodging on corn yields*:** Crop lodging often results in outright yield losses (Caldicott and Nuttall, 1979). As shown in Table 5, the averaged corn yield in CS rotation in 2012 was greatly higher under RT than under NT (11.5%, P<0.05) and under MP (8.7%, P <0.05), respectively. There were no significant differences in corn yields between MP and NT treatments for both CC and CS rotations. The lowest average corn yield occurred in CCS rotation under NT, which might be attributed to greater depletion of P and other nutrients at lower depth than in MP (Messiga *et al*., 2012), but also to slower soil warming in spring due to surface maize residues (Wilhelm and Wortmann, 2004; Ziadi *et al*., 2014). To evaluate the effects of Typoon Bolaven on corn yield under different tillage and rotation treatments, we define a variable, the ratio of corn yields in 2012 to the average yield of 2007-2011 (Table 5). Corn yields in all plots in 2012 were significantly lower than previous years' yields (Table 5), indicating significant lodging damages by Typhoon Bolaven. The corn yield loss was more significant under MP and NT than under RT (P<0.05) for CS rotation. The effect of lodging on grain yield is dependent on the severity of lodging and the time of its occurrence (Vera *et al*., 2012). Most severe yield losses occurred when plants of crops were lodged to angles of greater than 80° from the vertical, especially when plants were lodged in the early stage of seed development, near anthesis (Sisler and Olsen, 1951; Pendleton, 1954; Fisher and Stapper, 1987). Lodging occurs as plants approach physiological maturity will have less impact on grain yield (Vera *et al*., 2012). In our study the time of lodging occurrence was in the grain filling stage of corn, so yield was substantially reduced. The ratios of corn yields in 2012 to the average of 2007-2011 were MP-CC < NT-CCS < MP-CS ≈ NT-CS < NT-CC < RT-CS ≈ MP-CCS. The MP-CC plot had the lowest ratio of yields, which is consistent with the most serious lodging in MP-CC soils. This suggests that the combination of conventional tillage and continuous corn will make the plants prone to lodging when storm and heavy rain occur. As far as rotation was concerned, under CS rotation RT had absolute advantages on resistance to lodging. NT was better in preventing corn plant lodging and lodging-induced yield loss than MP only for CC. Although under CCS rotation, the lodging difference between NT and MP was not significant, but corn yield under NT was greatly lower than under MP. The reasons will be further explored. Under the same tillage treatment, CS rotation is more helpful than continuous corn to prevent yield loss from external forces exerted by wind and rain. Comparatively, continuous corn made corn more vulnerable to lodging under MP but not NT. Moreover, based on the corn yield in 2012 and the ratio of

Table 4. Correlation between soil physical properties and lodging scores under tillage and crop rotation.

Tillage		**MP-lodging score**			**NT-lodging score**			**RT-lodging score**		
Rotation		**CC**	**CCS**	**CS**	**CC**	**CCS**	**CS**	**CC**	**CCS**	**CS**
Depth=2.5	BD	ns	ns	ns	ns	ns	ns	ns	ns	ns
	PR	ns	ns	ns	ns	ns	ns	ns	ns	ns
Depth=7.5	BD	-0.960*	ns	ns	ns	ns	0.836*	ns	ns	ns
	PR	0.967*	ns	ns	ns	ns	ns	ns	ns	ns
Depth=15	BD	ns	ns	ns	ns	ns	ns	ns	ns	-0.985*
	PR	ns	ns	ns	ns	ns	ns	ns	ns	-0.999**
Depth=25	BD	ns	ns	0.995**	ns	-0.995**	ns	ns	ns	ns
	PR	ns	ns		-0.981*	ns	ns	ns	ns	ns

*shows significant at 0.05 level; **shows significant at 0.01 level; ns presents non-significant.

2012 yield to the average yield of previous five years, adoption of RT combined with CS rotation could be taken into consideration preferentially on a clay loam soil in Northeast China. Certainly, this needs be verified in the future because of our present limited rotation types under NT.

Table 5. Corn yield (kg·ha^{-1}) in 2012 and the ratio of 2012 to 2011 yield under tillage and rotation treatments.

Rotation	Tillage		
	MP	NT	RT
2012			
CC	7009b A	7895ab A	—
CCS	8840a A	6948a B	—
CS	8190ab A	8423b A	9517 B
Ratio of 2012 to average of 2007-2011 yield			
CC	0.647a A	0.759a A	—
CCS	0.865b A	0.711a B	—
CS	0.727ab B	0.727a B	0.864 A

Note: The same column followed by the lower case; the same row followed by the upper case;
There is no significant difference between the same letters in each column or row at 5% level.

***Conclusions*:** The severity of corn plant lodging differs among tillage and rotation practices. The lodging severity of corn plants increased with increasing in corn weight in rotation, CC > CCS > CS, which verified that rotation prevented crop from lodging. Under continuous corn management, NT results in significantly lower lodging compared with MP. The positive effect of NT on eliminating continuous corn from wind and rain induced lodging in this trial was supported by a large NT demo-plots in Jiutai County, Jilin Province, China. Different tillage systems and crop rotations did lead to differences in soil BD and PR. Although soil BD and PR might be major factors affecting corn lodging, particularly root lodging, the difference in soil BD and PR among management did not transfer into corn stem lodging at this study except for the plots under MP-CC treatment where root lodging occurred. Lodging damage of corn plants induced by Typhoon Bolaven did show significantly negative impact on grain yield, about 14% to 35% losses varying with treatments. However, the extent of lodging damage was no proportionally represented on corn grain losses. Considering both corn stem lodging damage and grain loss, moldboard ploughed monoculture corn was the worst combination among all management practices for Black soils. RT might be a promising practice better than both NT and MP in protecting corn plants from stem lodging and lodging induced yield decline; however, this optimistic effect was only based on the CS rotation and further test is needed on other types of crop rotation for clay loam soils in Northeast China.

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