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Source: Air, Soil and Water Research, 5(1)

Published By: SAGE Publishing

URL: https://doi.org/10.1177/ASWR.S8599

Air, Soil and Water Research

ORIGINAL RESEARCH

The Relationship Between Winter Temperature Rise and Soil Fertility Properties

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Abstract: The effects of winter temperature rises on soil microbial activity, nutrient and salinity in Ningxia Plain were studied in a field experiment using an infrared radiator to raise temperatures. Winter temperature rises led to increases in soil organic matter, available phosphorus, soil pH and total salt content, but decreased the available nitrogen in soil and the activities of soil catalase, urease and phosphatase. With a winter temperature of 0.5 °C–2.0 °C, the activities of soil catalase, urease and phosphatase were respectively decreased by 0.08–1.20 mL g^{-1}, 0.004–0.019 mg g^{-1}, and 0.10–0.25 mg kg^{-1}; soil organic matter was increased by 0.01–0.62 g kg^{-1}, available nitrogen decreased by 2.45–4.66 g kg^{-1}, available phosphorus increased by 2.92–5.74 g kg^{-1}; soil pH increased by 0.42–0.67, and total salt increased by 0.39–0.50 g kg^{-1}. Winter temperature rises decreased soil microbial activity, accelerated the decomposition of soil nutrients, and intensified soil salinization.

Keywords: climatic warming, soil nutrients, soil salinization, microbial activity, Ningxia Plain

Air, Soil and Water Research 2012:5 15–22

doi: 10.4137/ASWR.S8599

This article is available from http://www.la-press.com.

Introduction

The adverse effect of climatic warming on the global soil environment has emerged and aroused extensive attention in the world.[1] Climatic warming accelerates the mineralization rate of soil organic carbon, and causes a series of physical, chemical and biological soil changes[2], is conducive to accelerated microbial decomposition of soil organic matter, hastens the circulation of plant and soil nutrients, and leads to soil fertility decline, and quality degeneration of cultivated land.[3] Climatic warming in northern China has intensified soil moisture evaporation, driven soil salts upward, and increased soil salinity and salinization.[4] The annual average temperature in Ningxia Plain has generally risen (with some fluctuation) for 40 years, and the degree of temperature rise is higher than the average value for China, and winter temperature rise is more significant.[5] The increase of soil salinization caused by a winter temperature rise directly affects the growth of winter crops and sprouting of spring crops[6] Thus, studies of the effect of winter temperature rise on soil nutrients and salinity are important. In the present study, the effects of winter temperature rise on soil nutrients and salinity were studied in a field experiment using an infrared radiator to raise temperatures. This provides a reference basis for evaluating the effect of climatic warming on soil quality, and restoring and improving soil quality.

Materials and Methods

General situation of the test base

According to the survey data of soil salinization in 2009, the area of salinized soil in Ningxia Plain was 209,600 ha^{-1}, accounting for 49.7% of the total area of the cultivated land. The study was conducted at the Xidatan Experimental Station of the Ningxia Plain, which is in the arid region of the middle temperate zone, and has a continental climate. Its climate is characterized by a lack of rain, abundant sunshine, strong evaporation, and much wind and sand; annual average temperature of 9.1 °C and annual average rainfall of 185 mm. The rainfall is mainly concentrated in July–September, accounting for 70%–80% of the annual precipitation, and its annual average evaporation is 1825 mm.[7]

Experimental design

In the experiment, the mean daily temperature was increased using an infrared radiator for the designed temperature rise of 0, 0.5, 1.0, 1.5 and 2.0 °C. The experimental field was divided into 15 individual plots, which was replicated in three complete randomized blocks. The individual plot was 2 m wide and 4 m long, and plot spacing was 3.0 m. Each plot was equipped with two tube infrared radiators, mounted 1.2 m above the ground, and their power determined according to the desired temperature rise and local climatic conditions as 250, 500, 750 and 1000 W for increases of 0.5, 1.0, 1.5 and 2.0 °C, respectively. During the period 1 December 2009 to 28 February 2010, an increase of mean daily temperature was maintained day and night, with the average daily temperature of −5.7 °C in winter. The test plot was protected against the entry of surrounding people and animals by a fence.

Temperature monitoring

During the determined period of winter temperature rise, an increase of mean daily temperature was monitored continuously through computer-Temperature Control System. An automatic temperature detector was installed in each experimental plot: the temperature at 10, 20 and 30 cm above the ground within the plot was monitored using a sensor, recorded once every 20 min, and automatically outputted and stored in the Computer. Temperature error in each experimental plot was controlled within ±0.1 °C. Soil samples were respectively taken on 1 December 2009 and 28 February 2010 to measure the activities of soil catalase, urease and phosphatase, soil organic matter, available nitrogen (N), available phosphorus (P), available potassium (K), soil pH and total salt. In the experimental area, the soil organic matter was 7.15 g kg^{-1}, total N was 0.15 g kg^{-1}, total P was 0.15 g kg^{-1}, available N was 5.6 mg kg^{-1}, available P was 6.6 mg kg^{-1}, available K was 365.1 mg kg^{-1}, soil pH was 9.2, and total salt was 2.8 g kg^{-1}.

Determination method

The Catalase activity was determined using KMnO4 titration method, phosphatase activity using disodium phenyl phosphate colorimetry, and urease activity using diffusion layer titration. Soil organic matter and available N, P and K were measured using a STAL-2 portable soil NPK detector, which was made in Nanjing High-speed Analytical Instrument Factory, China. Soil pH and total salt were measured as follows: collected soil samples were air-dried indoors, and passed through a 1-mm sieve, and extracted with soil:water at 1:5 for all soil samples. CO_3^{2+} and HCO_3^- were measured using the double indicator titration method, CL– using $AgNO_3$ titration, SO_4^{2-} using EDTA back titration, Ca^{2+} and Mg^{2+} using EDTA titration, and K+ and Na+ using subtraction method. The soil total salt was calculated based on the above measured indexes, and soil pH was measured using a Micro Bench pH meter, which was made in Shanghai Nano Instrument Co., Ltd., China.

Results and Analysis

Soil microbial activity

The winter temperature rise led to decreased activities of soil catalase, urease and phosphatase; the higher the temperature, the greater the downward trend (Fig. 1). The winter temperature rise of 0.5 °C–2.5 °C

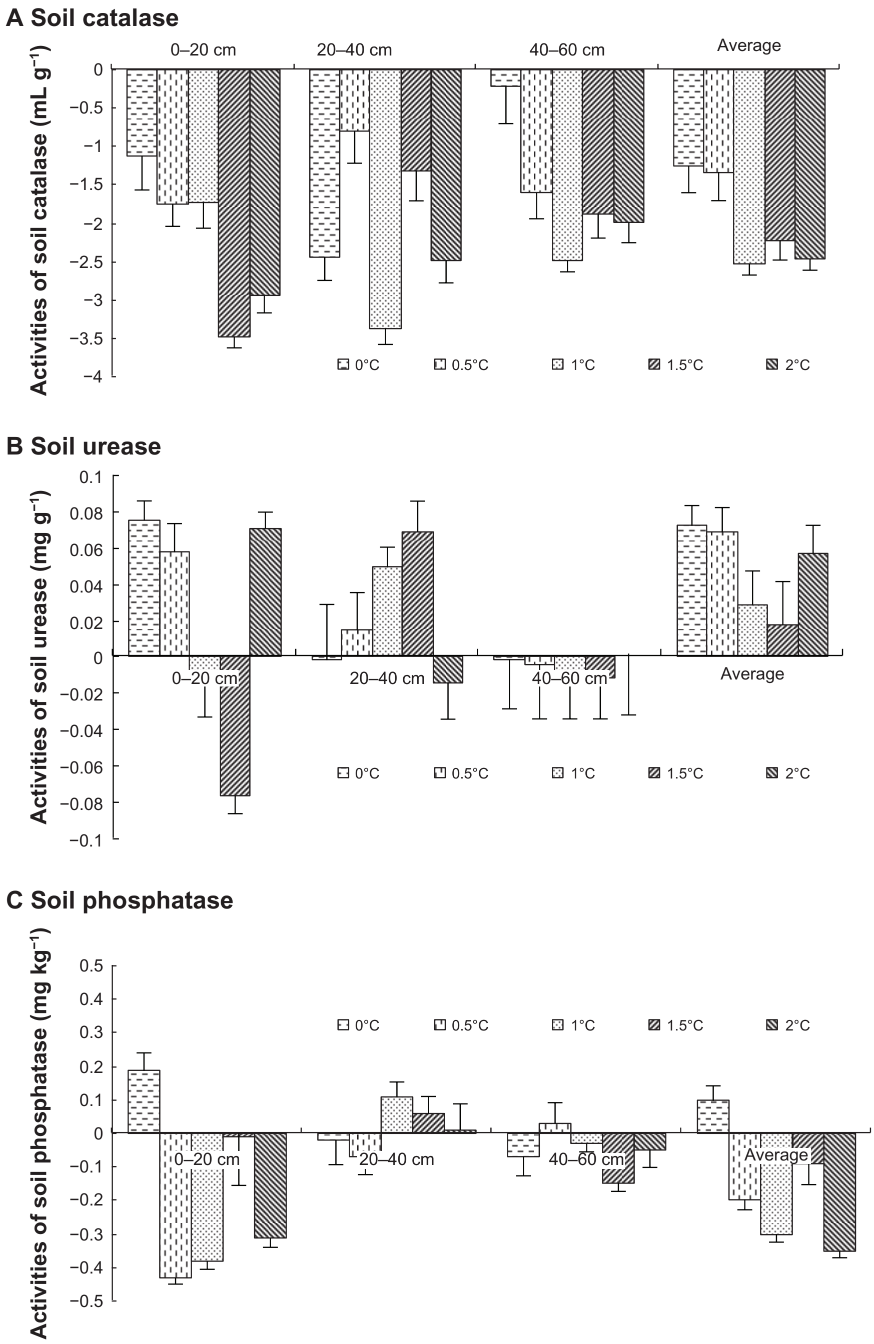

Figure 1. Relationship between winter temperature rise and the activities of soil catalase, urease and phosphatase.

decreased activities of soil catalase, urease and phosphatase by 0.08–1.20 mL g^{-1}, 0.004–0.019 mg g^{-1}, 0.10–0.25 mg kg^{-1}, respectively, compared with no winter temperature rise.

Soil nutrients

The increased winter temperatures led to significantly increased soil organic matter; the higher the temperature rise, the greater the increase in organic matter. The winter temperature rise of 0.5 °C–2.5 °C led to increased organic matter by 0.01–0.62 g kg^{-1} compared with no winter temperature rise (Fig. 2). This may be due to the increased winter temperature was conducive to the decomposition of plant broken branches and fallen leaves in soil, and improved soil organic matter.

The increased winter temperatures led to significantly decreased available N in soil; temperature rise of 0.5 °C–2.5 °C led decreases of 2.45–4.66 g kg^{-1} in available N compared to no temperature rise (Fig. 3A). The increased winter temperatures led to significantly increased available P in soil; increases of 0.5 °C–2.5 °C led to increased available P by 2.92–5.74 g kg^{-1} compared to with no temperature rise (Fig. 3B). The increased winter temperatures had no appreciable effect on the available K in soil (Fig. 3C).

Soil pH and total salt

The increased winter temperatures led to significantly increased soil pH; with the greater the temperature increase, the greater the increase in pH. Winter temperature increases of 0.5 °C–2.0 °C increased soil pH by 0.42–0.67 compared to no temperature increase (Fig. 4). The increased winter temperatures significantly increased soil total salt; the greater the temperature rise, the greater the increase in soil total salt. Temperature increases of 0.5 °C–2.0 °C increased soil total salt by 0.39–0.50 g kg^{-1} compared to no temperature increase (Fig. 5).

Discussion

Soil enzyme activity, an important index to evaluate soil quality, can reflect soil fertility. Catalase is related to the conversion of soil organic carbon, and soil urease activity is related to the total N content in soil[8] Catalase can promote the hydrolysis of hydrogen peroxide, and its activity is related not only to the amount and activity of microorganisms, but also the soil organic matter content, and to an extent reflects the intensity of soil microbiological processes.[9] Hofmann suggested using soil enzyme activity as an index of soil biological activity and productivity. Soil urease and phosphatase activities can be taken as the indexes of soil fertility, and the enzyme activity is influenced by the soil chemical properties and other enzyme activities.[10] Urease catalyzes urea to hydrolyze to ammonia, and promotes the hydrolysis of peptide bonds in organic matter. Its activity shows a positive correlation with soil microbial biomass, organic matter content, total N content and available N content, and can be used to characterize the conversion of organic N in soil.[11] Phosphatase can promote the hydrolysis of organic P compounds in soil, and its activity depends largely on the soil humus content, available P content and the microbial biomass able to decompose organic P compounds; and is an index

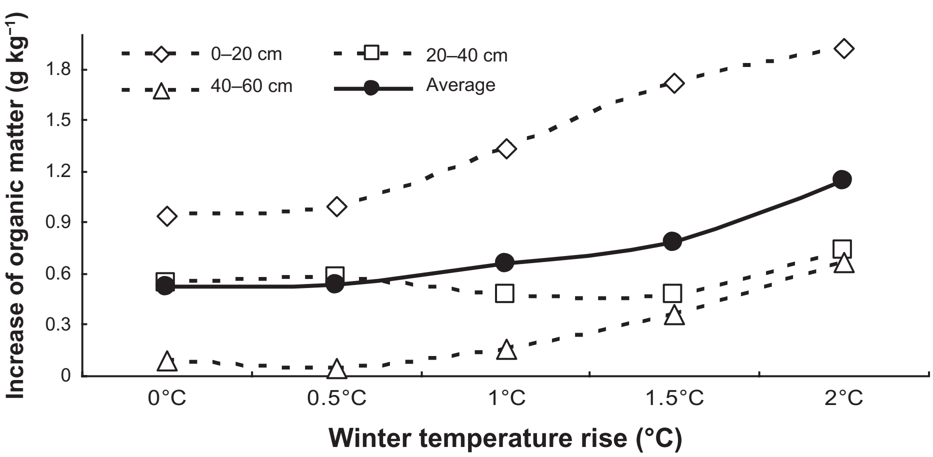

Figure 2. Relationship between winter temperature increases and soil organic matter.

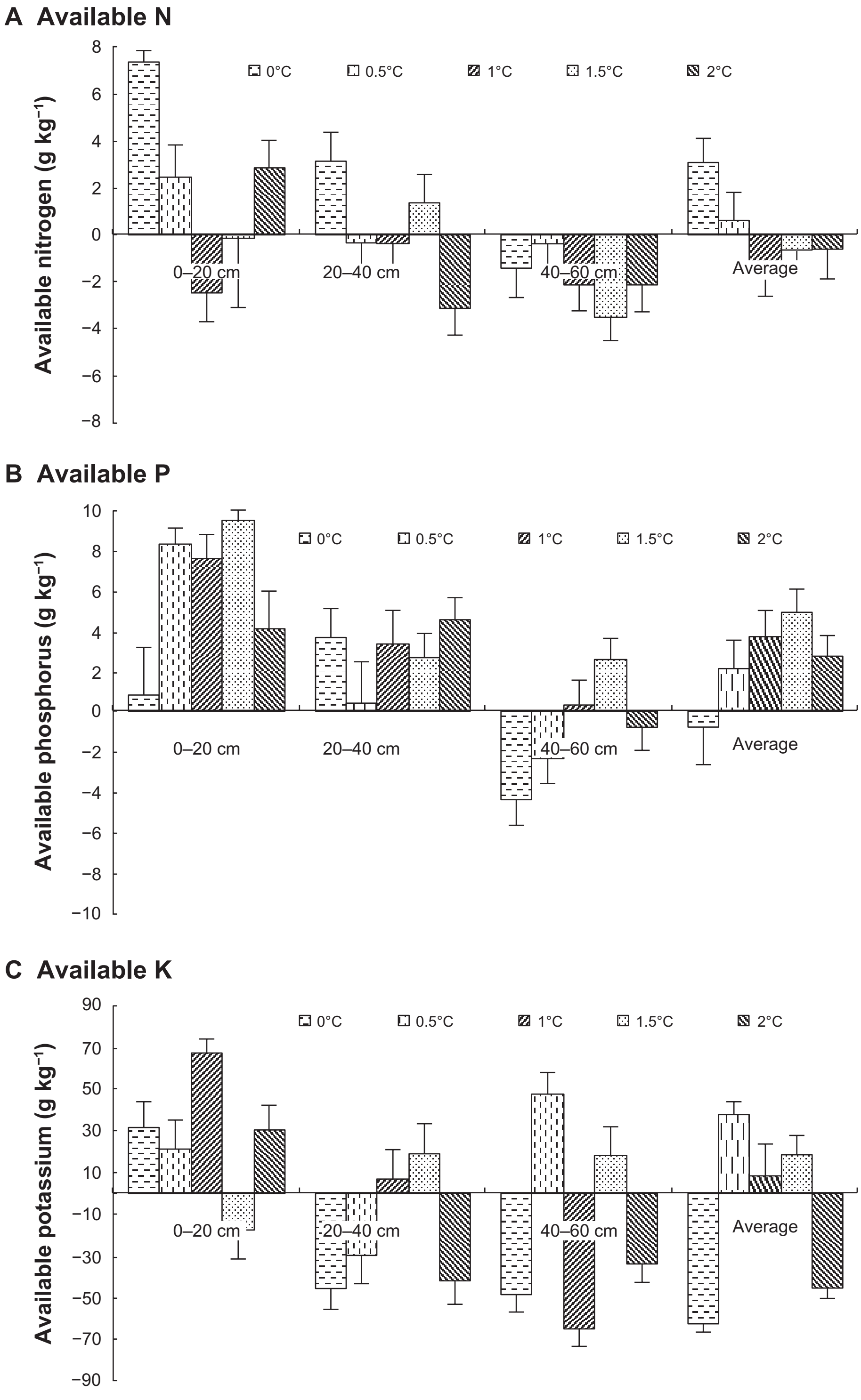

Figure 3. Relationship between winter temperature rise and changes in available N, P and K in soil.

to evaluate the biological conversion direction and intensity for soil P.

In general, temperature increases indirectly affect soil enzyme activities through affecting the soil microbial community structure, microbial diversity, microbial biomass, microbial respiration, mineralization rate of soil organic matter, soil hydrothermal conditions, decomposition of organic matter and other factors.[12] If the temperature is excessively high, soil enzymes will denature and lose their activity; if temperature is excessively low, enzyme activities will decline. Soil temperature has a significant effect on soil enzyme activities,

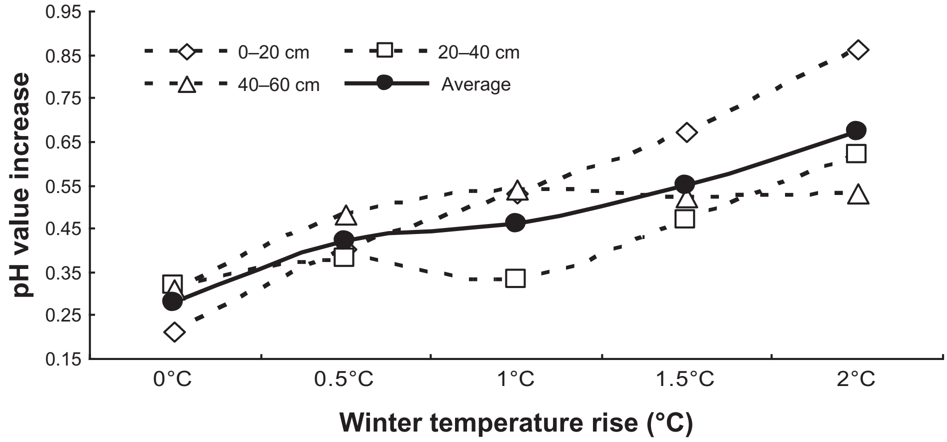

Figure 4. Relationship between winter temperature increases and soil pH.

and soil phosphatase activity can increase by 20% if the soil temperature increases by 6.2 °C.[13] However, the exact effect of winter temperature increases on the activities of soil catalase, urease and phosphatase is unknown. The present study showed that increased winter temperatures led to decreased activities of soil catalase, urease and phosphatase; with temperature increases of 0.5 °C–2.0 °C, these activities were decreased by 0.08–1.20.20 mL g^{-1}, 0.004–0.019 mg g^{-1} and 0.10–0.25 mg kg^{-1}, respectively.

Temperature is one of the main driving factors accelerating the mineralization of soil organic carbon. Climatic warming has accelerated the mineralization rate of soil organic carbon, resulting in accelerated microbial decomposition of soil organic matter, thereby speeding up the changes in soil nutrients. Studies have shown that temperature increases promote the decomposition of soil organic matter, resulting in decreased soil fertility.[14] Studies concerning the content, magnetic susceptibility and particle size of Pb, Cu, Zn, Cd and Mn in loess in Qishan showed that in the process of differentiating loess parent materials to soil, the differentiation degree and development degree of vegetation depended on local average rainfall and temperature.[15] In the present study, the winter temperature increase led to increased soil organic matter and available P. Winter temperature rise of 0.5 °C–2.0 °C led to increased soil organic matter by 0.01–0.62 g kg^{-1} and available P by 2.92–5.74 g kg^{-1}; and decreased available N by 2.45–4.66 g kg^{-1}.

Crops in saline soil need to consume more energy to absorb water from soil or make biochemical adjustments within plant cells compared to non-saline soils, thus in general too much salt in the root zone will reduce crop growth rate and crop yield.[16] Salinity in soil reduces the soil osmotic potential, thereby reducing the difference in water potential

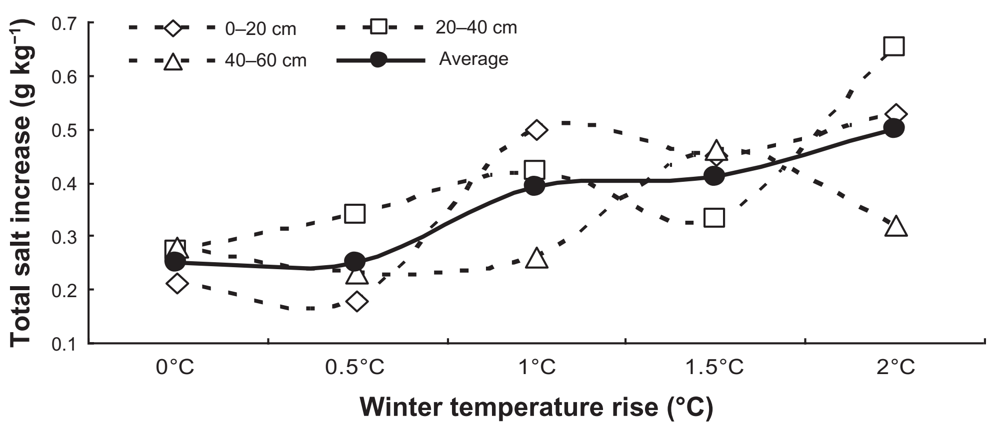

Figure 5. Relationship between winter temperature rise and soil total salt.

between internal and external to roots and so reducing soil water availability. When the concentration or activity of some ions in soil is too high, this can lead to disproportionality or deficiency of crop nutrients.[17] Climatic warming has accelerated the evaporation of soil moisture, driven soil salts upward, and caused increased soil salinity and salinization. Studies of soil salinity position in a recent 35-year period showed that when the annual average temperature in Ningxia Yellow River irrigation area increased, the total salt content of the soil showed a significant increasing tendency[4] In this 35-year period, the total salt in light, medium and heavy salinized soils had increased by 0.08, 0.13 and 0.19 g/kg, respectively. Simulated results for the Ningxia Yellow River irrigation area indicate that at temperature increases of 0.5 °C–3.0 °C, the total salt in light, medium and heavy salinized soils will increase by 0.03–0.17, 0.06–0.24 and 0.09–0.32 g/kg, respectively. After winter temperature increases, CO_3^{2-}, HCO_3^-, Na^+ and Mg^{2+} move upward and accumulate in the surface soil, which leads to increased soil salinity, and will directly affect the sprouting and growth of spring crops.[18] In the present study, the winter temperature rise led to significantly increased soil pH value and total salt content; the temperature increases of 0.5 °C–2.0 °C led to increased soil pH by 0.42–0.67, and total salt by 0.39–0.50 g kg^{-1}.

Conclusions

The effects of winter temperature rises on soil microbial activity, nutrients and salinity in the Ningxia Plain were studied in a field experiment using an infrared radiator to increase temperatures. The winter temperature increases of 0.5 °C–2.0 °C led to decreased activities of soil catalase, urease and phosphatase by 0.08–1.20 mL g^{-1}, 0.004–0.019 mg g^{-1}, and 0.10–0.25 mg kg^{-1}, respectively; increased soil organic matter by 0.01–0.62 g kg^{-1}, decreased available N by 2.45–4.66 g kg^{-1}, increased available P by 2.92–5.74 g kg^{-1}, increased soil pH by 0.42–0.67, and increased total salt by 0.39–0.50 g kg^{-1}. After winter temperature increases, the activities of soil catalase, urease and phosphatase showed a significant decreasing tendency; and soil organic matter and available N showed a significant increasing tendency. However, available N showed a significant decreasing tendency, and available K showed no significant changes; and soil pH and total salt significantly increased. In general, increased winter temperatures led to reduced soil microbial activity, accelerated the decomposition of soil nutrients, and intensified soil salinization.

Acknowledgements

This work was supported by the Chinese Public Welfare Meteorology Industry Research Project (GYHU201106029-03, GYHU200806021-05), the Program for New Century Excellent Talents in University (NCET-09-0859), and National Natural Science foundation of China (41165009).

Disclosures

Author(s) have provided signed confirmations to the publisher of their compliance with all applicable legal and ethical obligations in respect to declaration of conflicts of interest, funding, authorship and contributorship, and compliance with ethical requirements in respect to treatment of human and animal test subjects. If this article contains identifiable human subject(s) author(s) were required to supply signed patient consent prior to publication. Author(s) have confirmed that the published article is unique and not under consideration nor published by any other publication and that they have consent to reproduce any copyrighted material. The peer reviewers declared no conflicts of interest.

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