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Effect of inorganic fertilizers with organic amendments on soil chemical properties and rice yield in a low-productivity paddy soil

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ABSTRACT

Integrating inorganic fertilizers (NPK) with organic materials have been common practices for sustainable agriculture production in low-productivity paddy soil. A 4-year field experiment was conducted to investigate the effects of the annual application of inorganic fertilizer in contrast with the combined application of organic manures and NPK on rice grain yield and the soil chemical properties. Six treatments, including control (no fertilizer), NPK alone, NPK plus spent mushroom compost at 1.5 Mg ha^{-1} (NPK + MC), NPK plus green manure at 3.6 Mg ha^{-1} (NPK + GM), NPK plus cattle manure at 4.7 Mg ha^{-1} (NPK + CM), and NPK plus rice straw at 3.0 Mg ha^{-1} (NPK + RS)—were applied in this study. The results indicated that the rice grain yields for 2014 under the NPK + CM and NPK + RS treatments were 11.4% and 9.3% higher, respectively, compared with the NPK alone treatment. No significant differences in rice yield were observed between the plots using NPK and NPK + MC or NPK + GM treatments. The application of CM to the soil surface led to significantly higher soil pH (0.16–0.29 units), cation exchange capacity (CEC) (17.4%–21.9%), and lower exchangeable acidity and Al^{3+} concentrations at soil depths of 0–20 cm, compared with the NPK alone treatment. However, no significant differences in pH or concentrations of base cations in the soil were observed in the 0–10 cm soil layer after the application of NPK alone or NPK plus the other three organic amendments. Additionally, the application of NPK + CM at 4.7 Mg ha^{-1} y^{-1} showed the highest available P concentration at 0–10 cm depth. Overall, the rice grain yield, soil pH, and available P were effectively improved by NPK in combination with CM at 4.7 Mg ha^{-1}.

1. Introduction

Yellow clayey paddy soil is a typical low-productivity soil found in an area of 1.3 million ha in southern China (Liu et al., 2014). The limited productivity in this area is mainly attributed to the poor soil chemical properties, such as low pH and nutrient contents, as well as low levels of soil organic C (SOC). Yadav et al. (2000) analyzed the data from some long-term field experiments and found a downward trend in crop yields, owing to decreasing levels of soil nutrients. In order to ensure a stable annual rice yield, farmers have resorted to the use of larger than recommended doses of inorganic fertilizers (NPK) (Yadav et al., 2000; Liu et al., 2009). However, overuse of inorganic fertilizers inevitably causes a decline in the soil quality (e.g., soil acidification) and crop production (Guo et al., 2010). Integrating organic amendments with NPK application is a promising fertilization strategy for creating sustainable agriculture production systems, especially in soils of poor quality (Yang et al., 2015).

The chemical aspects of soil quality are important because they can be used to evaluate the ability of a soil to supply nutrients and buffer against chemical additives (Wang and Yang, 2003). Soil organic C (SOC) is a key attribute of soil quality (Gregorich et al., 1994). Higher SOC contents indicate higher levels of soil sorption, cation exchange capacity (CEC), and accessible nutrient values (Brady and Weil, 2002). It is possible to increase the SOC, along with other soil chemical

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properties, through the addition of organic materials. However, the benefits of organic amendments for soil chemical properties might vary, depending on their addition rates and composition (Arif et al., 2016).

Spent mushroom compost (MC), green manure (GM), cattle manure (CM), and rice straw (RS) are the four common organic materials widely used by local farmers in southern China. However, the impact of these organic amendments on soil chemical and biological properties can vary, as they all possess very specific and distinct qualities. Therefore, it is necessary to evaluate the effects of different organic amendments on the sustainability of agriculture systems. Recent studies have assessed the long-term impact resulting from integrated use of organic materials and NPK on soil properties and crop yield (Hati et al., 2007; Liu et al., 2010; Zhou et al., 2013; Yang et al., 2015). However, only a few studies have been conducted in poor-quality paddy soils, and little is known about the short-term changes in the chemical properties of this soil profile under mulching with a wide range of organic materials.

Therefore, the objectives of this study were to: 1) evaluate the effects of inorganic fertilizers with organic amendments on soil properties and yield; 2) explore the relationship between soil properties and yield.

2. Materials and methods

2.1. Experimental site and climate

This experiment has been running since 2011 in the town of Langya (29°1′N, 119°27′E), Jinhua, Zhejiang province, southeastern China. The climate is that of a typical subtropical monsoon region, with four distinct seasons, a mean annual temperature of 17.5 °C, and mean annual precipitation of 1424 mm. The cropping system in this area has historically included rice (middle June to early October). The soil is classified as Ultisols (USDA Soil Taxonomy), with 36.8% sand, 34.9% silt, and 28.3% clay. In April 2011, ten soil core samples from a depth of 0–20 cm were randomly collected for soil chemical analysis. Selected basic soil chemical properties of the topsoil before transplanting are shown in Table 1.

2.2. Experimental design and treatments

Six treatments were arranged in a randomized complete block design with three replicates, on individual plots of 5 m × 10 m. The six treatments, all applied annually, were (1) unfertilized control (CK), (2) nitrogen (N), inorganic phosphorus (P) fertilizer, and potash (K) fertilizer (NPK), (3) NPK plus spent mushroom compost at 1.5 Mg ha^{-1} (NPK + MC), (4) NPK plus milk vetch (*Astragalus sinicus* L.) at 3.6 Mg ha^{-1} (NPK + GM), (5) NPK plus cattle manure at 4.7 Mg ha^{-1} (NPK + CM), and (6) NPK plus rice straw at 3.0 Mg ha^{-1} (NPK + RS). Urea, calcium superphosphate, and potassium chloride were the sources of the N, P, and K, respectively. The same rates of NPK fertilizers were applied for treatments (2)–(6). The recommended rates of use of NPK fertilizer are 180 kg N, 90 kg P, and 120 kg K per hectare annually. Two-fifths of the N and a full dose of the P and K fertilizers were broadcast one day before transplanting. The remaining N was applied as a split-application in two equal rates at the tillering and booting stages.

In this experiment, the cropping system involved single cropping of rice. The fields remained fallow between the harvest and next planting. Each year, rice (*Oryza sativa* L.) was transplanted in mid-June, using two seedlings per hill at 19.8 cm × 19.8 cm spacing. Rice was harvested manually in the first week of October every year, after which all the straw was removed from the plots. The soil was ploughed to a depth of 15 cm in early June every year. All the varieties of organic manure were applied to the soil surface one day before rice transplanting. GM and RS were applied as intact plants. These four organic amendment application rates were adopted according to the local common use. On an average, MC, GM, CM, and RS were applied annually at rates of 1.5, 3.6, 4.7, and 3.0 Mg ha^{-1}, respectively, based on oven-dried weight. The application rates and chemical compositions of the different organic manures are shown in Table 2 and S1.

Table 1
Soil chemical attributes before experiment establishment in April 2011.

pH	SOC (g kg^{-1})	Total N (g kg^{-1})	Bray–P (mg kg^{-1})	NH_4OAc-exchangeable K^+ (mg kg^{-1})
5.14	15.3	1.53	17	97

Table 2
Application rate and element input for spent mushroom compost, milk vetch, cattle manure and rice straw.

Organic materials	Application rate	C	N	K	Ca	Mg	P	S
	Mg ha^{-1}	kg ha^{-1}						
Spent mushroom compost	1.5	742	15	4	45	3	3	2
Milk vetch	3.6	1372	60	58	45	12	11	13
Cattle manure	4.7	1364	98	56	106	25	48	14
Rice straw	3.0	1313	26	60	16	7	4	4

C, N, P, and K means total C, N, P and K.

Table 3
Rice grain yields under different fertilizer managements from 2011 to 2014 (Mg ha^{-1}).

Treatment	2011	2012	2013	2014
CK	5.9 ± 0.1c	6.5 ± 0.7c	6.9 ± 0.4b	5.5 ± 0.7c
NPK	8.5 ± 0.1b	8.4 ± 0.2b	9.3 ± 0.2a	8.3 ± 0.2b
NPK + MC	10.1 ± 0.03a	9.4 ± 0.2a	9.3 ± 0.1a	8.3 ± 0.1b
NPK + GM	10.2 ± 0.04a	9.3 ± 0.6a	9.2 ± 0.1a	8.7 ± 0.1ab
NPK + CM	10.2 ± 0.03a	9.5 ± 0.3a	9.7 ± 0.3a	9.2 ± 0.2a
NPK + RS	10.1 ± 0.1a	9.4 ± 0.3a	9.2 ± 0.3a	9.1 ± 0.1a

Different small letters in a column present significant difference at the 5% level. For all other abbreviations see Fig. 1.

2.3. Sampling and chemical analysis

Soil samples were collected by randomly taking six cores at depths of 0–5 cm, 5–10 cm, 10–20 cm, and 20–30 cm from each plot on October 10, 2014, four years after the experiment was established. Samples were air-dried and sieved through a < 2 mm mesh for analysis. Soil pH (H_2O) was measured in 1:2.5 soil to water suspensions. The CEC was determined using the ammonium acetate compulsory displacement method (Pansu and Gautheyrou, 2006). Soil exchangeable K^+ was extracted using 1 M NH_4OAc and analyzed using flame photometry. Soil exchangeable Na^+, Ca^{2+}, and Mg^{2+} were extracted using 1 M KCl (1:10), and their levels were determined using atomic absorption spectrophotometry (NovAA300, Analytik Jena, Germany). The total exchangeable base cations (EBC) was defined as the sum of exchangeable K^+, Ca^{2+}, Na^+, and Mg^{2+} (Yuan and Xu, 2011). The base saturation (BS) was defined as the proportion of EBC divided by the CEC. The total soil exchangeable acidity (H^+ and Al^{3+}) was extracted using 1 M KCl, and then titrated with 0.02 M NaOH to the phenolphthalein endpoint. One milliliter of 3% NaF was added to 100 ml of the extractant, and then the mixed solution was titrated with 0.02 M NaOH to the phenolphthalein endpoint to obtain the value of exchangeable H^+. The difference between exchangeable acidity and exchangeable H^+ is exchangeable Al^{3+} (Cai et al., 2015). Available P in the soil was measured using the ammonium fluorine extraction method (Bray and Kurtz, 1945). Dissolved organic C (DOC) was measured as described by Jones and Willett (2006). The microbial biomass C (MBC) was determined through fumigation-extraction (Vance et al., 1987; Wu et al., 1990). SOM was determined using $K_2Cr_2O_7$-H_2SO_4 oxidation (Walkley and