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EXPLORING THE ROLE OF ORGANIC FERTILIZERS IN ENHANCING CROP GROWTH AND SOIL HEALTH: BENEFITS, APPLICATIONS, AND SUSTAINABLE FARMING PRACTICES

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Abstract

Soil quality deterioration has become one of the fundamental processes leading to soil degradation. The successful enhancement of crop returns and soil condition depends heavily on improving organic fertilizer practices on farms. The complete assessment demands detailed understanding about how crop yield and soil quality reacts to different levels of organic fertilizer application. This research evaluated how organic fertilizer applications affect crop yields besides soil quality and animal foraging patterns across wheat (Triticum aestivum) and maize (Zea mays) rotation fields in fluvo-aquic soil conditions. We utilized six treatment groups consisting of unfertilized N control (UC) and conventional chemical fertilization (TF with 600 N kg ha-1 yr-1) as well as recommended chemical fertilization (RF with 400 N kg ha-1 yr-1) accompanied by no organic applications and three different organic fertilizer application rates at low (RFLO: 15.0 t ha-1 yr-1), medium (RFMO: 30.0 t ha-1 yr-1) and high (RFHO: 45.0 t ha-1 yr-1). Research findings demonstrated that wheat yields increased by 26.4% to 44.6% and corn yield rose by 12.5% to 40.8% when organic fertilizer was used instead of RF plot application methods. Soil organic carbon content expanded to 110.6% at its best compared to the UC plot while reaching 74.0% above values from the chemical fertilizer treatment (TF and RF). Moreover, total nitrogen in the soil grew to 59.2% beyond UC plot values yet achieved 39.2% above chemical fertilizer treatment (TF and RF). Cheap combination use of inorganic and organic fertilizers throughout multiple years greatly enhanced soil enzyme activities of sucrose by 30.1%-51.9%, urease by 28.4%-38.3% and β-1,4-glucosidase by 34.6%-122.4%. The activities of nitrite reductase along with polyphenol oxidase and catalase showed significant reductions ranging from 27.3% to 49.9%, 8.5% to 26.3% and 23.3% to 34.3% thus showing lower activities than inorganic nitrogen fertilizer alone. The application of organic fertilizer led to increased feeding activity of soil animals up to 35.2% to 42.5%, whereas excessive inorganic nitrogen fertilizer caused a decrease in soil animal activity.

Keywords: “Soil Quality”, “Organic Fertilizer”, “Soil Health”, “Fauna Feeding Activity”.

INTRODUCTION

The definition of organic fertilizers includes materials which contain particular chemical properties and possess rich nutritional value suitable for plant development (Moller and Schultheiss, 2015; Rajan and Anandhan, 2015). Microbiological high temperature fermentation of plant matter together with animal manure and human trash (such as garden waste and straw) results in organic fertilizer production (Chew et al., 2019). Through organic fertilization plants gain access to various nutritional elements and plants also receive beneficial microbial benefits and improved soil structure. Organic fertilizers represent a widespread choice for agricultural systems because they produce beneficial consequences for crop yields and soil structure (Brar et al., 2015; Maltas et al., 2018).

Soil quality and agricultural yields benefit from organic fertilization while organic and inorganic fertilizer combination represents a sustainable approach in maintaining agricultural ecosystems (Gentile et al., 2008). Soil fertility together with structure benefits from organic fertilizer application while simultaneously increasing the content of soil organic carbon and nutrients (Diacono and Montemurro, 2010; Liu et al., 2010). Studies show that applying organic fertilizers to the soil surface leads to substantial improvement of microbial diversity and nutrition feeding capacity for microorganisms (Chang et al., 2007; Diacono and Montemurro, 2010). Organic fertilizers applied to acidic soils modify both the CEC and the soil moisture content while creating diverse changes to the population structures of soil animals (Zelles et al., 1992; Abbott and Murphy, 2007). During aerobic fermentation of organic compost nutrient stability persists to help organic fertilizers support earthworm population establishment and stabilization (Bertrand et al., 2015). Prolonged chemical fertilizer usage under diminished pH conditions and environmental pressures ends in soil organic matter reductions and shifts the activity of soil organisms while changing soil microbial communities and decreasing soil invertebrate diversity (Fauci and Dick, 1994; Davies et al., 2022). A brief usage of urea inorganic fertilizer resulted in elevated eating behavior among soil creatures as observed two days post-application according to Wahyuningsih et al. (2019). Soil organic matter composed of empty fruit bunches demonstrates high significance to soil ecosystem function through increased soil animal feeding rate according to Tao et al. (2016).

Regular fertilizer treatments during wheat-maize rotation impact how soil behaves and works biologically (Welbaum et al. 2004; Kaiser et al. 2007; Thomas et al. 2007; Miao et al. 2011; Chen et al. 2015b; Miller et al. 2020; Miner et al. 2020). Soil response to fertilizer depends mainly on local climate factors, soil composition and nutrient type (Lupwayi et al. 2011; Yu et al. 2015). Research by Qaswar et al. (2020) and Gao et al. (2015) demonstrated that mixing organic and inorganic fertilizers can successfully substitute chemical fertilizer usage for wheat and corn production. Scientific studies indicate that wheat and corn production rises when farmers replace chemical fertilizers with organic fertilizers in ratios between 20% and 30%. (Research findings from Zhang et al. 2016b). Organic fertilizer applications span widely because compost amounts for use range from 10.0 to 35.0 tons per hectare (Hannet et al., 2021) and compost dry matter falls between 8.8 and 14.0 tons per hectare. Total liquid fertilizer use reaches 68.3 tons per hectare (Feng et al., 2013). Different levels of wheat-maize rotation systems need organic fertilizer applications at specific rates to achieve optimal fertilizer management. Soil total carbon, organic carbon, nutrient levels, enzymatic actions and animal activities require prolonged testing of combined inorganic chemical fertilizer and different organic fertilizer methods.

We want to analyze the outcomes of combining both inorganic and organic fertilizers at varying amounts on farm production and soil health for fluvo-aquic soil regions of northern China.

RESEARCH METHODS

Researchers have implemented testing methods since 2015 at Tianjin Experimental Farm located where Tianjin meets Beijing (39.46 N, 117.7 E). The area experiences a typical rainy season climate according to Zhou et al. (2021) during 2015-2020 with 12.9 °C mean temperature and 586 mm average annual rainfall. Seasonal precipitation behaves unpredictably in this area except during July to September when most rain falls. The soil of this farming area consists of fluvo-aquic soil with measurements of TN at 0.82 g kg−1, OM at 12.6 g kg−1, TP at 0.80 g kg−1, and pH at 8.1 g kg−1 throughout the top 20 cm of the soil.

Experimental design

The research project took place during wheat and maize seasons from October 2019 through October 2020 under a farming rotation system with steady crop types and cultivation methods. Before the study started all wheat and maize straw got deposited in the land to proceed with traditional practices. Research teams set up six distinct trials in 2015 using 288 m2 plots with three separate test areas. The experimental treatment program included nonfertilized UC control as well as TF with 600 N kg per hectare per year plus RF with 400 N kg per hectare per year which received organic fertilizer (O) in zero amount O, a low rate of 15.0 (RFLO), a middle rate of 30.0 (RFMO), and a highest rate of 45.0 t per hectare yearly (RFHO). The experts used soil analysis results and crop yield targets to design proper fertilization methods for specific irrigation scenarios (Cai & Qin, 2006; Yang et al., 2015). Based on Zhou et al. (2021), farmers typically use three fertilizers which include 46.4% N urea, 18% N and 20.09% P diammonium phosphate and 49.6% K potassium chloride. For this study the researchers applied further nitrogen fertilizer limits as it became the main controlling element of effect. They put 200 kg of P and K nutrients as base fertilizers per hectare yearly. The manufacturing plant Xixing Fertilizer Technology Co. Ltd produced the organic fertilizer by heat treating garden waste and agricultural straw. According to Zhou et al. (2021), the organic fertilizer contained 86.6±4.9 mg of MO and 6.18±0.10 mg of TN along with 3.39±0.07 mg of TP per kilogram. The project required 6 different investigations by applying half the regular yearly amount of each fertilizer - nitrogen, phosphorus, and potassium - for wheat and corn during both seasons. Table 1 presents the specific amounts of fertilizer for all treatment groups. A 66% share of all inorganic nitrogen fertilizer and phosphate and potassium chloride fertilizer goes into base fertilizer before wheat planting while a 33% portion of nitrogen serves as wheat and corn top dressing fertilizer. Before planting wheat the agricultural team applies organic manure and merges it throughout the top layer of soil through rotary tillage equipment.

TABLE 1. Application rates of fertilizers under different fertilization treatments

Treatment	2019 October Organic (t·ha⁻¹)	2019 October N (kg·ha⁻¹)	2019 October P (kg·ha⁻¹)	2019 October K (kg·ha⁻¹)	2020 April N (kg·ha⁻¹)	2020 June N (kg·ha⁻¹)	2020 June P (kg·ha⁻¹)	2020 June K (kg·ha⁻¹)	2020 August N (kg·ha⁻¹)
UC	0	0	50	50	0	50	50	50	0
RF	0	120	50	50	80	120	50	50	80
RFLO	15	120	50	50	80	120	50	50	80
RFMO	30	120	50	50	80	120	50	50	80
RFHO	45	120	50	50	80	120	50	50	80
TF	0	180	50	50	120	180	50	50	120

Field sampling and processing

In accordance with the quadrant approach researchers selected three 1 sq meter sample points per treatment to determine winter wheat yields (Lu et al. 2018). At maturity the summer maize harvest a random subset of 20 plants from each center row was selected on a total of 20 plot sites with plant yield collected by hand (following Lu et al., 2018). Our machinery harvested all remaining crops.

On October 24, 2019, and October 22, 2020, chemical properties were recorded from twenty soil samples (taking five cores of five cm diameter each) per treatment at a depth of 20 cm just before harvest. The study checked chemical soil traits including TC, TOC, TN, AN, TP, AP, TK, Ca, Mg, K, Na, CEC, EC, and pH plus TC and TN contents. Our team measured the soil pH and EC readings after the samples had soaked in water for half an hour using glass electrodes and diluted with a 1:2.5 solution based on Zhang et al. (2016b). According to the Dumas dry combustion method on the PerkinElmer 2400 Series II CHNS/O Analyser in Shelton, CT USA, this instrument calculated both total nitrogen (TC) and nitrogen (TN) for our dry soil samples. The soil received K2Cr2O7-H2SO4 digestion to measure its total organic carbon content. Measuring the soil nitrogen amount relied on alkaline hydrolysis diffusion procedures. A mixed acidic solution of H2SO4 and HClO4 extracted soil to measure total phosphorus (TP) content through molybdenum blue colorimetry. The available phosphorus level in soil samples was determined using colorimetry after extraction through sodium bicarbonate solution at pH 8.5. The sample needed flame photometry alongside the H2SO4-H2O2 digestion to estimate TK levels in soil as recommended by Bao in 2008 and Sunnemann et al. in 2021. The soil sample underwent extraction with 1.0 mol L−1 ammonium acetate before ICP-OES (Agilent, 710 series) analyzed exchangeable Na, Mg, K, and Ca content of the samples (Setia et al., 2013). The cation exchange capacity was determined by colorimetry with hexaamminecobalt(III) chloride extraction following ISO standards (2018). For soil enzyme testing we first filtered dry soil through a 2mm plant. A soil enzyme kit from Suzhou Kemin Biotechnology Co., Ltd. (Suzhou) was used to spectrophotometrically measure the activities of six soil enzymes involved in the carbon and nitrogen cycle: soil catalase, soil nitrite reductase, soil sucrase, soil urease, soil polyphenol oxidase, and soil β-1,4-glucosidase (Liu et al., 2018 ; Gao et al., 2019).

Soil fauna feeding activity

Törne set up the bait sheet test in 1990 to examine soil conditions and determine what animals consume food. Römbke et al. (2006) explain that the bait sheet contains a multiple-holed 1.0 mm thick PVC board which measures 120 mm wide by 6.0 mm thick by 1.0 mm thick. Each opening measures 1.5 mm in diameter internally and 2.0 mm for the outside with space separating 85 mm between open tubes. The standard bait sheet content contains 27% of small bran flakes (under 500mm), 70% cellulose particles and 3% activated carbon reports Eisenhauer et al. (2014). The bait strip went into soil vertically with its top opening positioned below the surface while normal meal filled the biconical holes. The soil faunal activity assessment took place from September 15 to September 30 in 2019 followed by September 9 to September 24 in 2020. Five experimental areas were created for each treatment with five bait strips included in each plot. Based on this design we assessed 150 soil faunal eating activities spread across 15 to 20 cm. Each test site received its planned number of bait strips and researchers checked them by assigning scores 0 for full, 0.5 for partially used and 1 for empty after two weeks (from Vorobeichik and Bergman, 2021). During this research we utilized a HOBO U23-003 sensor made by Onset Computer Corporation to measure soil temperature.

Statistical analysis

The Origin Pro 2022 program combined with SAS 9.2 Package ran all statistical calculations. The study used Spearman's correlation to analyze how soil chemical properties relate to one another while Duncan's multiple range test performed ANOVA and showed differences in treatment results. A reliable analysis showed both positive and negative results at the 5% level.

RESULTS

Crop production

The chart shows different ways to manage fertilization that impacts both maize and wheat production. The chosen fertilization techniques affected both wheat and maize yields but failed to change output numbers year after year. For both maize and wheat in these years farmers recorded production results between 5.40 and 9.77 tons per hectare and 0.68 to 6.35 tons per hectare. Neither standard fertilizer treatments nor six different organic fertilizers affected wheat output during 2018-2019. But in 2019 maize output grew by 34.7% when farmers applied RFHO fertilizer and 36.6% when using TF treatment methods. From 2019-2020 wheat yields increased by 36.4% with medium organic fertiliser and TF compared to 50.6% and 41.5% more with high organic fertiliser and TF respectively. The different organic fertilizers including RFMO, RFHO, and TF brought similar wheat outputs in the experiments. The TF and RFHO maize plots saw maize yields increase by 42.8% and 47.2% respectively in both 2018-2019 and 2019-2020 tests ($p < 0.05$ compared to RF)

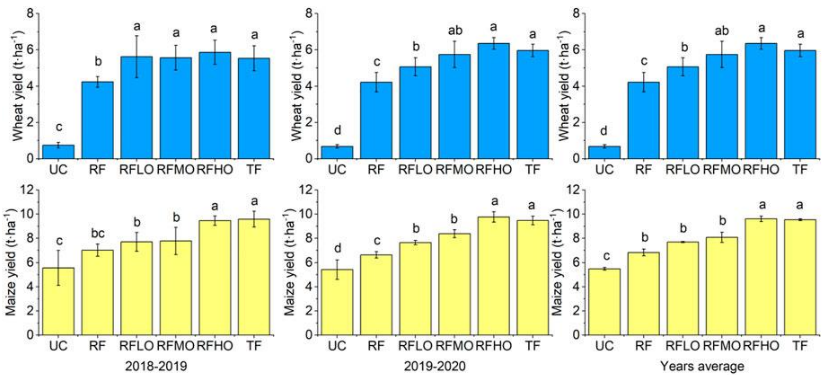

FIGURE 1. Wheat and maize yield (2018–2019, 2019–2020)

DISCUSSION

Research data proved that organic fertilization produced larger wheat outputs than suggested fertilizers at conventional levels ($p<0.05$). Wheat and maize yields from the RFMO and RFLO organic fertilizer plots remained similar to RF-treated plots as shown by the statistical zero difference ($p>0.05$). Both RFMO and RFLO had lower production than the RFHO and TF conventionally fertilized plots. Yang and associates (2014) revealed that combining organic and inorganic nitrogen fertilizers improved both crop yields and nutrient retention in wheat-corn rotations. Organic fertilizers show higher effectiveness because all chemical fertilizers are deposited for corn planting while all organic fertilizers enter the soil during wheat growing season to enrich soil organic matter and enhance water penetration and airflow (Choudhary et al., 2018; Li et al., 2020). Further research shows organic fertilization helps delay plant leaf and root breakdown which then increases photosynthetic time and grain filling time to boost production numbers as reported by Welbaum et al. (2004) and Li et al. (2012). Research proves that farmers achieve highest possible crop yields when they use suitable mixed approaches to manage water and fertilizer as recommended by Zhang et al. (2021). The limited availability of nitrogen for plants because of flooding potentially lowered wheat yields when using recommended fertilizer applications in our experiment according to Li and Rao (2003) and Shang et al. (2015). Increased yields result when using conventional fertilizer methods because soil fertilization with inorganic nitrogen fertilizers shows strong crop growth results. Organic fertilizers added to soil demonstrate significant effects on yield levels and TOC amounts (Table 2). Additional testing of different organic and inorganic fertilizer mixes is needed to examine their impact on soil fertility when grown with maize and wheat.

CONCLUSIONS

Our team analyzed the outcomes of agricultural use between both organic and inorganic fertilizers on crops and soil life activity alongside superfood availability. Using inorganic fertilizer alongside organic materials over many years helped us improve soil nutrient levels and carbon content plus animal grazing while raising enzyme activities of sucrose urease and beta-1,4-glucosidase in soil. Applying various amounts of organic fertilizer did not boost soil enzyme activities yet it helped boost soil organic carbon 27.9%–74.0%, total nitrogen by 24.6%–39.2% and animal activities rose by 35.2%–42.5%. A recommended rate of organic fertilizer at 30 tons per hectare per year will benefit soil conditions in our study site. Our findings show how organic fertilizers should be used in wheat-maize farming systems.

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