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Long-term effects of combined application of chemical nitrogen with organic materials on crop yields, soil organic carbon and total nitrogen in fluvo-aquic soil

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A B S T R A C T

Integrating fertilizer nitrogen with organic materials was an important management strategy for sustainable agriculture production systems in most soils low in organic matter. A 33-year-old experiment with various fertilizations in a double cropping system rotated with winter wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) on a fluvo-aquic soil in Tianjin was evaluated. The six treatments used were control, N, NPK, NM, NS and NGM, representing various combinations of N, P, K, organic manure (M), straw (S) and green manure (GM) fertilizer applications. The specific objective of this study was to evaluate the long-term effects of combined use of organic materials and chemical fertilizer nitrogen on crop yields, soil organic carbon (SOC) and soil total nitrogen (TN).

As a result, wheat and maize yields in the plot under the N treatment decreased with time, whereas the yields increased in the plot under NM treatment for both crops. The yields in NS and NGM treatments maintained a stable and higher level. Generally, both wheat and maize yields were significantly higher in NM and NPK than those in other treatments. The SOC and TN contents with all treatments showed an increasing trend with time. Compared with the N treatment, the average SOC and TN contents were 38.0 and 17.3%, 14.2 and 6.7%, and 12.9 and 6.1% larger, respectively, for NM, NPK, and NS. In addition, the SOC contents with the five treatments (N, NGM, NS, NPK and NM) increased by 25.5, 33.1, 42.1, 69.7 and 145.6%, respectively, by 2012; for TN they increased by 6.6, 17.8, 23.2, 35.5 and 57.5.5%, respectively, above the values obtained in 1979. TN contents were significantly correlated with SOC at each treatment ($P < 0.01$). Soil C/N ratios were generally around 9 to 14 during cultivate time. The average soil C/N ratio in NM was significantly higher than those in other treatments, and the soil C/N ratios among the other four treatments were not significantly different.

Overall, the results suggest that organic manure along with chemical N must be used to sustain the productivity and promote C and N sequestration of wheat–maize system in the fluvo-aquic soils of the Tianjin areas.

1. Introduction

Concerns over food security and global climate change require an improved understanding of how to achieve optimal crop yields whilst minimizing the harmful effect on agro-ecosystem (Guo et al., 2012). Fertilizer management is used primarily to sustain crop yield and maintain soil fertility. Good fertilizer management can improve soil quality, but poor fertilizer management can degrade soil physical, chemical, and biological properties (Chen et al., 2011). Mapanda et al. (2011) concluded that the application of mineral-N and manure input may play an important role with reference to global warming.

Nitrogen (N) is one of the most important nutrients used worldwide to increase and maintain crop production and is considered a key element in maintaining the sustainability and economic viability of farming systems across the world (Fixon and West, 2002). Nitrogen deficiency limits cell division, chloroplast development, enzyme activity, and reduce dry-matter yields (Salvagiotti et al., 2008). Its addition to agricultural cropping systems is an essential aspect of modern crop management (Robertson and Vitousek, 2009). The aims of agricultural N management are to provide enough N to plants to maximize crop growth and yield and to minimize environmental impact of other ecosystems (Giola et al., 2012). Environmental problems

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related to the use of N fertilizer was focus primarily on the effects of nitrate leaching in the groundwater and nitrous oxides emissions in the atmosphere (Galloway et al., 2004). Application of N through chemical fertilizers is the dominant and main source of N input in the crop production systems worldwide (Abbasi and Tahir, 2012). And to meet the food demands of an increasing population, more mineral fertilizer N is being applied to the soils in China. This use accounts for more than one quarter of the total N fertilizer used around the world. So, nitrogen management is still an important issue and need more researches in China.

Conventional agroecosystems, especially in China, have been characterized by high input of chemical fertilizer instead of organic amendments, leading to deterioration of soil quality. With increasing global concerns about energy crisis and environmental protection, it is becoming more important to rely on local abundant agricultural bio-resources than on chemical fertilizer (Liu et al., 2009). And there is a renewed interest in organic materials, such as farmyard manure (FYM), composts, poultry manure, crop residues, and green manure, as sources of plant nutrients. Unlike chemical fertilizers, nutrients contained in organic manures are released more slowly and are stored for a longer time in the soil, thereby ensuring a long residual effect. Concerted efforts have been tried to use these organic sources to provide the same amount of food with less fossil fuel-based inorganic fertilizers. It is possible because increased recycling of organic materials is likely to release a substantial amount of nutrient especially nitrogen into the mineral N pool, reducing fertilization costs, and providing an amount of available N that allows maintenance of crop yields (Panwar et al., 2010; Thy and Buntha, 2005). Numerous studies have been conducted both under laboratory and field conditions to access the effect of these materials or manure on crop yield and soil nutrient condition (Aulakh et al., 2000; Abbasi et al., 2007; Gopinath et al., 2008; Azeez and Van Averbeke, 2010). Although, Gopinath et al. (2008) indicated that the grain yield of wheat in all the treatments involving organic amendments, that is, composted FYM, vermicompost, and lantana compost was markedly lower than with the mineral fertilizer treatment. But there were more workers had reported positive effects of organic substrates applied alone or in combination with chemical fertilizers on productivity of crop (N' Dayegamiye and Tran, 2001; Kundu et al., 2007; Singh et al., 2009; Shah et al., 2009), and strongly encouraged application of organic materials in crop production in many places as a replacement for part or all of the mineral fertilizer used (Pinitpaitoon et al., 2011).

No doubt, chemical fertilizerscan provide an essential nutrients for crop improvement to obtain higher yields, but are too costly for the resource-poor farmers. Meanwhile, the use of organic materials alone may not be enough to maintain the present level of crop production because of its limited availability and relatively low nutrient content (Bayu et al., 2006). It has been demonstrated that balanced mineral fertilization and incorporation of organic fertilizer can improve crop yield (Cai and Qin, 2006) and soil organic carbon (Kukal et al., 2009) in agricultural soils. So an integrated nutrient-management program in which both organic materials and chemical fertilizer were used has been suggested as a rational strategy. It is commonly believed that the combination of organic and chemical fertilizer will increase synchrony and reduce losses by converting inorganic nitrogen into organic forms and is important not only for enhancing the efficiency of the fertilizers, but also in reducing environmental problems that may arise from their use. However, because of economic pressure, and lack in knowledge of fertilizer management, nutrient-deficient fertilization and agroecosystem pollution by fertilization practice are still widespread in developing countries such as China. Therefore, it was necessary to compare the effects of different organic materials on sustainability of agricultural systems.

Several studies had already been conducted to assess the effects of integrated use of chemical fertilizer and organic materials on crop productivity and soil nutrient. However, very few studies have been reported in the north of China and little information has been published on crop yields, soil organic carbon and total nitrogen in relation to conjoint use of chemical N fertilizer and organic materials, especially in a heavy loamy fluvo-aquic soil. Therefore, we hypothesized that combine application of chemical N and organic materials under these conditions will improve the soil conditions and thereby increase nutrient release, nutrient uptake, and ultimately crop yield. Consequently, the objectives of this study were, to assess the effects of organic materials applied in combination with chemical N on wheat and maize productivity, soil organic carbon and total nitrogen at Tianjin, China.

2. Materials and methods

2.1. Experimental site

Field research was carried out at former experimental station (117°60′E, 39°10′N), Tianjin Institute of Agricultural Resource and Environment Sciences, Tianjin, northern China. Fluvo-aquic soil, developed from river alluvium, is widely spread in Tianjin and accounted for 72%. With a warm and semi-humid continental monsoon climate, the area receives an averaged annual precipitation of 607 mm, about 80% of which occurs from June to September. The averaged annual evaporation is 1736 mm. The annually averaged temperature is 11.6 °C. The active accumulated temperature, the sum of the daily temperature which is over 10 °C, is about 4200 °C.

2.2. Cropping practice

The experiment was cultivated with a winter wheat – summer maize rotation system. For each year, winter wheat seeds were sown in strips around October 1, and harvested in early June in the following year. Summer maize seeds were sown in holes within 1–2 days after winter wheat was harvested in June, and harvested in late September. Winter wheat and maize were planted at 20 cm and 50 cm row spacing and at a rate of 210 kg ha^{-1} and 69,000 seeds ha^{-1}, respectively, by hand sowing. In the crop growth stage, winter wheat was irrigated 3 times (80 mm before winter, 80 mm at tillering and 90 mm at the initial grain filling stages) and maize was no irrigated. Herbicides and pesticides were applied to control weeds and insect growth during the growth periods when it was needed. Crops were harvested manually by cutting straws close to the ground. Thus stubble left in the field was negligible, and roots were left in the soil. All above-ground biomass were removed from the field, and the maize roots were also removed when field were plowed. Grain and straws were weighted separately after air dried.

2.3. Experimental design

There were six treatments with four or three replicates (Table 1). Treatments included: (1) non-fertilization (CK); (2) chemical nitrogen (N); (3) chemical nitrogen, phosphorus and potassium combination (NPK); (4) chemical nitrogen and organic manure combination (NM); (5) chemical nitrogen and straw combination (NS); (6) chemical nitrogen and green manure combination (NGM). Each plot had an area of 16.7 m^2 and was isolated by cement baffle plates.

Chemical nitrogen, phosphorus and potassium fertilizers were urea, calcium superphosphate, and potassium chloride, respectively. For the relevant treatments, nitrogen, phosphorus and potassium were applied at rates of 495 kg N ha^{-1} $year^{-1}$, 142.5 kg P_2O_5 ha^{-1} $year^{-1}$, 71.3 kg K_2O ha^{-1} $year^{-1}$, respectively. The