Effects of Magnetized Brackish Water Irrigation on Trace Elements and Carbon-Nitrogen-Phosphorus Nutrient Characteristics in Populus × euramericana I-107 (Postprint)

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Abstract

To investigate the effects of magnetization on soil and plant nutrient characteristics under saline conditions, Populus × euramericana 'I-107' was used as experimental material, with magnetized and non-magnetized brackish water irrigation treatments applied. The soil-plant nutrient supply-demand relationship was revealed through determination of trace elements and carbon, nitrogen, and phosphorus contents in soil and plant tissues. The findings indicated: (1) Under brackish water irrigation, Fe content decreased in both leaves and roots; leaf Zn, Mn, and Cu contents increased, while root Mn and Zn contents decreased and Cu content increased. Total carbon content increased in both leaves and roots, whereas total nitrogen and total phosphorus contents decreased; leaf C/N ratio declined, while root C/N and C/P ratios increased. (2) Under magnetized brackish water irrigation, Fe, Zn, and Cu contents in both leaves and roots increased, while Mn content decreased; leaf C, P, and C/N ratio increased, while N content decreased; root C, C/N, and C/P ratios increased. (3) In soils under brackish water irrigation, total contents of Fe, Mn, Zn, and Cu micronutrients all decreased, while their available contents increased; OC and N, C/P and N/P ratios decreased, while total phosphorus and C/N ratio increased. (4) Under magnetized brackish water irrigation, soil total Fe, Mn, and Zn contents increased while Cu decreased; available contents of Fe, Mn, Zn, and Cu increased; OC and N, C/P and N/P ratios increased. These results demonstrate that magnetization beneficially regulates plant micronutrient uptake and distribution, enhances soil nitrogen fixation capacity, and improves carbon supply to plants. Moreover, under saline conditions, plants maintain normal photosynthesis to meet growth and development requirements by increasing Fe content and C/N ratio.

Full Text

Effects of Magnetized Brackish Water Irrigation on Microelements and Carbon-Nitrogen-Phosphorus Nutrient Characteristics in Populus × euramericana 'Neva'

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Abstract: Soil salinity can affect the absorption and transportation of mineral nutrients in plants, as well as the nutrient retention capacity of soil. To investigate the nutritional supply-demand relationship between soil and plants under saline conditions, irrigation experiments were conducted using one-year-old seedlings of Populus × euramericana 'Neva' , analyzing the contents of microelements, carbon, nitrogen, and phosphorus along with ecological stoichiometry. The results showed that: (1) Under non-magnetized brackish water (NMBW) irrigation, Fe content in both leaves and roots decreased, whereas Cu content increased, and Zn and Mn contents increased in leaves but decreased in roots. Total carbon content in leaves and roots was promoted by NMBW irrigation, whereas total nitrogen and phosphorus contents were reduced; the C/N ratio decreased in leaves but C/N and C/P ratios were elevated in roots. (2) Under magnetized brackish water (MBW) irrigation, the contents of Fe, Zn, and Cu in both leaves and roots improved, while Mn content decreased. Total carbon and phosphorus contents and the C/N ratio of leaves were increased, while nitrogen content decreased; total carbon content and C/N and C/P ratios of roots were promoted. (3) Under NMBW irrigation, the Fe, Mn, Zn, and Cu contents of soil decreased, whereas available microelement content increased; organic carbon and total nitrogen contents and C/P and N/P ratios decreased, but total phosphorus content and the C/N ratio increased. (4) MBW irrigation improved the total Fe, Mn, and Zn contents of soil, as did the available Fe, Mn, Zn, and Cu contents, whereas total Cu content decreased. Organic carbon and total nitrogen contents and C/P and N/P ratios in soil all increased. Therefore, magnetization improved the absorption and distribution of microelements in plants and could also improve the nitrogen sequestration capacity of soil and the carbon supply to plants. Moreover, magnetization could increase the Fe content and C/N ratio of plants under saline conditions, which could maintain normal photosynthesis rates and improve plant growth and development under salt stress.

Keywords: magnetization; brackish water; microelements; carbon; nitrogen; phosphorus; ecological stoichiometry

Introduction

Plants and soil constitute the main nutrient storage pools in ecosystems. The characteristics of nutrient element contents vary with soil type and plant species, while being influenced by external environmental factors to some extent. Soil nutrient content and its availability are important chemical indicators in ecosystems that affect plant growth and development. These two components interact as an integrated whole. Microelements are key components of various enzymes, growth hormones, and vitamins in plants, playing important roles in plant growth and development. Microelements such as Fe, Mn, Zn, and Cu required for various physiological metabolic activities in plants are mainly derived from soil, and the supply level of microelements in soil affects plant metabolic functions. Carbon, nitrogen, and phosphorus are fundamental elements in plant life activities and important components for energy metabolism, variation, and information expression in living organisms. Carbon constitutes structural substances of plants, while nitrogen and phosphorus are functional substances. These three elements are essential nutrients for plants, and their stoichiometric ratios serve as important indicators for determining soil nutrient supply to plants during growth processes. Studying different types of mineral nutrients between plants and soil and exploring nutrient migration patterns and plant nutrient limitation conditions during soil ecological chemical cycling processes are important for revealing plant adaptation mechanisms to saline habitats.

With rapid economic development, the contradiction between freshwater supply and demand has become increasingly severe. Many scholars have studied brackish water irrigation methods and technologies, and the rational development of groundwater brackish resources has gradually become a focus of international attention. Research on the effects of soil salinity on soil quality and crop yield and quality has yielded certain results, providing a theoretical basis for brackish water utilization. Although brackish water utilization meets crop water requirements at different stages, excessive brackish water irrigation can cause deterioration of the soil ecological environment and reduce crop yield and quality. To address soil salinization caused by long-term brackish water irrigation, it is necessary to study relevant treatment technologies to reduce adverse effects on the soil environment and plant growth and development.

Magnetized water treatment technology, as a new agricultural irrigation technology, offers advantages including environmental friendliness, high efficiency, and low investment. When liquid water passes through a magnetic field at a certain flow rate, water molecule and ion hydration is enhanced, solubility increases, and soil ion exchange capacity and ion saturation improve. This can prevent excessive accumulation of salts caused by long-term brackish water irrigation to a certain extent. Magnetized water irrigation can increase the content of microelements and carbon-nitrogen-sulfur in seeds, improve soil desalination rates, save irrigation water volume, and improve water use efficiency. Compared with ordinary water, magnetized water makes soil loose after irrigation.

This study used Populus × euramericana 'Neva' as experimental material. By determining microelements and carbon-nitrogen-phosphorus in plant tissues and soil, we analyzed plant absorption and utilization of various nutrient elements and soil nutrient retention status to elucidate the mechanism of magnetized brackish water irrigation on plant nutrient transport and cycling, providing a theoretical basis for brackish water development and utilization and magnetized water treatment technology application.

1. Experimental Materials

The experimental material consisted of one-year-old Populus × euramericana 'Neva' seedlings. The pot experiment was conducted at the experimental station of Shandong Agricultural University (117°08 E, 36°11 N). The tested soil was mainly loam with pH 7.0, containing 0.80, 0.53, and 0.70 g/kg of organic matter, total nitrogen, and total potassium, respectively, and 318.50, 201.30, and 13.50 mg/kg of available nitrogen, available phosphorus, and available potassium, respectively. Each pot contained 10 kg of soil with dimensions of 24.0 cm diameter and 30 cm height. The cuttings, with average heights of (1.52±0.11) cm and diameters of (1.5±0.1) cm, were inserted in early June and uniformly managed with tap water irrigation before the experiment.

2. Experimental Design

A simulated seawater mass ratio of NaCl:Na SO :CaCl :MgCl = 4:2:2:1 was used to prepare irrigation brackish water at a concentration of 4.0 g/kg. Four different irrigation treatments were established: magnetized brackish water irrigation (M4: magnetized 4 g/L saline solution irrigation), non-magnetized brackish water irrigation (NM4: non-magnetized 4 g/L saline solution irrigation), magnetized freshwater irrigation (M0: magnetized 0 g/L saline solution irrigation), and non-magnetized freshwater irrigation (NM0: non-magnetized 0 g/L saline solution irrigation). Magnetized water was treated using Magnetic Technologies L.L.C equipment with a magnetic field strength of 160 mT and flow velocity of 12.7 m/s.

3. Sample Collection

Rhizosphere soil from the middle part of the cultivation container (10-15 cm depth) was collected in late August and air-dried in the laboratory to remove residual roots and gravel. Simultaneously, mature leaves from the middle part of cuttings and root systems were collected. After repeated washing with tap water and deionized water, plant samples were oven-dried at 105°C for microelement and total carbon (TC), total nitrogen (TN), and total phosphorus (TP) content determination.

4. Measurement Methods

Plant tissue mineral element content determination: Fe, Mn, Zn, and Cu were determined by atomic absorption spectrophotometry. Total carbon was measured by the K Cr O -H SO method. Total nitrogen was determined by the Kjeldahl method. Total phosphorus was measured by the vanadium-molybdenum yellow colorimetric method.

Soil mineral element content determination: Total Fe, Mn, Zn, and Cu were determined by atomic absorption spectrophotometry after H SO -H O digestion. Available microelements were extracted by ASI method and measured by atomic absorption spectrophotometry. Organic matter was determined by the K Cr O -H SO method. Total nitrogen was measured by the Kjeldahl method. Total phosphorus was determined by the molybdenum blue colorimetric method. Available nitrogen was measured by the alkali hydrolysis diffusion method. Available phosphorus was determined by the NaHCO molybdenum-antimony anti-colorimetric method.

5. Data Processing

Data were processed using Excel 2013 and SAS 9.0 software. One-way ANOVA was used for significance analysis, and Duncan' s multiple-range test was applied for multiple comparisons ($P < 0.05$). Correlation analysis among nutrient elements was performed using SPSS 16.0.

2. Results and Analysis

2.1 Effects of Magnetized Brackish Water Irrigation on Plant Microelements

Significant differences in microelement contents were observed among different treatments in leaf tissues. Compared with the control (M0, NM0), brackish water irrigation treatments (M4, NM4) increased Fe, Mn, and Zn contents by 16.6%-19.3%, with Zn and Mn showing the greatest increases of 6.7%-17.6% and 51.8%-61.7%, respectively. Compared with non-magnetized brackish water irrigation, magnetized brackish water irrigation increased Fe and Zn contents by 15.0%-29.8%, with Zn increasing by 72.8% and 4.8% in M4 and NM4, respectively, and Fe increasing by 50.6% and 78.5% in M4 and NM4, respectively. Cu content increased by 12.1% and 33.4%.

In root tissues, brackish water irrigation decreased Fe, Mn, and Zn contents, with non-magnetized brackish water irrigation reducing them by 20.5%, 36.9%, and 25.2%, respectively. Magnetization significantly increased Fe, Mn, and Zn contents in root tissues. Compared with non-magnetized brackish water irrigation, magnetized brackish water irrigation increased Fe and Zn contents by 24.5% and 6.7%, respectively, while decreasing Mn by 4.0%.

2.2 Effects of Magnetized Brackish Water Irrigation on Plant Carbon-Nitrogen-Phosphorus Contents

In leaf tissues, total carbon, nitrogen, and phosphorus contents ranged from 246.6 to 559.8 mg/kg. Compared with the control (M0, NM0), brackish water irrigation reduced total carbon, nitrogen, and phosphorus contents, with total carbon showing the greatest decrease of 28.9%-39.7%. Compared with non-magnetized brackish water irrigation, magnetized brackish water irrigation increased total carbon and phosphorus contents and the C/N ratio by 28.9%, 8.1%, and 25.9%, respectively, while decreasing total nitrogen by 21.7%-36.9%. M4 treatment increased total carbon and phosphorus by 37.0% and 123.2%, respectively, and C/N ratio by 53.1%, while decreasing nitrogen by 61.3% and 65.5%.

In root tissues, brackish water irrigation increased total carbon content by 103.7%-123.8% and C/N ratio by 201.4%-246.6%, while decreasing total nitrogen and phosphorus contents and N/P ratio. Compared with non-magnetized brackish water irrigation, magnetized brackish water irrigation increased total carbon content and C/N and C/P ratios by 33.7%, 133.0%, and 12.4%, respectively, in M4 treatment, and by 42.8%, 45.0%, and 21.7%, respectively, in NM4 treatment. M4 treatment increased total carbon by 121.0% and 51.7% compared with NM4.

Compared with leaves, roots had higher total carbon content and C/N ratio, with magnetized brackish water irrigation plants showing higher values than non-magnetized brackish water irrigation plants. However, total phosphorus and N/P ratios were slightly lower in magnetized brackish water irrigation plants. This indicates that magnetization enhanced carbon enrichment capacity in both leaf and root tissues.

2.3 Effects of Magnetized Brackish Water Irrigation on Total and Available Soil Microelements

Analysis of total soil microelements revealed that compared with the control (M0, NM0), brackish water irrigation decreased Fe, Mn, and Zn contents by 6.1%, 13.8%, and 9.5%, respectively, in NM4 treatment, and by 21.9%, 7.2%, and 23.8%, respectively, in M4 treatment, with Cu showing opposite trends. Compared with non-magnetized brackish water irrigation, magnetized brackish water irrigation increased Fe, Mn, and Zn total contents by 11.0%, 19.6%, and 47.0%, respectively, while decreasing Cu by 19.2% and 49.1%.

Analysis of available soil microelements showed that compared with the control (M0, NM0), brackish water irrigation decreased available Fe, Mn, and Zn contents by 43.3%, 43.1%, and 20.0%, respectively, in NM4 treatment, and by 18.1%, 40.9%, and 12.4%, respectively, in M4 treatment, while increasing available Cu by 23.4%. Compared with non-magnetized brackish water irrigation, magnetized brackish water irrigation increased available Fe, Mn, Zn, and Cu contents by 3.6%, 8.2%, 8.6%, and 16.8%, respectively.

2.4 Effects of Magnetized Brackish Water Irrigation on Soil Carbon-Nitrogen-Phosphorus Characteristics

Carbon, nitrogen, and phosphorus are important components of soil nutrients that affect soil nutrient cycling and ecosystem health. Their contents influence soil microbial activity, litter decomposition rate, and organic carbon accumulation. Measurements of organic carbon, total nitrogen, and total phosphorus revealed that nutrient contents in soil followed the order: organic carbon > total nitrogen > total phosphorus.

Compared with the control (M0, NM0), brackish water irrigation decreased soil organic carbon and total nitrogen contents and C/P and N/P ratios, with N/P ratio showing the greatest decrease of 23.4%. Compared with non-magnetized brackish water irrigation, magnetized brackish water irrigation increased soil organic carbon and total nitrogen contents by 31.9% and 24.3%, respectively, in NM4 treatment, and by 28.1% and 22.4%, respectively, in M4 treatment. Total phosphorus content decreased by 25.0% and 19.9%, while C/N ratio increased by 38.0% and 15.9%.

The C:N:P stoichiometric ratio is the ratio of total mass of carbon, nitrogen, and phosphorus in soil and an important indicator in soil ecological stoichiometry. Compared with the control, C/P and N/P ratios in brackish water irrigation soil decreased by 44.5% and 34.0%, respectively, in NM4 treatment, and by 37.2% and 6.1%, respectively, in M4 treatment. Compared with non-magnetized brackish water irrigation, C/N, C/P, and N/P ratios in magnetized brackish water irrigation soil increased by 79.4%-91.0%, 28.4%, and 54.7%-116.1%, respectively.

3. Discussion

3.1 Magnetized Brackish Water Irrigation Affects Plant Nutrient Characteristics and Carbon-Nitrogen-Phosphorus Stoichiometry

After magnetized brackish water irrigation, Fe and Zn contents in plant leaves and roots were higher than in non-magnetized brackish water irrigation plants, similar to research results on microelements in snow peas and chickpeas. This is due to the long-term magnetic field effect on nutrient migration within plants. The presence of a magnetic field can increase certain hormone contents. Studies have found that magnetic fields increase gibberellin and zeatin content in sunflowers, stimulating plants to enhance nutrient element absorption.

Iron transport in plants generally occurs through xylem and is related to the apoplast. The weak transport capacity of iron from roots to leaves is consistent with research results on iron absorption and transport inhibition, mainly because iron reductase activity on the plasma membrane is affected by the apoplast. Darker leaf color under magnetization is due to its effect on iron transmembrane transport and apoplast iron activation through apoplast regulation, allowing activated iron to be transported across the plasma membrane to leaves for chlorophyll synthesis or released into the medium.

The higher accumulation of Fe, Mn, and Zn in leaves indicates that under saline conditions, magnetization enhances root absorption capacity and root-to-leaf transport capacity, as well as detoxification and storage capacity. The relatively high Fe content maintained by magnetization can enhance protein activity and maintain normal photosynthesis.

Nitrogen and phosphorus are important elements constituting various proteins and genetic materials. Carbon assimilated through photosynthesis is the substrate and energy source for plant physiological and biochemical processes, and its distribution characteristics occupy an important position in nutrient cycling processes. After brackish water irrigation, the highest total carbon content in leaves and roots was lower than the control, indicating that under saline conditions, plants can maintain certain carbon accumulation levels but reduced enrichment. The decrease in nitrogen content directly determines photosynthetic capacity, and reduced nitrogen content indicates decreased photosynthetic capacity. This is due to soil salinity affecting available nitrogen content and direct plant absorption, as salt ion intake leads to leaching of NO with salts.

Compared with non-magnetized brackish water irrigation, magnetized brackish water irrigation maintained relatively high total carbon and total phosphorus contents in both leaves and roots, with higher accumulation in leaves than roots, while total nitrogen content decreased with higher accumulation in roots than leaves. Magnetization changed the distribution pattern of the three nutrient elements in plants. The C/N ratio indicates plant growth rate and limitation conditions. The C/P ratio reflects the correlation between plant growth rate and phosphorus use efficiency. Under magnetization, the C/N and C/P ratios in leaves and roots increased compared with non-magnetized irrigation, with roots lower than leaves, indicating that roots are temporary storage and transport organs for photosynthates, and the moderate C/N ratio indicates efficient photosynthate transport outward.

Correlation analysis showed that C, N, and P contents were negatively correlated with Fe, Mn, and Zn contents in leaves and roots. Fe is a key electron transporter and plays important roles in plant cell respiration, photosynthesis, and metal protein catalytic reactions. Chloroplasts are important sites for photosynthesis, using light energy to convert CO into carbohydrates. Fe is an essential element in plant life activities, and light energy absorption, transfer, and transformation are achieved through thylakoid membranes on chloroplasts, which are the main components of chloroplasts. The assimilation and cycling of CO occur in the chloroplast stroma. The absorption and distribution of Fe are important for regulating carbon cycling to improve plant photosynthetic efficiency. There is antagonism between Fe and Mn, Zn, and the absorption and transport of Fe are negatively correlated with Mn and Zn absorption and distribution. The enrichment of Mn and Zn in leaves and roots requires further study on their mechanisms.

3.2 Magnetized Brackish Water Irrigation Promotes Total Nutrient Accumulation and Available Nutrient Utilization

Soil total nutrient content represents the source and sink of soil nutrients and the potential supply level of certain nutrients, while available nutrient content reflects nutrient availability for plant absorption. The combination of both reflects soil nutrient status. After brackish water irrigation, soil total microelement content decreased while available microelement content increased. Magnetized brackish water irrigation maintained relatively high total nutrient levels and lower available nutrient levels compared with non-magnetized brackish water irrigation. Under magnetization, soil maintained relatively high total microelement content while promoting plant absorption and utilization of available nutrients.

Plant nutrient content measurements showed that magnetized brackish water irrigation increased microelement accumulation. The decrease in total content and increase in available content represent an active plant adaptation to the environment. The improvement of soil microelements by magnetization is a long-term and slow process. High available element content can hinder plant growth, and plants in long-term saline environments can regulate through precipitation and degradation.

3.3 Effects of Magnetized Brackish Water Irrigation on Carbon-Nitrogen-Phosphorus Characteristics

Organic carbon is an indispensable fertility indicator in soil and participates in global carbon cycling. Its vertical distribution pattern in soil profiles is an important factor affecting soil carbon dynamics and an important research content of soil carbon cycling. Soil organic carbon content is higher than nitrogen and phosphorus, and magnetized brackish water irrigation maintained relatively high organic carbon content, indicating that magnetization is beneficial for increasing soil organic matter quantity and humification coefficient, thereby improving soil carbon sequestration capacity.

Soil nitrogen and phosphorus are important nutrient elements that directly reflect soil nutrient status in ecosystems. Soil nitrogen content results from the balance between nitrogen mineralization and accumulation, and organic matter content contributes most to nitrogen, with the two being closely related. Organic matter decomposition by microorganisms is the main source of available nitrogen that crops can directly utilize and is the main factor affecting soil nitrogen mineralization processes. Soil nitrogen and phosphorus contents are lower than organic carbon content. Magnetized brackish water irrigation maintained relatively high nitrogen content and lower phosphorus content, while plant phosphorus content increased, indicating that magnetization can affect nitrogen mineralization, maintain certain available nitrogen supply levels, and facilitate the release of available phosphorus from soil solid phase to liquid phase, accelerating phosphorus absorption and utilization by plants.

The soil C:N:P ratio is the ratio of carbon, nitrogen, and phosphorus in organic matter or other components and is an important indicator for measuring soil organic matter composition and soil quality. The C/N ratio is negatively correlated with soil organic matter decomposition rate; lower C/N ratio indicates stronger mineralization and vice versa. Lower C/P ratio is beneficial for microbial activity and organic matter decomposition and nutrient release. In magnetized brackish water irrigation, increased soil organic carbon content and C/N ratio indicate that magnetization slows organic matter decomposition rate under saline conditions. This not only maintains carbon required for microbial life activities and provides carbon sources for microbial body construction but also enhances soil carbon sequestration capacity and nitrogen cycling.

Phosphorus is an element with small spatial variability and easy deposition, with relatively stable changes. The N/P ratio maintained relatively high levels, lower than the average phosphorus content in Chinese soils (0.56 g/kg), indicating phosphorus deficiency in saline soils. The increased N/P ratio under magnetization can supplement nitrogen deficiency under saline conditions to some extent and maintain plant nitrogen and phosphorus absorption. The decreased C/P and N/P ratios in brackish water irrigation indicate that magnetization enhances phosphorus migration rate.

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Note: Figure translations are in progress. See original paper for figures.