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ORIGINAL PAPER

Analysis of influence factors on aggregate stability and size distribution in mollisoils

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Abstract

The present work screened four factors (i.e., tillage, initial soil water content (IWC), freezing–thawing (F–T) and drying–wetting (D–W) cycles) to examine the Mollisols aggregate size distribution and stability. Soils were sampled from no-till (NT) and conventional tillage (CT) treatments in the 0–10 cm soil layer and conducted 0/3/6/11 F–T and D–W cycles. Three different IWC values were considered: 130, 230, and 330 g/kg, and our trials set up four aggregate size classes: larger aggregate size fractions (LWSA, >1.00 mm), medium aggregate size fractions (MWSA, 0.25–1.00 mm), small aggregate size fractions (SWSA, 0.106–0.25 mm), and particles (PA, < 0.106 mm); and the mean weight diameter (MWD) was used to analyze water-stable aggregate stability (WAS). Significant decrease of LWSA and WAS in NT was observed in the snowmelt stage, but the opposite results occurred during the crop growth period. In the simulated experiment, significant interactive effects of tillage and IWC on LWSA and WAS were observed in the F–T and D–W cycles, which showed that LWSA and WAS elevated as the F–T and W–D cycle numbers and IWC increased for both NT and CT treatments exhibited negative correlation with WAS. The greater amount of LWSA in NT was observed than CT in the F–T cycles, while the opposite results were in W–D cycles. The SWSA fraction had a negative relation with LWSA for NT treatment, and the MWSA fraction had a contrary variation with LWSA for CT treatment. In either tillage treatment, PA was not greatly affected. We therefore suggested to evaluate size distribution and stability of the Mollisols aggregates by including tillage, IWC, F–T and W–D cycles.

Keywords Water-stable aggregate · Freezing and thawing · Drying and wetting · Tillage · Initial water content

Introduction

Soil water-stable aggregate stability (WAS) is a vital soil physical characteristics that greatly affects soil constructer and function, and indirectly impacts crop yield by its influence on available fertilizer, water content and and penetration resistance of soil (Almajmaie et al. 2017b; Castro Filho et al. 2002; Wu et al. 2016). Generally, stable water aggregate content on soil surface plays a determining role in the crust formation potential, while WAS serves as a favorable predictor for the susceptibility of soil to erosion and runoff (Barthès and Roose 2002; Almajmaie et al. 2017a).

WAS usually shows high variations among different seasons and years irrespective of the residue system. Generally, the reduced WAS level is seen in winter, whereas the increased level can be detected in spring. These changes are mostly great compared with heterogeneities among diverse cropping systems and soils (Perfect et al. 1990). The magnitude of WAS changes varies depending on some factors such as climate, tillage, and organic-matter incorporation, which are responsible for controlling these fluctuations. Soil organic matter (SOM) has been identified to elevate WAS through promoting aggregate cohesion and reducing wettability (Chenu et al. 2000; Zheng et al. 2019). Many articles suggest an increased WAS level within the conservation tillage (like no-tillage (NT)) relative to conventional tillage (CT), which is achieved through decreasing soil erosion and increasing SOM content (Bottinelli et al. 2010; Somasundaram et al. 2017).

In Northeast China, Mollisols have been well-known for the favorable soil aggregate structure, great SOM level, and

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the resultant great crop productivity, which thus exert an important part in the food security in China (Liu et al. 2010). The climate of the Mollisol region is in the northern temperature zone that has the predominant continental monsoon climate (rainy and hot during summer, wheresa arid and cold during winter); besides, during the rainfall and snowmelt periods, the most obvious problems are erosion and runoff (Hu et al. 2007). In the last several decades, relative to CT, conservation tillage, in particular for NT, is promoted for the sake of maintaining and building soil fertility and soil structure, while controlling soil erosion and water loss (Zhang et al. 2011). Several studies reported that different tillage types resulted in different soil properties in the wetting–drying (W–D) and freezing–thawing (F–T) cycles, such as differences in soil water content, structure, organic-matter content, chemical properties, and root development (Arthur et al. 2013; Boizard et al. 2013).

The F–T and W–D cycles are the weathering process that considerably changes soil engineering properties. Natural soil W–D cycles are physical events that profoundly affect WAS development (Cosentino et al. 2006; Bravo-Garza et al. 2009) showed that climate has direct impacts on WAS by affecting soil water content, and indirectly stimulate microbial activity. Amezketa reported that the percentage decrease in WAS was decided by the stability and original size of aggregates, soil type, F–T cycle number, freezing temperature and soil water content during freezing. Frost action is also reported to promote stability (Oztas and Fayetorbay 2003). Interannual and seasonal WAS variability are possibly due to the interaction between seasonal W–D and the growing crops-related plant/microbial debris accumulation (Bottinelli et al. 2017; Panettieri et al. 2015; Rahman et al. 2018; Suwardji and Eberbach 1998). However, it is still unknown about how W–D and F–T cycles affect soil structure, since the increased and decreased WAS levels have been reported after the F–T and W–D cycles (Denef et al. 2001; Henry 2007). The soil conditions, like initial water content (IMC), also influence structural stability, and previous studies found high IMC to both increase (Xiao et al. 2020; Wangemann et al. 2000) and decrease (Lado et al. 2004; Le Bissonnais and Singer 1992). These studies on the effect of tillage, IWC, and numbers of cycles (NC) on aggregate size and stability without attention to their combination may be the reason for this disparity.

Previous research also indicated that topsoil WAS shows significant negative correlation with the susceptibility of soils to soil loss and runoff. However, no quantitative work has been documented on how soil aggregate in different IWC is affected by F–T and W–D cycles in the CT and NT systems within the Mollisol region in Northeast China. This work focused on investigating the effects of tillage, NC and IWC on the stability and size of soil aggregates through both laboratory and field experiments (Cordao Neto et al. 2018).

Materials and methods

Experiment sites and systems

Experiments were performed on a 5% slope-steepness farmland located in the Hailun Monitoring and Research Station of Mollisol Erosion, Guangrong Village (47°23’N, 126°51’E), Hailun City, Heilongjiang Province in Northeast China. In our study position, the continental monsoon climate is dominant (rainy and hot during summer, arid and cold during winter). The precipitation mainly focuses on June to August (60–70%), with the mean of 530 mm. The extreme maximum and minimum temperatures are 37 °C and −39.5 °C, respectively, with the mean annual temperature of 1.5 °C. Meanwhile, annual average available accumulated temperature (≥10 °C) is 2450 °C and annual sunshine is approximately 2600–2800 h. The frost-free period is approximately 120 days. The soil is a typical Mollisols (Udolls) with silty clay loam texture, high clay content, high SOM content, high water holding capacity, high shrink-swell, and poor drainage.

The experiment was a randomized complete-block design with three replications and the main plot included three tillage treatments: NT and CT. General soil properties are listed in Table 1. Individual treatment plots were 40 m × 8.4 m with soybean and maize rotation. The fields had a mean slope of 5% in east-west direction. For NT, we just collected the mature crop seeds, with even coverage of biomass (around 10 and 3 t/ha for corn and soybean, respectively) on plot surface in post-harvest period. Using the NT planter, soybean and corn were grown during early May in the next year. With regard to CT, we eliminated the above-ground biomass with hands, then the rotary tillage was used to form a ridge in autumn. Later, the conventional planter was utilized to grow soybean and corn on the ridges during early May. Thifensulfuron-methyl (120 g/ha) and acetochlor (1500 mL/ha) were applied at 1 day post-planting to control weeds. The distance between two rows was maintained at 68–70 cm in the soybean and maize systems; for maize, the in-row spacing was maintained at 25–30 cm, and altogether 50,000 plants were planted per hectare, whereas the in-row spacing for soybean was kept at 5 cm and altogether 300,000 plants were planted for each hectare of land. No irrigation was applied to any system. The crop was soybean in 2014 and corn in 2015.

Soil sampling and analysis

F–T and W–D cycles

For the F–T and W–D field experiment, soil samples were collected with a shovel from both NT and CT from 0–10 cm depth; the sampling date is listed in Fig. 1. Samples were taken back to the laboratory to analyze aggregate size and WAS.

Table 1 Soil physical and chemical properties in no tillage (*NT*) and conventional tillage (*CT*) in the 0–10 cm depth

Tillage	Bulk density g/cm^3	Total porosity %	Field capacity g/kg	Organic matter g/kg	pH	Clay %
NT	1.08	59.3	371.8	43.2	6.67	40.7
CT	1.11	58.1	359.6	39.7	6.61	40.2

Using the PVC cylinders (height, 10 cm; diameter, 10 cm), the no-distribution soils for the laboratory experiment were collected under the two tillage systems at the 0–10 cm soil depth, and air-dried. The weight of each PVC cylinder and sample was measured. (1) For the F–T laboratory experiment, soil samples were collected and taken back in October 2014. The seal lid was used to cover the top of the cylinder, whereas the plastic wrap was utilized to cover the bottom, for the sake of avoiding evaporation in F–T cycles. The selected numbers of F–T cycles were 0, 3, 6, and 11 (each cycle comprised one freezing and one thawing periods before the following freezing). Thereafter, each sample was subjected to 12 h of freezing under −15 °C and 36 h of thawing under 4 °C within a temperature-controlled cabinet. Temperatures were reached through rapidly and progressively decreasing or increasing in 1.5 h. (2) For the W–D laboratory experiment, samples were collected in May 2015 (after sowing), and one seal lid was used to cover the top of every cylinder, whereas 15 μm nylon mesh fabric glued at the top with methylene chloride was used to cover the bottom. Soil samples were incubated in the slow-drying-slow-rewetting system and conducted 0, 3, 6, and 11 W-D cycles. After soil drying, the seal lid was removed and soils were incubated within a room at 24 °C by the sufficient air flow. Every 3 days, moisture loss was measured by weight (Luis Vilcapoma et al. 2019). When 60% of the moisture content at initial soil water content (IWC) was found, deionized water was slowly added to bring the soil samples back to IWC by a small sprinkler. Three different IWC levels were considered: 130, 230, and 330 g/kg. Three replicates were set for every system.

Soil aggregate

Four aggregate sizes were separated: large water-stable aggregate (LWSA, >1.00 mm), medium water-stable aggregate (MWSA, 0.25–1.00 mm), small water-stable aggregate (SWSA, 0.106–0.25 mm), and particles (PA, < 0.106 mm). We classified 50–60 g soil samples into 3 parts and put them into 3 sieves (1.00/0.25/0.106 mm, respectively). Then, the soil-wetting approach proposed by Sun et al. (2017) after modification was used to separate water-stable aggregates. Aggregate stability was expressed as the mean weight diameter (MWD), calculated as the sum of the mass fraction of soil (W_i) left in the sieve after fractionation into four size classes, ranging from <0.25 to 2 mm, multiplied by the mean aperture of the sieve meshes (D_i) and divided by the initial soil weight (W):

$$MWD = \frac{\sum W_i D_i}{W}$$

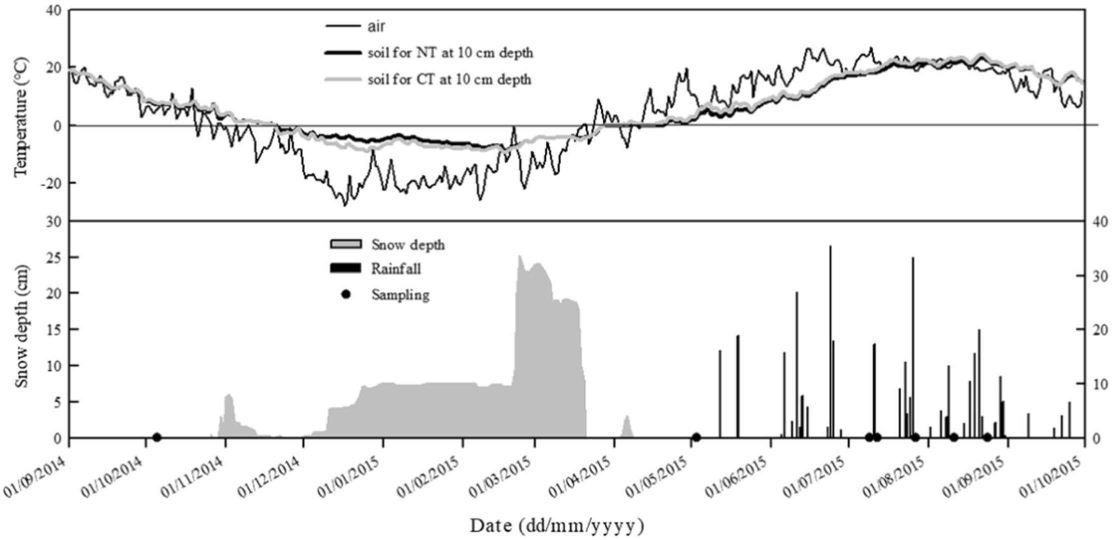

Fig. 1. Air temperature, snow depth, rainfall, and sampling date during the experiment period

Statistical analysis

SPSS22.0 was employed to conduct statistical analyses, while SigmaPlot 12.0 was utilized to prepare the charts. Each treatment was conducted thrice. ANOVA and average separation experiments on MWD and 4 aggregate sizes were conducted by using the general linear model (GLM). In the presence of significant effects, we utilized the Tukey's honestly significant difference test ($P < 0.001$, $P < 0.01$, $P < 0.05$) for discriminating across diverse treatment means.

Results and discussion

F–D and W–D cycle field experiment

Our study showed that soils at 10 cm depth under both tillage systems froze during cold climates, especially when there was no snowpack. Besides, in the soil depth of 10 cm, there was neglectable diurnal fluctuation among different positions that had different average precipitation and winter temperatures (Fig. 1), demonstrating the generally reduced soil-temperature variations compared with air-temperature alterations. On average, soil temperature increased by 1–1.5 °C under NT relative to CT in the soil layer of 10 cm during the entire winter, from pre-freezing during autumn (October 5th, 2014) to the eventual thawing during spring (07 May 2014), and was attributed to straw mulching in NT by decreasing surface reflection (Henry 2007; Sun et al. 2017).

The field experiment also showed a significant decline in LWSA under both tillage systems (Table 2). The initial amount of LWSA under NT was disrupted mostly in SWSA, while LWSA under CT was much more disruptive and released mostly MWSA over the whole winter. This is consistent with many other studies that reported that F–T events were responsible for macroaggregate mechanical breakdown (Dagesse 2011; Kochiieru et al. 2020). PA was not significantly affected under each tillage system. A decreasing trend for the MWD from before freezing to after thawing was found in the NT and CT systems. These results indicated that seasonal F–T events could result in a significant decrease in AS. A similar result was reported by Edwards (2013), namely, the increase in snowmelt erosion had an important effect on WAS. The study also showed that MWD under NT system increased compared with CT system, indicating that NT had higher WAS, which was associated with the lower nutrient and carbon losses in runoff at thaw for NT, leading to higher primary production when compared with that for CT.

In the field experiment of W–D cycles, we collected soil samples before and after continual rainfall for measuring different aggregate sizes and stability levels (Table 2). The amount of LWSA under NT increased dramatically ($P < 0.05$) between spring and summer, while MWSA had the opposite tendency. Significantly higher MWD was observed in August, conforming to additional articles (Bottinelli et al. 2017; Chen et al. 2016). The increase in LWSA and MWD for the NT system in our study was probably due to fertilization, and increased microbial activity and biomass as a result of

Table 2 Distribution and stability of soil aggregate under no-tillage (*NT*) and conventional tillage (*CT*) in field experiment

Tillage	Date	IWC (g/kg)	LWSA (%)	MWSA	SWSA	PA	MWD (mm)
NT	05 October 2014	150.23	48.51 b	36.52 ab	8.07 a	6.90 a	3.06 b
	07 May 2015	150.21	39.02 c	43.32 a	9.81 a	7.85 a	2.61 c
	09 July 2015	120.22	45.00 b	44.14 a	7.04 a	3.83 a	2.94 bc
	14 July 2015	193.24	47.74 b	38.99 ab	6.57 a	6.70 a	3.04 b
	26 July 2015	211.12	50.87 ab	38.55 ab	4.76 a	5.82 a	3.20 ab
	11 August 2015	270.23	58.54 a	30.99 b	5.15 a	5.31 a	3.55 a
	24 August 2015	283.23	58.25 a	29.50 b	4.80 a	7.45 a	3.52 a
CT	05 October 2014	148.26	29.35 a	22.05 b	26.88 b	21.72 a	1.90 a
	07 May 2015	147.93	18.38 b	26.08 b	38.06 a	17.48 a	1.36 b
	09 July 2015	113.23	23.42 ab	33.27 b	25.80 a	17.51 a	1.55 ab
	14 July 2015	207.73	22.82 ab	32.93 b	24.79 b	19.46 a	1.52 ab
	26 July 2015	198.45	19.33 b	38.13 a	28.18 ab	14.36 a	1.37 b
	11 August 2015	263.23	19.78 b	30.92 ab	31.55 ab	17.75 a	1.35 b
	24 August 2015	277.67	22.18 b	28.96 b	32.33 ab	16.53 a	1.40 b

The diverse letters after data suggest that the differences are of statistical significance between diverse cycles ($P < 0.05$). *LWSA*, large water-stable aggregate; *MWSA*, medium water-stable aggregate; *SWSA*, small water-stable aggregate; *PA*, particles; *IWC*, initial water content; *MWD*, mean weight diameter climate and the natural decomposition of crop-residue mulching (Guérif et al. 2001; Helgason et al. 2010; Perfect et al. 1990). Nonetheless, the SOM humidification and decomposition quantities during this stage requires further investigation, because soybean-root biomass was similar in both high- and low-yield pools prior to the full-pod stage (in late July–early August) in the same study area (Jin et al. 2010). For CT, the amount of LWSA initially increased and then decreased from spring to summer, while the opposite was observed in MWSA. This was related to manure application to improve organic-matter content after sowing in spring; then, LWSA under CT was susceptible to raindrop impact due to no crop-residue mulching in summer. Ramos et al. (2003) reported that bare soil surface, exposed to erosive agents and drop impact, promotes soil-surface sealing and crusting during rainfall, which increases runoff through promoting erosion while decreasing infiltration (Ramos et al. 2003). Jirků et al. (2010) also found that the WAS of three soil types (Haplic Cambisol, GreyicPhaeozem, Haplic Luvisol) was decreased due to summer-rainfall events (Jirků et al. 2010). No marked seasonal differences in PA were observed in either tillage systems. Significantly greater LWSA and MWD were observed in NT, indicating that NT had higher AS when compared with CT. A similar result was found in other studies that proposed that NT resulted in the increased soil nutrient and SOM contents, reduced raindrop impact, and was conductive to accelerating the formation of macroaggregates and the effect on WAS (Helgason et al. 2010; Six et al. 2000).

F–T cycle laboratory experiment

F–T also had significant effects on the stability and size of aggregates in the laboratory experiment; to be specific, WAS reduced as the F–T cycle number increased for both tillage systems (Fig. 2). Several other studies showed similar results (Dagesse et al. 1997; Oztas and Fayetorbay 2003). For aggregate sizes, a decreased amount of LWSA was significant ($P < 0.05$) after six F–T cycles under CT, but had no marked difference for NT. Meanwhile, a significant increase in SWSA was found under both tillage systems with the increase of F–T cycles. No significant decline in MWD was found in NT, while significant differences in CT were observed after six and three F–T cycles when the IWC was 130 and 330 g/kg, respectively. Significant interactions occurred between

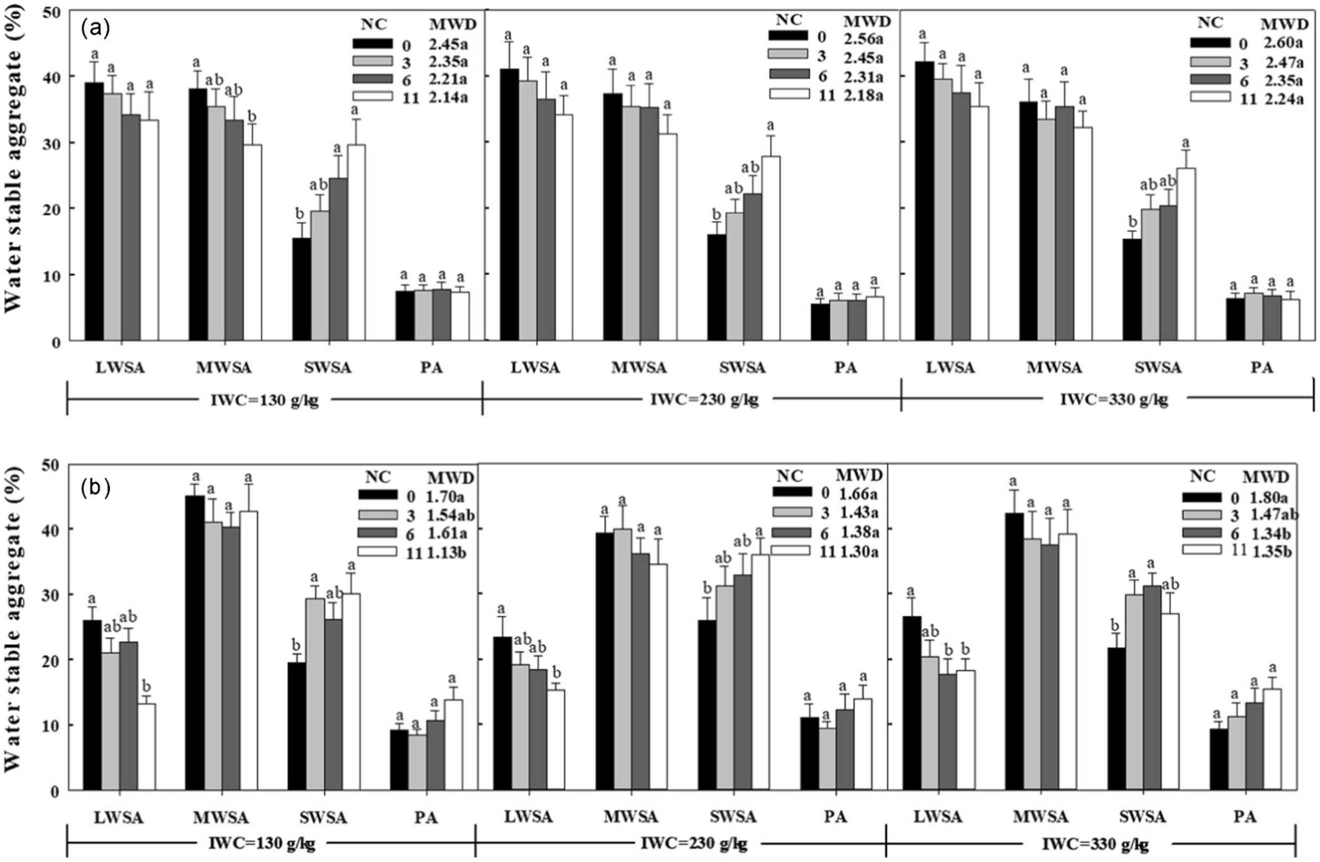

Fig. 2. Role of –F-T cycle number in the size and MWD (mm) of aggregates under **a** NT and **b** CT in laboratory simulations. The diverse letters after data suggest that the differences are of statistical significance between diverse cycles (P < 0.05). LWSA, large water-stable aggregate; MWSA, medium water-stable aggregate; SWSA, small water-stable aggregate; PA, particles; IWC, initial water content; NC, number of cycles

LWSA, SWSA, and MWD with tillage and NC (Table 3). WAS destabilization induced by F–T cycles was greater in CT than in NT. Therefore, significantly greater LWSA and MWD were observed in NT than in CT, which was probably attributed to no destabilization and higher organic matter (Zhang et al. 2011; Mikha and Rice 2004), namely, WAS in NT was more insensitive to F–T cycles.

Our study showed that the amount of LWSA and MWD were correlated well with tillage, IWC, and NC after F–T cycles (Table 3), and an increase in WAS for NT with IWC increase (Fig. 2a), while the opposite was observed in CT (Fig. 2b). Mamedov et al. (2006) found that soil loss was aggravated with the increase in IMC, mostly ascribed to the increased slaking (Mamedov et al. 2006). Hence, NT could avoid or reduce soil degradation compared with CT. The present study also indicated that LWSA and MWD decreased with the increase of F–T cycles, while NT had greater LWAS and WAS than CT did in the laboratory experiment. These observations demonstrated that NT could keep more WAS as F–T cycle number increased relative to CT. Such result was possibly associated with the fact that, at the soil depth of 0-10 cm, the increased LWSA resulted in the increased soil water content and decreased soil bulk density under NT relative to CT, a reduction in shear strength and soil cohesion (Kemper et al. 1987), and a disruption in larger-size stable aggregate. Accordingly, in our experiments, the adoption of NT was an effective way to have a stable structure during spring thaw, and F–T cycle number had less influence on the WAS variation of NT relative to CT, especially in the case of great soil water content.

W–D cycle laboratory experiment

In the W–D laboratory experiment, LWSA significantly decreased (P<0.05) under NT following 3 W–D cycles, but W–D cycle number did not significantly affect CT. Although the LWSA under NT was not stable as it was under CT, NT had greater LWSA than CT before and after the W–D cycles. The amount of SWSA under both tillage systems increased with the increase in W–D cycles (Fig. 3). Bravo-Garza et al. (2009) found that W–D cycles positively affected water-stable aggregate (MWSA and LWSA) production, and might accelerate their production and decomposition dynamics. No regular difference in PA was found under either tillage systems.

W–D cycles always result in a structure formation and larger water-stable-aggregate breakdown. This has been proved in our study, as a decline in MWD was observed under both tillage system soils with the increase of W–D cycles (Fig.

Table 3 Multifactor analysis for effects of tillage (*T*), initial water content (*IWC*) and cycle number (*CN*) on different aggregate sizes, and mean weight diameter (*MWD*) and correlation coefficients (*r*) between measured variables

Source of variation	DF	LWSA		SWSA		MWSA		PA		MWD	
		MS	r	MS	r	MS	r	MS	r	MS	r
F–T cycles											
T[a]	1	5462.91 ***	−0.930 **	545.27 ***	0.676 **	915.42 ***	0.597 **	412.37 ***	0.802 **	14.40 ***	−0.924 **
IWC	2	16.17 **	0.682 **	32.42 ***	−0.159	49.76 ***	−0.026	2.20 ***	0.058	0.04 **	0.623 **
NC	3	189.51 ***	−0.296	83.98 ***	−0.437 **	342.68 ***	0.599 **	23.72 ***	0.326	0.56 ***	−0.311 *
T × IWC	2	13.86 **		54.83 ***		58.83 ***		14.21 ***		0.05 ***	
T × NC	3	8.34 *		14.97 ***		40.72 ***		21.43 ***		0.02 *	
NC × IWC	6	6.18 *		8.72 **		9.46 *		1.30		0.02 *	
T × NC × IWC	6	8.70 **		5.42 *		8.68		1.64		0.02 **	
Error	48	2.27		1.91		3.95		0.89		0.01	
W–D cycles											
T	1	507.42 ***	0.353 **	130.55 ***	−0.223 *	98.89 ***	0.096	576.30 ***	0.338 **	1.64 ***	0.219 *
IWC	2	106.83 ***	0.529 *	139.90 ***	0.025	795.81 ***	−0.146	208.65 ***	−0.010	0.31 ***	0.419 *
NC	3	704.71 ***	−0.513 **	209.48 ***	−0.312 **	1453.29 ***	0.392 **	79.61 ***	0.113	2.19 ***	−0.512 **
T × IWC	2	1.35		22.43 ***		9018.58 ***		818.91 ***		0.01	
T × NC	3	371.38 ***		169.79 ***		5243.64 ***		148.03 ***		1.16 ***	
NC × IWC	6	1.54		100.73 ***		55.64 ***		111.20 ***		0.01	
T × NC × IWC	6	7.14 *		54.68 ***		150.23 ***		74.75 ***		0.23 *	
Error	48	2.05		2.22		2.42		12.66		0.07	

*, **, and ***, significance at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively. –, negative relationship. a, we designed no tillage as 1 and conventional tillage as 2 in statistical analysis. *F–T*, freezing-thawing; *W–D*, wetting-drying; *DF*: degrees of freedom; *LWSA*, large water-stable aggregate; *MWSA*, medium water-stable aggregate; *SWSA*, small water-stable aggregate; *PA*, particles. *MS*, mean square

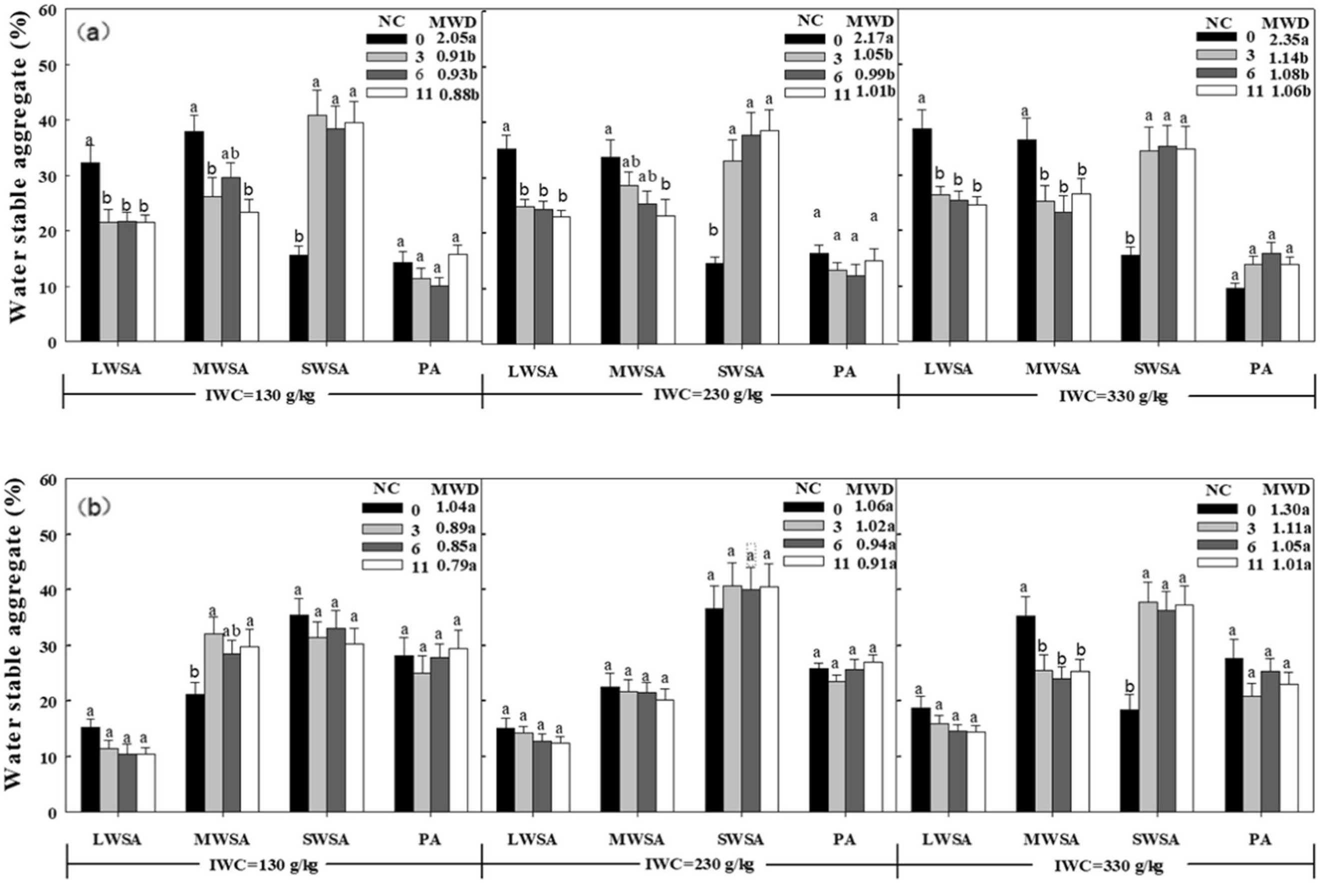

Fig. 3. Effect of wetting and drying cycles on aggregate size and mean weight diameter (MWD, mm) under **a** NT and **b** CT in laboratory simulations. The diverse letters after data suggest that the differences are of statistical significance between diverse cycles ($P < 0.05$). LWSA, large water-stable aggregate; MWSA, medium water-stable aggregate; SWSA, small water-stable aggregate; PA, particles; IWC, initial water content; NC, the number of cycles

3). Many researchers reported that, compared with organic matter or straw application, W–D cycles could reduce WAS but be less impacting on WAS. In general, the IWC condition of the soil was indicated as a key factor in W–D events (Vermang et al. 2009). The low soil water content induced the increased internal expansion pressure, giving rise to maximal expansion and decreasing WAS. Our study also showed that tillage, IWC, and NC had better correlation with LWSA and MWD, which indicated that higher IWC resulted in higher LWSA and more stable WAS in both tillage systems without attention to the NC. When conducting WAS test, the soil water content had certain influence on slaking. The extent of slaking decreased as IWC increased until saturation was reached. Even though WAS was measured on air-dried samples, IWC had certain impact on WAS (Caron et al. 1992). Water content did not affect the stability or size of soil aggregates, and its influence on aggregate features was not generalized. On the other hand, soil water affects aggregation by other ways (Lado et al. 2004; Yang and Wander 1998).

Many studies have proved that, in comparison with NT, W-D cycles have greater influences on soil aggregates under CT, since tillage will persistently expose new surface soils to W-D cycles through blending with the plow layer; besides, it can integrate the crop residues and use them as the protective barrier under NT (Beare et al. 1994; Paustian et al. 2000). By conducting long-term filed experiments, Nouwakpo et al. (2018) reported that soil aggregates under CT generally decreased compared with that under NT (Nouwakpo et al. 2018). There is a greater SOM level under NT than CT, and the increased SOM degradation is induced by W–D cycles, since there are more available resoluble organic substances for the degradation by microorganisms during the W–D cycles (Sørensen 1974).These observations were similar to our study, which showed significant interactions occurring between LWSA and MWD with tillage, IWC, and NC; LWSA and MWD in NT were greater compared with in CT after W–D cycles.

Conclusions

According to our field experimental findings, the CT and NT systems exhibit seasonal changes in the stability and size of soil aggregates. To be specific, the remarkably decreased

WAS and LWSA are seen during the snow melting process, whereas their markedly increased levels are seen under NT, and contrary observations are found under CT in the crop-growing period. Furthermore, in the laboratory experiment, this study showed significant interaction between tillage, IWC, and NC with aggregate size and WAS after F–T and W–D cycles. The amount of LWSA and WAS increased with the increase of IWC, and the opposite was found in NC for both tillage systems after F–T and W–D cycles. Although the LWSA under NT was not stable as it was under CT, soils under NT could maintain greater LWSA and AS in W–D events than CT. Compared with CT, WAS variation in NT was less affected by F–T cycles, especially in the case of high soil water content. Therefore, for Mollisol region in Northeast China, NT must be adopted to improve the soil structural stability.

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Author Contributions L.W., Q.C designed the experiment; L.W. and Q.C. carried out the experiment; X.W. analyzed the data and wrote the manuscript.

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Declaration

Conflicts of interest The authors declare no conflict of interest.

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