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Diversity and abundance of soil fauna as influenced by long-term fertilization in cropland of purple soil, China

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ABSTRACT

The relationship between soil fauna groups and different fertilization regimes has been of continuous concern. Little attention has been paid to the response of soil fauna to changes in soil fertility. Thus, the aim of this study was to investigate the response of soil fauna communities to fertilizer management practices, to explore the inter-relationships between soil fauna communities and fertilization regimes so as to identify soil fauna species or groups that are sensitive to changes in soil fertility. This long-term fertilization experiment was conducted with a no fertilizer control and six fertilization regimes: CK (control, no fertilizer), N (synthetic N fertilizer), NPK (synthetic fertilizer: nitrogen, phosphorus and potassium), OM (pig manure), OMNPK (pig manure plus nitrogen, phosphorus and potassium), RSD (crop residues returned) and RSDNPK (crop residues returned with nitrogen, phosphorus and potassium). The application of organic fertilizers (i.e., pig manure or crop residues) promoted the diversity of the soil fauna communities due to the abundant organic matter the fertilizers supplied for the communities' survival and development. Furthermore, organic–inorganic compound fertilizers (i.e., treatment of OMNPK or RSDNPK) were beneficial for richness and diversity of soil fauna communities due to their abundance of organic matter and supply of nutrients. Indices of soil fauna communities (i.e., TI, the DG (density-group) index, the number of individuals of Nemata, Lumbricida, Collembola and Oribatida) showed the same trend with an increase in the soil organic matter. Therefore, indices of soil fauna communities can be applied to indicate certain features of soil fertility, such as soil organic matter content, but they cannot be used to reflect integrated assessment for soil fertility.

1. Introduction

Soil fauna plays a key role in agricultural ecosystems because soil fauna groups directly or indirectly take part in the decomposition and mineralization of soil organic matter (Carrillo et al., 2011; Bernard et al., 2012). While the application of fertilizers is essential to enhancing crop yields (Diekötter et al., 2010), fertilizers affect soil properties by changing the species and quantity of plant residues and root exudates, which subsequently changes the diversity and composition of soil fauna communities by changing the ecosystem of the soil fauna (Reeve et al., 2010). Thus, variations in soil fauna community diversity in croplands are closely connected with different fertilizer regimes (Kautz et al., 2006; Brennman et al., 2006).

Previous studies have reported the effects of changes in soil organic matter and soil fertility on the composition and diversity of soil fauna communities. These prior studies emphasized the importance of studying the relationship between soil fertility and soil fauna communities (Sanderson, 2007; Wu et al., 2011; Basset et al., 2012). They also reported that long-term fertilization led to the reduction of some invertebrate species and the increase in some fauna groups (e.g., Collembola and Acarina) (GuÐleifsson, 2002). The application of green manure or crop residues influenced the populations of soil fauna (Fu et al., 2009; Zhu et al., 2010). The long-term application of organic manure increased the population of earthworms and predatory soil fauna in savannas (López-hernández et al., 2004) but had a lesser effect on the overall diversity and richness of the soil fauna communities (Frampton and Van den Brink, 2002). Andrén (1984) reported that mineral fertilizers normally increased mesofauna abundance. However, several other studies revealed no such effects (Lindberg and Persson, 2004). Furthermore, the continuous application of nitrogen fertilizer could significantly reduce the quantity of soil

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Nematodas and soil protozoa (Reeleder et al., 2006; Qi et al., 2011). These results indicate that the abundance and diversity of the soil fauna community are significantly influenced by different fertilization regimes. However, other studies found no such obvious effects. Although the relationship between long-term fertilization and soil fauna community diversity has received increased attention, research on purple soils is lacking, particularly regarding the response of soil fauna communities to fertilization regimes, the functions soil fauna play with respect to changes in soil fertility, and the way fertilization influences soil fauna. In addition, previous studies demonstrated that there is a close relationship between changes in soil fertility/quality and changes in soil fauna (Knoepp et al., 2000; Yan et al., 2012; Lu et al., 2013). Therefore, these findings suggest that further studies are needed to determine whether soil fauna can be used to indicate soil fertility/quality changes in purple soils. Purple soil is widely distributed in the hilly areas of southern China, and it is notably concentrated in a land area of approximately 160,000 km^2 in the Sichuan Basin (Zhu et al., 2009). The combination of this purple soil, which is rich in mineral nutrients, the subtropical monsoon climate has allowed this area to be widely cultivated and to produce abundant agricultural products. It is the most important agricultural zone in southwestern China. However, purple soil is deficient in organic matter and nitrogen due to extensive soil erosion and degradation. Fertilization remains an important method to intensively utilize croplands in this area while maintaining and improving crop yields. Long-term fertilization can inevitably lead to changes in the physical, chemical and biological properties of soil. Soil fauna has been shown to be sensitive to changes in soil conditions (Vasconcellos et al., 2013). Regarding purple soils, research is still lacking on the relationship between fertilization regimes and the soil fauna community and the role that soil fauna plays with respect to changes in soil fertility. Therefore, this study aims to determine the following: (1) the effects of fertilization regimes on the abundance and diversity of the soil fauna community; (2) the relationship between major soil fauna groups and fertilization regimes.

2. Materials and methods

2.1. Site description

The study site is located at the Yanting Agro-ecological Experimental Station of Purple Soil, Chinese Academy of Science under the Chinese Ecosystem Research Network (CERN). The station is located at 31°16′N, 105°28′E, at an altitude of 400–600 m, and in the middle of the Sichuan Basin, southwestern China. The soil in the study area is called purple soil and is classified as a Pup-Orthic Entisols in the Chinese soil taxonomy and as an Entisol in the U.S. Taxonomy (Zhu et al., 2009). The study site represents the intensive agriculture lands found in a subtropical monsoon climate and has an annual mean temperature of 17.3 °C and a mean precipitation of 826 mm (1981–2009).

2.2. Experimental design

Long-term fertilization experiments have been conducted since 2003 on croplands of purple soil with a plot size of 8 m (length) by 4 m (width) and a soil depth of 60 cm. The plots were hydrologically isolated with partition walls filled with cement to avoid unexpected species moving between the individual plots (Zhu et al., 2009). The present study includes a non-fertilized control and six fertilizer treatments as follows: CK (no fertilizer), N (synthetic N fertilizer: 280 kg N ha^{-1} yr^{-1}), NPK (synthetic fertilizer, N: 280 kg N ha^{-1} yr^{-1}, P: 180 kg P_2O_5 ha^{-1} yr^{-1}; K: 72 kg K_2O ha^{-1} yr^{-1}), OM (pig manure: 280 kg N ha^{-1} yr^{-1}), OMNPK (synthetic N fertilizer: 168 kg N ha^{-1} yr^{-1} plus pig manure: 112 kg N ha^{-1} yr^{-1}, N: 280 kg N ha^{-1} yr^{-1}; P: 180 kg P_2O_5 ha^{-1} yr^{-1}; K: 72 kg K_2O ha^{-1} yr^{-1}), RSD (crop straw returned: 13 t ha^{-1} yr^{-1}) and RSDNPK (synthetic N fertilizer: 238 kg N ha^{-1} yr^{-1} plus crop straw returned 13 t ha^{-1} yr^{-1}, N: 280 kg N ha^{-1} yr^{-1}; P: 180 kg P_2O_5 ha^{-1} yr^{-1}; K: 72 kg K_2O ha^{-1} yr^{-1}). The pig manure applied in the study area was collected from the same pig farm. The C and N contents of the pig manure were comparable throughout the experimental period, with average N content of 4.8 ± 0.4 g N kg^{-1} and a C:N ratio of 16 ± 2 (±SE). Wheat (maize) straw, with an average N content and C: N ratio of 6.4 ± 0.6 (8.8 ± 0.7) g N kg^{-1} and 66 ± 2 (48 ± 4), respectively, was cut into small pieces (approximately 5 cm long) (Zhou et al., 2013). This processed fertilizer was then incorporated into the plots of the RSDNPK treatment prior to planting maize (wheat) (Zhou et al., 2013). Each fertilizer treatment had three field replications. All fertilizer treatments were applied once at the beginning of each crop season. The experimental plots were planted with winter wheat (*Triticum aestivum* L.) in rotation with summer maize (*Zea mays* L.) in accordance with the local farming system and typical intensive agriculture techniques found in the Sichuan Basin of the upper Yangtze River, China.

2.3. Sampling methods

Topsoil samples were collected from 5 sampling points per plot and were mixed into a composite sample that was air-dried and sieved through a 2 mm sieve. Soil organic matter (SOM) was analyzed by dichromate oxidation and titration using ferrous ammonium sulfate (Liu, 1996). Soil total nitrogen (TN) was measured using the Kjeldahl method. Soil total phosphorus (TP) was determined using H_2SO_4/H_2O_2 digestion followed by colorimetric analysis. Soil total potassium (TK) was analyzed, after H_2SO_4/H_2O_2 digestion, using atomic absorption spectrophotometry (Baruah and Barthakur, 1999).

Table 1
Main soil physicochemical properties under different fertilization regimes.

Soil properties	CK	N	NPK	OM	RSD	OMNPK	RSDNPK
SOM (g kg^{-1})	7.71 ± 0.06bc	8.16 ± 1.25b	8.87 ± 0.51b	9.94 ± 0.11a	10.88 ± 0.45a	10.20 ± 0.81a	10.90 ± 0.61a
MBC (mg kg^{-1})	133.90 ± 2.76c	151.11 ± 13.35bc	263.04 ± 33.71a	250.75 ± 20.27ab	240.05 ± 8.83ab	294.66 ± 29.17a	310.59 ± 26.27a
MBN (mg kg^{-1})	36.86 ± 3.49e	54.83 ± 4.85 cd	42.81 ± 1.66de	64.22 ± 3.87abc	62.63 ± 3.98bc	71.79 ± 2.98a	78.87 ± 2.33a
TN (g kg^{-1})	0.64 ± 0.07a	0.66 ± 0.08a	0.74 ± 0.01a	0.71 ± 0.01a	0.70 ± 0.01a	0.76 ± 0.04a	0.77 ± 0.05a
C/N	14.16 ± 0.68ab	14.00 ± 0.68ab	13.42 ± 0.07bc	12.36 ± 1.22bc	15.54 ± 0.96a	12.05 ± 0.08bc	11.99 ± 2.59c
TP (g kg^{-1})	0.63 ± 0.02a	0.63 ± 0.02a	0.75 ± 0.03a	0.72 ± 0.06a	0.69 ± 0.03a	0.73 ± 0.04a	0.75 ± 0.06a
TK (g kg^{-1})	20.32 ± 0.97a	20.53 ± 0.90a	21.63 ± 0.83a	19.99 ± 0.89a	19.63 ± 1.30a	19.55 ± 1.39a	20.07 ± 0.84a
AN (mg kg^{-1})	44.52 ± 3.95c	54.06 ± 11.37b	54.86 ± 17.10b	55.56 ± 9.45b	59.08 ± 11.40ab	61.23 ± 8.86ab	63.63 ± 9.21a
AP (mg kg^{-1})	4.19 ± 0.11b	4.38 ± 0.89b	5.76 ± 0.75b	10.44 ± 2.41a	4.71 ± 0.70b	12.33 ± 0.96a	10.30 ± 0.67a
AK (mg kg^{-1})	78.33 ± 4.77b	76.55 ± 1.36b	87.48 ± 9.06b	86.88 ± 13.80b	95.45 ± 9.85b	138.87 ± 12.67a	132.84 ± 11.09a
SBD (g cm^{-1})	1.38 ± 0.04a	1.38 ± 0.06a	1.32 ± 0.05ab	1.31 ± 0.05a	1.18 ± 0.05b	1.28 ± 0.05a	1.26 ± 0.04ab
SP (%)	48.01 ± 1.64a	47.83 ± 2.26a	48.02 ± 1.00ab	50.30 ± 1.85a	55.65 ± 1.76b	51.52 ± 1.98a	51.63 ± 2.00ab

Treatments with the same letters (a or b) at each rows are not significantly different (ANOVA with LSD test, $p > 0.05$).