Effect of poultry litter and livestock manure on soil physical and biological indicators in a rice-wheat rotation system

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ABSTRACT

Organic manure is considered as a beneficial fertilizer on soil quality and an excellent alternative resource of chemical fertilizer (CF). However, organic manure from intensive farms may have a negative impact on soil quality because of containing some harmful components, such as heavy metal and antibiotics. The aim of this study was to determine the influence of poultry litter (PL) and livestock manure (LM) from intensive farming on soil physical and biological indicators of soil quality. Results showed that PL and LM amendment increased soil macropore and mesopore volumes and decreased soil micropore volumes. Tensile strength in PL and LM treatment were lower than those in CF, while soil aggregate wet stability index were greater than those in CF. Compared with CF treatment, the microbial biomass C and N contents (+89%, +74%), soil basal respiration rate (+49%) and soil microbial quotient (+45%) in PL and LM treatment were significantly greater. Significant linear correlations were found between soil organic carbon and most soil physical and biological properties ($P < 0.01$). The results suggested that modern intensive farm manures can be alternate chemical fertilizers as a main fertilizer to improve soil physical and biological indicators in a rice-wheat system.

Keywords: intensive farm manures; chemical fertilizer; soil pore structure; soil aggregate stability; soil quality

In recent years, the high demand for livestock and poultry products in China has caused a dramatic increase in the growth of the livestock and poultry farming industry. The amounts of animal excreta have a corresponding increase. Data from estimation showed that the amount of manures and litters in China was about 2.21 Gt in 2003, taking more than 40% of the total agricultural organic waste resources (Huang et al. 2006). Increasing animal excreta have become a threat to the rural ecological environment.

Chemical fertilizers play a vital role in food safety in China over the past 30 years. However, application of chemical fertilizers caused the degradation of soil quality, such as soil acidification (Blake et al. 1999), soil hardening (Lai et al. 1992). Increasing the amount of organic manures amendments to agricultural soil was encouraged by scientists and local government. Several researchers reported that traditional organic manure (e.g. farmyard manure and green manure) can be potentially beneficial for soil physical, chemical and biological properties (Li and Zhang 2007, Ludwig et al. 2007, Liu et al. 2009). There is litter information, however, on the effect of animal excreta addition to soil quality in China. Animal excreta from modern intensive farms contains some harmful components, such as heavy metal, pathogenic microorganisms, and veterinary drugs (Zhang et al. 2005). Detrimental impacts on soil quality may occurr after long-term application of animal excreta. Soil physical properties, such as soil pore

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structure and aggregate stability, were the basal indicators to define soil quality. Soil pore plays a very important role in soil structure formation, soil moisture and nutrients maintaining, and microbial diversity protection, while aggregate stability has a positive impact on the seed germination, plant roots and shoots development. Soil biological and biochemical properties were often proposed as early and sensitive indicators of soil ecological stress or other environmental changes (Dick 1994). The objective of this study was to determine the influence of livestock manures and poultry litters from modern intensive farms on soil physical and biological indicators of soil quality.

MATERIAL AND METHODS

The experiment was established by agricultural department of local government in 1988 on a fluvisol in Haian County, Jiangsu, China (120°12'~ 120°53'E, 32°22' ~ 32°43'N). The mean annual precipitation is 1025 mm, and the mean annual temperature is 14.5°C. There are about 220 frost-free days in a year. The soil is a Gleyed paddy soil classified as a Typic Gleyi-Stagnic Anthrosols in Chinese Soil Taxonomy.

The experiment was under a one-year rotation of rice-winter wheat. The treatments were PL (poultry litter), LM (livestock manure), and CF (chemical fertilizer) in a randomised block design with 3 replications. The plot size was 7.5 × 5 m. The poultry litter was collected from an intensive laying-hen farm, while the livestock manure was gathered from an intensive pig farm. The PL and LM were applied at a rate of 21 t/ha in wet weight (about 54% and 60% moisture content, respectively) before each rice transplanting or wheat sowing. On an average, the PL contained 8.98, 9.83 and 5.34 g/kg N, P and K, and LM contained 9.18, 7.89 and 4.02 g/kg N, P and K, respectively on a dry weight. After surface broadcast application, LM and PL were incorporated to cultivated soil with a cultivator. Supplemental N was applied to balance the available N rate and the total N amount was 150 kg/ha for each crop. The CF treatment was fertilized with urea, calcium magnesium phosphate, and muriate of potash for each corps at a rate of 150 kg N/ha, 30 kg P_2O_5/ha and 45 kg K_2O/ha, respectively. The ratio of basal, tillering and panicle fertilizer of N was 4:2:4. P fertilizer was applied as a basal dose. Half of K was broadcasted as a basal fertilizer and half was top-dressed on booting stage in both crops.

Undisturbed soil samples were collected in the cultivated layer (0–15 cm) and the plow pan (15–25 cm) at five random points in each plot after winter wheat harvest in May 2006. The five samples were mixed to obtain a composite sample. Part of the soil samples were air-dried to the plastic limit and separated into aggregates by hand along the natural failure surfaces. Aggregates of 3–5 mm and 10–20 mm in diameter were selected to measure soil aggregate wet stability and tensile strength, respectively. Some fresh composite soil samples were sieved to 2 mm and all visible plant debris was removed by handpicking using tweezers, and kept at 4°C for less than 1 month for soil microbial properties analyses. Other soil samples were air-dried for soil chemical properties analyses. 12 soil cores (100 cm^3) were collected by the stainless steel cylinder in each layer for determining the soil total porosity and soil pore size distribution.

Soil chemical properties were determined with methods described by Lu (2000), and were presented in Table 1. Soil total organic carbon (SOC) was measured by a K_2CrO_7-H_2SO_4 oxidation procedure. Dissolved organic carbon (DOC) and hot

Table 1. Selected soil properties in cultivated horizon (Ap) and plow pan (P) of long-term fertilized field

Treatment		pH (H_2O)	EC (μS/cm)	TN	TP	TK	SOC	DOC	HWOC	Clay	Silt	Sand
				(g/kg)				(mg/kg)		(%, v/v)		
Ap (0–15 cm)	PL	7.34	272.7	1.81	1.10	18.18	17.76	198.31	459.57	9.19	28.47	62.34
	LM	6.85	294.8	1.93	0.95	17.90	18.97	221.57	503.33	8.71	27.65	63.64
	CF	6.24	227.9	1.45	0.68	16.99	14.40	176.38	209.05	9.20	21.56	69.24
P (15–25 cm)	PL	7.51	165.27	0.92	0.70	17.67	9.46	109.81	161.54	10.07	26.61	63.33
	LM	7.25	181.80	1.16	0.65	16.92	10.57	172.77	204.98	10.31	33.31	56.38
	CF	7.51	141.33	0.93	0.62	15.99	8.57	120.39	111.76	8.34	20.12	71.54

EC – electrical conductivity; TN – total nitrogen; TP – total phosphate; TK – total potassium; SOC – soil total organic carbon; DOC – soil dissolved organic carbon; HWOC – hot water extractable organic carbon water extractable carbon (HWOC) was extracted by a method of Ghani et al. (2003), and determined by a total organic carbon analyzer (Shimadzu TOC-5050A, Kyoto, Japan).

Total porosity was determined by undisturbed soil core and its validity checked by using dry bulk density and average particle density values (2.65 g/cm^3). Soil pore size distribution was classified by the Kay's soil pore classification system (Kay 1990). Micropore (< 0.5 μm) was determined from the volumetric moisture content at –600 kPa. Mesopore (0.5 ~ 30 μm) and macropore (> 30 μm) were calculated as differences between moisture retained at –600 kPa and –33 kPa and between saturation and –33 kPa, respectively.

Soil aggregate wet stability was measured by a method of Le Bissonnais (1996) and expressed using the normal mean weight diameter (NMWD). Tensile strength (TS) was performed in an indirect method described by Dexter and Kroesbergen (1985).

Soil microbial biomass (MBC, MBN) was estimated using the chloroform-fumigation-extraction method (Joergensen et al. 1996). MBC was calculated using a k_{EC} factor of 0.45 and MBN was corrected by a k_{EN} factor of 0.54. Soil microbial quotient (SMQ) was calculated as MBC/SOC. Soil basal respiration rate (BR) was measured by incubation-alkaline absorption method (Lu 2000).

Data were analyzed using the SPSS 13.0 for Windows. One-way analysis of variance (ANOVA) for each depth (0–15 and 15–25 cm) was performed to find the effects of fertilizer treatments on soil physical and biological properties. The least significant difference (*LSD*) was used to compare means of measured soil properties at $P < 0.05$ when ANOVA indicated a significant value. Linear correlation analyses between soil properties were performed using *LSD* analysis.

RESULTS AND DISCUSSION

Soil porosity and pore size distribution. Soil total porosity and pore size distribution after long-term application of PL, LM and CF are displayed in Figure 1. The soil total porosity in PL and LM treatments were considerably greater than those in CF treatment (Figure 1a). Compared with CF, the PL and LM application significantly increased the soil macropore (mac-P) and mesopore (mes-P) volume and decreased the soil micropore (mic-P) volume in the cultivated horizon (Figure 1b). The highest mac-P and mes-P volume was observed in LM treatment, while the highest mic-P volume was in CF treatment (Figure 1b). PL and LM application decreased the soil mes-P volume and increased the soil mic-P and mac-P volumes in plow pan, compared with CF (Figure 1c). Many previous studies demonstrated that application of traditional organic manure (e.g. farmyard manure, green manure) can improve soil pore structure and distribution (Celik et al. 2004, Rasool et al. 2008, Liu et al. 2009). For instance, Celik et al. (2004) found that soil TP, mac-P and mic-P (< 30 μm) in farmyard manure and compost treatments were higher than in CF treatment. Rasool et al. (2008) also reported that long-term application of farmyard manure significantly increased soil total porosity compare with CF treatment. Haynes and Naidu (1998) explained that increasing soil organic matter content is the main reason why soil pore structure was improved after applying organic manure. In our study, we observed higher SOC, DOC and HWOC contents in PL and LM treatments (Table 1) and a highly positive linear

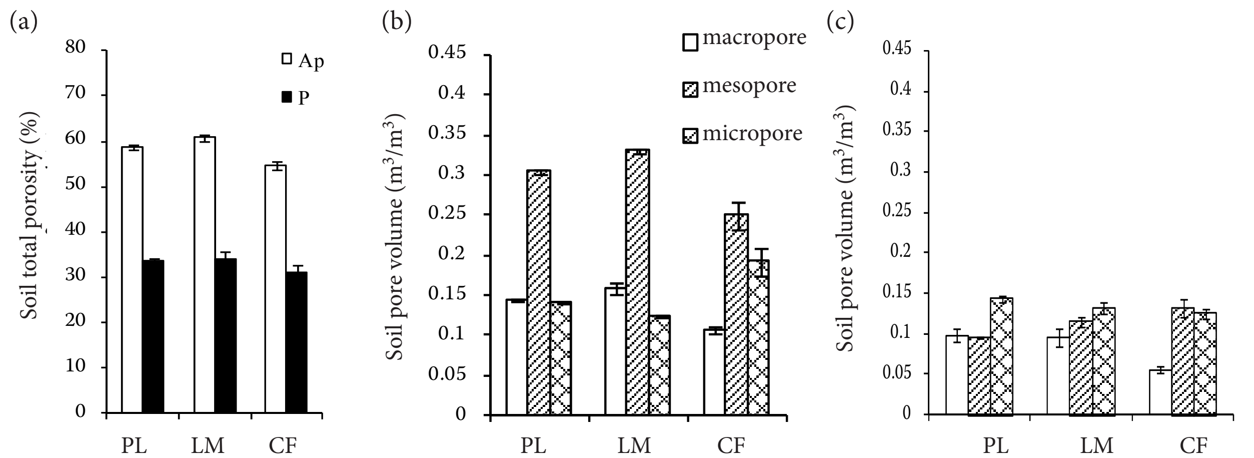

Figure 1. Soil total porosity (a) and pore size distribution in cultivated horizon (b) and plow pan (c) after application of poultry litter (PL), livestock manure (LM) and chemical fertilizers (CF)

Table 2. Linear correlation coefficient between soil physical, biological indicators and soil organic carbon pools

	TP	mac-P	mes-P	mic-P	TS	NMWD	MBC	MBN	BR	SMQ
mac-P	0.92**									
mes-P	0.93**	0.82**								
mic-P	0.10	–0.06	0.05							
TS	–0.87**	–0.88**	–0.81**	–0.23						
NMWD	0.80**	0.85**	0.73**	–0.26	–0.68**					
MBC	0.96**	0.92**	0.94**	–0.09	–0.84**	0.82**				
MBN	0.95**	0.92**	0.93**	–0.11	–0.81**	0.86**	0.99**			
BR	0.94**	0.94**	0.86**	–0.13	–0.79**	0.88**	0.97**	0.98**		
SMQ	0.93**	0.94**	0.87**	–0.13	–0.83**	0.79**	0.98**	0.97**	0.97**	
SOC	0.98**	0.89**	0.97**	0.07	–0.88**	0.80**	0.97**	0.96**	0.92**	0.92**
DOC	0.89**	0.79**	0.87**	0.03	–0.76**	0.84**	0.85**	0.83**	0.80**	0.76**
HWOC	0.95**	0.92**	0.90**	–0.18	–0.80**	0.85**	0.99**	0.98**	0.97**	0.97**

TP – total porosity; mac-P – macropore; mes-P – mesopore; mic-P – micropore; TS – tensile strength; NMWD – normal mean weight diameter; MBC – soil microbial biomass carbon; MBN – soil microbial biomass nitrogen; BR – soil basal respiration rate; SMQ – soil microbial quotient; SOC – soil total organic carbon; DOC – soil dissolved organic carbon; HWOC – hot water extractable organic carbon

correlation between SOC, DOC, HWOC and TP, mac-P, mes-P (Table 2). This indicated that modern intensive farm manure have a similar effect on soil pore structure and size distribution with traditional organic manure.

Soil aggregate stability. Soil aggregate stability, the capability of soil aggregate to resist an external stress, could be expressed by wet stability and mechanical stability. The PL and LM application significantly influenced soil aggregate stability (Figure 2). The tensile strength (mechanical stability indicator) of soil aggregate in the PL and LM treatment were less than 20 MPa in Ap and 52 MPa in P layer, lower than those in the CF treatment (Figure 2a). While the soil aggregate wet stability index NMWD in the PL and LM treatments were greater than that in the CF treatment in both Ap and P layer (Figure 2b). Similar results were reported by Li and Zhang (2007) and Hati et al. (2008) when they amended soil with farmyard manure. Soil organic matter is a key factor in the formation of soil stable aggregate (Tisdall and Oades 1982), it was confirmed by the close relationship between soil aggregate stability index and soil organic carbon content (Table 2).

Soil microbial biomass and activity. Soil microbial biomass and activity in the PL, LM and CF treatments were shown in Table 3. The MBC

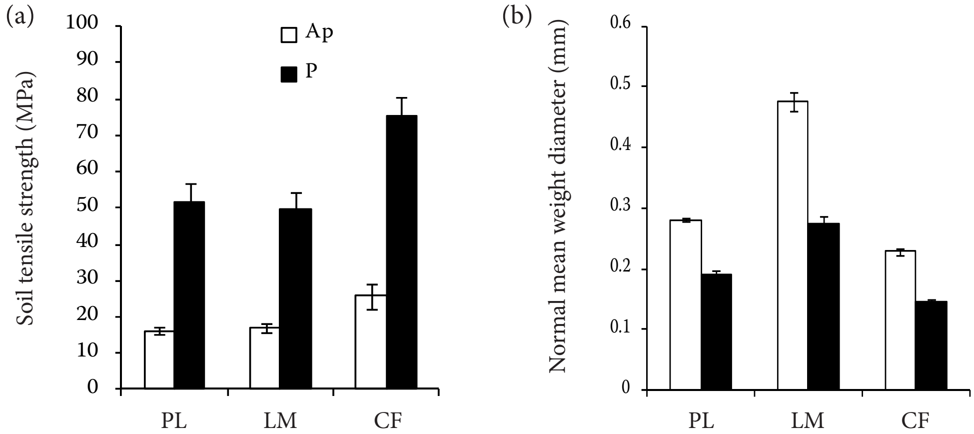

Figure 2. Tensile strength (a) and normal mean weight diameter (b) of soil aggregate after application of poultry litter (PL), livestock manure (LM) and chemical fertilizer (CF)

Table 3. Soil microbial biomass, soil basal respiration rates, soil microbial quotients and soil microbial metabolic quotients in poultry litter, livestock manure and chemical fertilizer treatment

Treatments		MBC (mg/kg)	MBN (mg/kg)	MBC/MBN	BR (mg CO_2/g/day)	SMQ (%)
Ap (0–15 cm)	PL	1209.0 ± 3.4	84.66 ± 0.93	14.29 ± 0.19	105.25 ± 4.36	6.81 ± 0.02
	LM	1331.9 ± 2.6	107.35 ± 0.57	12.41 ± 0.21	137.96 ± 2.35	7.02 ± 0.03
	CF	633.9 ± 3.4	49.01 ± 0.52	12.94 ± 0.16	53.33 ± 1.56	4.40 ± 0.01
P (15–25 cm)	PL	422.6 ± 2.4	36.69 ± 1.03	11.54 ± 0.45	55.42 ±1.96	4.47 ± 0.11
	LM	409.8 ± 2.1	31.11 ± 0.57	13.25 ± 0.67	42.10 ±2.14	3.88 ± 0.07
	CF	276.6 ± 2.2	23.21 ± 0.52	11.94 ± 0.34	17.67 ±1.21	3.23 ± 0.04

MBC – soil microbial biomass carbon; MBN – soil microbial biomass nitrogen; BR – soil basal respiration rate; SMQ – soil microbial quotient

and MBN contents in the PL and LM treatments were higher than those in the CF treatment. The highest MBC and MBN contents were observed in the Ap layer of LM treatment among all treatments (Table 3). Higher soil microbial biomass was probably due to higher available C substrates and nutrients contents (Akmal et al. 2004). Ritz et al. (1997) pointed out that the MBC/MBN ratio can provide some information of soil microbial community structure. Results of the difference in soil MBC/MBN ratio (Table 3) may suggest that the soil microbial community structure were changed in PL, LM and CF treatments. Soil basal respiration rate is a direct indicator of soil microbial community activity. Soil BR in the CF treatment was lower than 54 mg CO_2/g soil/day, while soil BR in the PL and LM treatments was 42~138 mg CO_2/g soil/day, 1.97~3.14 times over those in the CF treatment. This result was in line with the result of Liu et al. (2009), who found that soil BR in farmyard manure and green manure treatments were higher than in NPK treatment. Soil microbial quotient was used effectively to follow the state of soil organic matter after the addition of organic materials (Insam and Merschak 1997). The higher SMQ, the more active organic matter is present in the soil. Compared with CF treatment, the PL and LM application significantly increased the value of soil microbial quotients (Table 3). In line with the results of Kaur et al. (2005) who found that the highest value of SMQ was observed in soil that received PL 7 years and lowest in soils that received only CF. This may indicate no significant toxicity effect on soil microbial biomass and activities after application of modern intensive farm manure compared with CF, although those animal excreta have some harmful components. However, further research is needed to know whether changes on soil organism community structure and function or not after long-term application of those animal excreta to rice-wheat rotation system.

Generally, application of modern intensive farming manure can improve soil physical and biological properties compared with only chemical fertilizers. On the other hand, the total product of rice and wheat of PL, LM and CF treatment in 2006 was 12.80, 13.58 and 12.38 t/ha, respectively. Therefore, we should increase the area of field application of intensive farming animal excreta. To do so, eco-environment stress caused by modern intensive farming development and chemical fertilizers application will be reduced. However, we also should strengthen the risk management of those animal excreta.

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