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Long-term fertilization effects on processing quality of wheat grain in the North China Plain

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ABSTRACT

A 28-year fertilization experiment was carried out in the wheat–maize rotation region of North China. The effects of different sources of organic manure and inorganic fertilizers on grain processing quality were studied in winter wheat (*Triticum aestivum* L.). The results showed that wheat protein contents and processing quality were significantly improved with both organic manure and inorganic fertilizer treatments after long-term fertilization. Various effects of long-term fertilization on different quality parameters were found, with the descending order of dough stability time, dough development time, sedimentation value, wet gluten, dry gluten, and water absorption rate. Grain protein content, dry gluten content, wet gluten content, sedimentation value, and water absorption rate were also significantly improved. The durations of dough development and stabilization were significantly improved, and bread volume and baking score were increased. Grain protein content and processing quality were generally improved for the long-term and continuous fertilization. However, there was no significant difference in wheat quality between T_4 (high amount of organic manure) and T_5 (high amount of inorganic fertilizer). The effect of optimal amounts of inorganic fertilizer was greater than that of organic manure treatments at base-line application levels.

1. Introduction

The main purpose of agricultural production is to obtain high crop yields and good quality. Many studies revealed significant roles of fertilizer on crop production over the past several decades (Roberts, 2009). However, as yields increase, the quality of crop products often decline. Therefore, research has focused on improving crop yield while resolving the problems causing poor quality (Abad et al., 2004; Fang and Meng, 2013; Zhao et al., 2006).

Wheat is one of staple food crops in the world and its quality becomes more valued over time. Commercial value is determined by the processing quality of flour. Dough appearance, structure, smoothness, taste, elasticity and odor are highly related to the processing quality of wheat flour. With continuous improvement in human living standards domestic consumption of bakery products gradually increases. Thus, the comprehensive quality parameters of wheat flour, baking quality of dough, and processing technologies determining the quality of bakery products must also be improved. In addition to the influence of genetic factors and ecological conditions wheat quality is significantly influenced by cultivation measures, especially fertilization regimes (Zhao et al., 2007). Therefore, fertilization has become a basis for modern agricultural production. It is the major source of crop nutrients that take part in the metabolism of crops and is therefore closely associated with crop yield and quality (Gu et al., 2004). Many studies on the effects of fertilization on yield and quality have been reported, but most are based on short-term fertilization in winter wheat (Hussain et al., 2002; Jan et al., 2002; Li et al., 2014). Although the effects of long-term fertilization on crop quality were reported, the results were inconsistent (Cai and Hao, 2013; Gu et al., 2004; Luis et al., 2001; Mäder et al., 2007) (Fig. 1).

The Rothamsted Institute in England is a famous agricultural research center and it is also the oldest long-term experimental station in the world. Many important results on agricultural research from long-term experiments have been obtained, particularly in agronomy, soils, plant nutrition, ecology and environmental science (Fan et al., 2008; Harpole and Tilman, 2007; Jenkinson et al.,

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Table 1
Basic nutrients of the soil in 2013 (0–20 cm).

Treatment	Organic matter (g/kg)	Total N (g/kg)	Total P (g/kg)	Total K (g/kg)	Available P (mg/kg)	Available K (mg/kg)
T_0	8.829	0.750	0.73	18.9	5.2	73.4
T_1	18.984	1.605	1.35	19.8	186.1	162.2
T_2	9.758	0.945	1.10	19.7	31.2	89.5
T_3	14.971	1.313	1.14	19.8	103.6	97.7
T_4	28.108	2.474	1.77	18.8	378.9	337.1
T_5	11.893	1.046	1.80	19.7	64.8	166.3

1991; Poulton, 1996; Sands et al., 2009; Silvertown et al., 2006). These are considered "definitive experiments" and have made important contributions to modern agriculture. However, short-term experiments have never replicated these results (Jenkinson, 1991). Long-term experimental stations for fertilization were also established in France, Germany, and the USA, and have obtained large amounts of useful data (Berzsenyi et al., 2000; Cadavod et al., 1998; Jouany et al., 1996; Salinas-Garcia et al., 1997). Optimal supplies of inorganic fertilizer can achieve higher crop yields than use of organic manure and do not reduce soil productivity (Jenkinson, 1991; Poulton, 1996; Holbrook and Ridgman, 1989; Kunzova and Hejcman, 2009; Korsaeth, 2012). Organic carbon and organic nitrogen contents in soils were significantly improved by long-term use of organic manure, and soil physical conditions were also improved. Soil carbon content increased significantly with long-term fertilization using inorganic fertilizer. Because the fertilizer not only increased crop productivity, but also increased the amount of vegetative material remaining in the soil, the numbers of microbial organisms also increased (Angers et al., 1992; Berzsenyi et al., 2000; Delschen, 1999; Galantini and Rosell, 2006; Manna et al., 2007; Schjønning et al., 1994). Nitrate leaching is a major source of nitrogen loss and higher levels of nitrogen fertilization increase nitrogen leaching. It is clear that nitrogen losses are highest when nitrogen fertilizer exceeds optimal levels (Goulding et al., 2000).

Research on the effects of long-term fertilization started relatively late in China, but a large number of studies currently underway have reported effects on soil properties, and crop yields in complicated and varied ecological conditions (Yang, 2011; Ju et al., 2006; Wu et al., 2011; Wang et al., 2011; Xu et al., 2008; Dong et al., 2012; Chen et al., 2014; Cai and Qin, 2006). Long-term fertilization using either organic manure or inorganic fertilizer had significant effects in improving crop yields, soil properties, microbial compositions and soil enzymatic activities. It also improved the nutrient, organic carbon and organic nitrogen contents. The results have provided theoretical and practical information for sustainability of different fertilizer use and improvement of crop yields. Consequently, such experiments promote the use of optimum fertilization for agricultural production and environmental protection.

A few studies on long-term fertilization in China have been carried out for more than 25 years (Liu et al., 2005b; Yang et al., 2006b), but only limited reports are available on the effects of long-term application of organic and inorganic fertilizers involving equivalent nitrogen levels. A long-term fertilization experiment conducted by our group since 1986 has permitted evaluation of the effects on soil nutrient levels, crop yields and processing quality. The results provide a research base and some guidelines for wheat quality improvement, maintenance of high-quality agricultural production, and development of sustainable agriculture.

2. Materials and methods

2.1. Plant material

Winter wheat cultivar Jimai 22 was grown during the 2011–2012 and 2012–2013 cropping seasons. After harvest grain samples of 2.5 kg was collected from each plot for quality assays. Jimai 22 is a high yielding cultivar with medium gluten content. It was developed by the Crop Research Institute, Shandong Academy of Agricultural Sciences and released in 2006.

2.2. Field trials

Field trials were conducted at the Experimental Station of the Chinese Academy of Agricultural Sciences, Yucheng, Shandong (116°34′E, 36°50′N), a warm temperate area with a semi-humid monsoon climate, average annual temperature of 13.4 °C, a ≥0 °C accumulated temperature of 4951 °C, an annual sunshine of 2640 h, a frost-free period of 206 d, and an average annual precipitation of 570 mm (>70% precipitation during hot rainy season of June–September). The soil is a fluvo-aquic light loam (i.e., clay content of 21.4%, silt content of 65.6%, and sand content of 3.0%). Fluvo-aquic light loam covers >70% of the arable land of the North China Plain, where an extensive wheat–maize rotation system has been practiced for the past 28 years. There has been no mycotoxin contamination and any mycotoxin infection from maize to wheat during that period.

Randomized complete blocks of six fertilizer treatments were used in the study (Table 1). Each treatment was repeated four times, with a plot area of 28 m^2. The experiment has been implemented each year since 1986. The six fertilizer regimes were: T_0, no fertilizer or manure (CK); T_1, conventional dosage of organic manure (OM); T_2, half conventional dosage of organic manure and half of inorganic fertilizer (MF); T_3, conventional dosage of inorganic fertilizer (IF); T_4, high dosage of organic manure (HM), and T_5, high dosage of inorganic fertilizer (HF). Conventional dosages of nitrogen (N) and phosphorous (P) were applied at 450 kg/ha of N and 300 kg/ha of P_2O_5 since 1986; and potash (K) (K_2O 150 kg/ha) has been applied since 1992. The high-dosage of fertilizer supply was a double amount of the conventional dosage. The organic manure was cattle manure with primary nutrient contents of 1.0–1.8% N, 0.6–1.0% P_2O_5, and 1.2–2.0% K_2O. The N supply amount per year was based on total N conversion from any N fertilizer. Regardless of inorganic fertilizer or organic manure, a half amount was supplied on maize and the other half was applied on wheat annually. P, K fertilizer and organic manure were supplied to the soil as basal fertilizers before crop planting; 40% of N fertilizer was used as basal fertilization and 60% as topdressing fertilization. N, P, and K fertilizers were urea, superphosphate, and potassium sulfate, respectively.

2.3. Kernel and flour analyses

After harvesting, wheat kernels were stored for three months in a dry storeroom, and then used for quality tests.

(1) *N contents*: The dried wheat kernels were pulverized using a grinder and passed through an 80-mesh sieve. Grain N content was determined by sampling 0.2 g of grain and adding 6 ml of concentrated sulfuric acid and catalyst to complete digestion at 420 °C. A Full-Automatic Azotometer (Kjeltec 2300, FOSS Company) was used to determine N content.