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Organic amendments increase corn yield by enhancing soil resilience to climate change

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ABSTRACT

A 22-year field experiment was conducted in Gongzhuling, Jilin province, China to investigate corn yield response to fertilization practice. Compared to an unfertilized control (CK), all fertilization treatments, including inorganic nitrogen fertilizer only (N), balanced inorganic fertilizers (NPK), NPK plus corn straw (SNPK), and NPK plus farmyard manure (MNPK), resulted in significant increases in corn yield. However, only organic matter amendments sustained increasing yield trends, with annual rates of 0.137 and 0.194 t ha^{-1} for the SPNK and MNPK treatments, respectively ($P < 0.05$). During the 22 years, the daily mean, maximum and minimum temperatures increased by 0.50, 0.53, and 0.46 °C per decade, whereas precipitation displayed no significant change but showed large seasonal variation. According to a regression analysis, increased air temperature exerted positive effects on corn yields under the SNPK and the MNPK treatments. Under both treatments, soil organic carbon contents and soil nutrient availabilities increased significantly compared to their initial levels in 1990, whereas soil bulk density and total porosity changed slightly under the two treatments, which showed higher soil water storage than other treatments. In contrast, significant increases in soil bulk density and decreases in soil total porosity and soil nutrient availability were observed under the CK, N and NPK treatments. The contributions of soil fertility to corn yield were 28.4%, 37.9%, 38.4%, 39.0%, and 42.9% under CK, N, NPK, SNPK, and MNPK treatments, respectively, whereas climate changes accounted for 27.0%, 14.6%, 12.4%, 11.8%, and 10.8%. These results indicate that, in Northeast China, organic matter amendments can mitigate negative and exploit positive effects of climate change on crop production by enhancing soil quality.

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1. Introduction

Fertilizer application plays an important role in soil quality improvement and crop productivity enhancement [1,2]. Sound fertilization can directly increase crop yield by improving soil nutrient availability and can indirectly enhance crop yield sustainability by improving soil physical and chemical resilience to climate variation [3]. However, long-term application of inorganic fertilizers, especially unbalanced chemical fertilization, may result in soil acidification and nutrient depletion [4,5]. Consequently, poor fertilization practice may intensify climate change impacts on crop production, especially in high-latitude areas [6]. Organic matter amendments, for example green manuring and crop straw return, have been widely recommended as practices enhancing crop yield while increasing soil quality [1,7,8]. However, some field studies have not found significant effects of manure application and straw return on soil quality [9,10]. The main reasons for uncertainty about fertilization effects may be short experimental periods, given that fertilization effects on soil quality occur on a long-term time scale [10,11]. Thus, long-term field experiments can assist in guiding the assessment of fertilization effects and innovations in agronomic techniques [12–14]. Furthermore, high-latitude areas have experienced and will continue to face the largest changes in air temperature and precipitation [6], so that it is necessary and urgent to design fertilization practices for sustainable crop production in these areas.

Northeast China, a typical cool, high-latitude rainfed cropping region, is one of the most important grain cropping regions in China [15]. During the past decades, intensive cropping of monoculture corn and poor fertilization practices have resulted in severe soil quality degradation and corn yield decline in the region [16,17]. Although great efforts have been made in the assessment of fertilization effects on crop yield and soil quality in the region, few have focused on relationships between crop yields and climatic factors under different fertilizer regimes [16–19]. Fortunately, there is a novel experiment using different fertilization regimes (chemical fertilizer only, unbalanced fertilization, farmyard manure, and crop straw residue) in Gongzhuling, Jilin province, China. This experiment has been conducted with a continuous corn cropping system since 1989 and accordingly offers a chance to assess the long-term impacts of fertilization on corn yield and soil quality, and the consequent effects on soil resilience to climate change. We conducted an integrated study of historical variation in crop yield and climate factors and of changes in soil quality. Our objective was to identify the mechanism underlying fertilization effects on corn yield and soil resilience to air temperature and precipitation changes in a high-latitude area.

2. Materials and methods

2.1. Experimental site

A long-term fertilization experiment with monoculture corn under rainfed conditions has been conducted since 1990. The experiment site is located at the National Long-term Location Monitoring Base on Black Soil Fertility and Fertilizer Efficiency, Gongzhuling (43°30′23″N, 124°48′34″E, 220 m above sea level), Jilin province, China. This site is in the northern temperature zone with a continental monsoon climate, which is cold and arid in winter and hot and rainy in summer. Annual precipitation is 562 mm, with almost 80% occurring from June to September, and annual average temperature and sunshine duration are 5.6 °C and 2710 h, respectively. The soil is classified as Haplic Phaeozem in the FAO–Unesco system and Cumulic Hapludoll (Mollisol) in the U.S. classification system [20]. The soil properties prior to the experiment had the following characteristics: pH 7.6, soil organic carbon (SOC) 12.7 g kg^{-1}, total nitrogen (TN) 1.4 g kg^{-1}, total phosphorus (TP) 0.61 g kg^{-1}, total potassium (TK) 18.4 g kg^{-1}, available nitrogen (AN) 114.0 mg kg^{-1}, available phosphorus (AP) 11.8 mg kg^{-1}, and available potassium (AK) 158.3 mg kg^{-1}. Corn had been cultivated in the experimental field for at least 50 years before 1990.

2.2. Experimental design and management

A randomized complete block design was used with three replicates in this long-term experiment. The experiment included five treatments: (1) unfertilized control (CK), (2) inorganic nitrogen fertilizer only at a rate of 165 kg N ha^{-1} (N), (3) balanced inorganic fertilizers at 165 kg N ha^{-1}, 82.5 kg P_2O_5 ha^{-1}, and 82.5 kg K_2O ha^{-1} (NPK), (4) balanced inorganic fertilizers at 112 kg N ha^{-1}, 82.5 kg P_2O_5 ha^{-1}, and 82.5 K_2O kg ha^{-1} plus corn straw residue at a rate of 7.5×10^3 kg ha^{-1} (SNPK), and (5) balanced inorganic fertilizers at 50 kg N ha^{-1}, 82.5 kg P_2O_5 ha^{-1}, and 82.5 kg K_2O ha^{-1} plus farmyard manure at a rate of 2.3×10^4 kg ha^{-1} (MNPK). The N contents in corn straw and farmyard manure were 7.0 and 5.0 g kg^{-1}, respectively. For this reason, the total N application rates for N, NPK, SNPK, and MNPK treatments were kept at 165 kg ha^{-1}. The C:N ratios of maize straw residue and farmyard manure in dry matter were 66:1 and 26:1, respectively.

Each replicate plot was 130 m^2 in size. Four corn hybrids: Danyu 13, Jidan 222, Jidan 209, and Zhengdan 958, were used over the experimental period. Seeds were sown in early May at a density of 5.05×10^4 plants ha^{-1} with a spacing of 60 cm × 33 cm. Seeding was done manually on the ridge in 5-cm depth of soil after land preparation followed by basal fertilizer application. The sources of inorganic N, P, and K fertilizers were urea, triple superphosphate (TSP) and muriate of potash (MoP). One third of the urea and the full amounts of TSP and MoP were applied as a basal dose. The remaining two thirds of the urea was used for side dressing at the corn jointing (V6) stage and the chopped corn straw was also applied at that time in the SNPK plots each year. The farmyard manure was applied in autumn after corn harvesting in the MNPK plots every year. Tillage operations included (1) removing aboveground biomass manually, incorporating stubble and main roots into the soils by rototiller, and leveling the field after harvest in autumn; (2) cultivating again and building ridges to 20 cm height before planting in spring; and (3) rebuilding the ridge twice at approximately 20-day intervals after planting. The land