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RESEARCH ARTICLE

Soil profile characteristics of high-productivity alluvial cambisols in the North China Plain

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Abstract

The North China Plain (NCP) is one of major breadbaskets in China. Crop growth and grain yield differ significantly with spatial variations of soil properties. This study aims to identify the key soil properties in relation to the grain yield for the winter wheat (*Triticum aestivum* L.)-maize (*Zea mays* L.) cropping system in a high-productivity farmland of the NCP. The field trials were conducted in three fields with different grain yield levels in Tai'an City, Shandong Province, China, during the 2009–2012 period. Consistent field management strategies were applied in the three fields. Fifty-one physical and chemical indicators of the soil profile as related to grain yield were evaluated. An approximate maximum of 17.8% annual average grain yield difference was observed in the fields during the period of 2009–2012. The soil indicators were classified into three clusters with specific functions using cluster analysis, and three key indicators were extracted from each cluster to characterize the different soil properties of three fields. The first cluster represented soil water retention capacity, and the key indicator was available soil water (ASW), which ranged from 153 to 187 mm in the 1.2 m profile and was correlated positively with grain yield. The second cluster represented soil water conductivity, as measured by saturated hydraulic conductivity (K_s). The higher yield field had a greater capacity to retain topsoil water for its lower K_s (1.9 cm d^{-1}) in the 30–70 cm soil layer as compared to the lower yield field. The third cluster represented nutrient storage and supply, as indicated by the ratio of nutrient content to silt+clay content of the top soil layer. The ratio of soil organic matter (OM), total nitrogen (TN), available P, exchangeable K^+ to silt+clay content in the 0–20 cm soil layer were 19.0 g kg^{-1}, 1.6 g kg^{-1}, 94.7 mg kg^{-1}, 174.3 mg kg^{-1} in the higher yield field, respectively, and correlated positively with the grain yield. By characterizing the differences in soil properties among fields with different yield levels, this study offers the scientific basis for increasing grain yield potential by improving the soil conditions in the NCP.

Keywords: soil quality assessment, cluster analysis, grain yield, key soil indicators

1. Introduction

The North China Plain (NCP) is one of the major breadbaskets in China, which covers an area of 1.445 million km^2, accounting for 15% of China's total land area. Its share of arable land and sowing area in terms of the country's total is 36 and 37%, respectively (CNBS 2012). Grain demand is likely to expand rapidly in the next decades in China due to population and income growth. However, grain yield has

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been observed to be highly variable, even between different fields with the same topography and with the same soil type in the NCP, and the mechanisms accounting for this variability are not yet clearly understood. It is necessary to decrease the variation in grain yield so that relative low-yield fields can reach the production level of the high-yield fields.

Sustainable food production is one of the most important service functions of soil and is a central principle of soil quality (Doran and Parkin 1994). A great number of soil quality assessments with respect to grain yield have been conducted. Because soil properties have often been correlated with each other, it is usually necessary to establish a minimum set of soil indicators to represent the soil quality. Some typical methods have been used to obtain this minimum set of soil indicators such as comparing soil properties (Larson and Pierce 1991) and principal component analysis (Sena *et al.* 2002; Yao *et al.* 2013).

Several studies have been conducted to investigate the relationship between soil properties and grain yield. Topography may be the most important factor that affects grain yield (in studies that assessed the topographic variables) (Kravchenko and Bullock 2000; Jaynes *et al.* 2003; Jiang and Thelen 2004). Govaerts *et al.* (2006) reported that a superior soil structure, including features such as a higher aggregate stability, a higher percentage of macro-aggregates and dry mean weight diameter, was positively correlated with crop yield for a long-term tillage, residue management and wheat and maize rotation trial. Blanco-Canqui *et al.* (2006) explored that soil temperature, water holding capacity and the stability of aggregates were the principal determinants of grain yield under different rates of stover mulch with long-term no-till management. Jagadamma *et al.* (2008) found that the soil's organic carbon stock, mean weight diameter, soil C:N ratio and exchangeable K^+ are related to grain yield in a continuous corn cropping system under different application rates of nitrogen. Lower microbial biomass carbon, total nitrogen (TN), available silicon, pH and available zinc were considered as the primary yield limiting factors in acid sulfate paddy soils of Guangdong Province, China (Liu *et al.* 2014b). Lower status of pH, organic matter (OM), TN were considered as the major constraints limiting crop productivity for low productivity albic soil in eastern China (Liu *et al.* 2014a). It has been reported that soil properties such as soil texture, OM and available water could all have a significant effect on corn yield (Quiroga *et al.* 2006).

In general, most of the studies on soil properties related to grain yield were focused on the topsoil. Larson and Pierce (1994) suggested that soil indicator properties should be evaluated over the entire soil root zone. In this study, experiment were conducted in three fields with different grain yield levels in the high yield area of NCP, both grain yield and soil profile structure properties were observed. A better understanding of the relationships between grain yield and soil profile structure and properties could lead to a more efficient implementation of strategies to improve crop productivity in the high yield area of the NCP. Thus, the objectives of this study were the following: 1) to identify the difference of soil profile structure and properties between different fields with different yield levels; 2) to select key indicators to assess the soil quality of food productivity in the NCP, using soil quality assessment methods; and 3) try to explain how the differences of soil profile structure and properties and yield gaps formed.

2. Results

2.1. Crop yield

Three fields with different grain yield levels in the high yield area of NCP were selected in this study, and named Field A, Field B and Field C, respectively, as the sequence of the grain yield level with Field A>Field B>Field C. The yield data are shown in Fig. 1. The average yields for winter wheat in Fields A, B and C were 7 856, 7 248, and 6 766 kg ha^{-1}, respectively. The yields in Fields A and B were, respectively, 14.7 and 7.2% higher than the yield in Field C from 2009 to 2012. The average yields for maize were 9 116, 8 465, and 7 576 kg ha^{-1} in Fields A, B and C, and Field A and B yields were, respectively, 20.3 and 11.7% higher than that of Field C from 2009 to 2012. The annual grain yields (including winter wheat and maize) in Fields A and B were 17.8 and 9% higher than the yield of Field C from 2009 to 2012.

The gaps of grain yield among Fileds A, B and C was varied yearly. The yield gap was more significant in the higher yield year such as year 2012. It was dependent of the climate and field management factors. This situation would be discussed in another paper.

2.2. Soil indicator differences

Descriptive statistics from univariate analysis of variance (ANOVA) of all 51 soil properties are summarized in Table 1 and Fig. 2. The soil texture of the three fields was silt loam except the layer at 45–100 cm in Field A (silt) and the layer at 100–120 cm in Field C (silty clay). Although the soil of the profile in Fields A, B and C had the same soil texture, there were small differences in soil particle composition between the three fields. The profile of Field A had the highest silt content with values ranging from 0.58 to 0.83 g g^{-1}, compared with Field B with values ranging from 0.51 to 0.65 g g^{-1} and Field C with values ranging from 0.46 to 0.60 g g^{-1}. The profile of Field B had the highest sand content which ranged from 0.17 to 0.39 g g^{-1}, compared with Field A values that ranged from 0.06 to 0.30 g g^{-1}, and Field C