Postprint: Ecological Effects of Trichoderma Preparation on Ameliorating Coastal Saline Soil Raised Fields

Authors: Chen Jian' ai, Duan Youchen Guo Feng, Yang Wuhan, Chen Weijing, Wan Shubo

Date: 2017-11-06T00:00:00+00:00

Abstract

Biological amelioration of coastal saline soil is an environmentally friendly ecological technology characterized by low investment, short duration, rapid effectiveness, and long-term benefits. Through field trials, Trichoderma preparation [active ingredient: Trichoderma conidia, 1×10 (CFU)·g 1] was applied to coastal moderately saline terraced fields (salt content 2.99 g·kg 1, sandy loam soil). Topsoil samples were collected from the soil amelioration terraced field experimental area under different treatments (Trichoderma application and conventional control) and auxiliary experimental areas including solar greenhouse (salt content 0.98 g·kg 1, loam soil), coastal slightly saline reclaimed field (salt content 1.75 g·kg 1, light loam soil), and coastal severely saline river beach land (salt content 26.19 g·kg 1, sandy loam soil) for laboratory analysis to investigate the ecological effects of Trichoderma application in coastal moderately saline terraced fields. In coastal moderately saline terraced fields, the Trichoderma treatment increased soil compactness by 177.04%, water-stable aggregates (0.25 mm) by 265.78%, soil water content by 320.83%, and soil alkaline-hydrolyzable nitrogen, available phosphorus, readily available potassium, and organic matter contents by 96.14%, 42.17%, 105.65%, and 63.79%, respectively, compared with the control. Microbial cultivation via soil dilution method showed that bacteria, actinomycetes, fungi, and nitrogen-fixing bacteria increased by 170.95%, 82.68%, 152.17%, and 471.93% compared with the control, respectively. Compared with coastal severely saline river beach land, the Trichoderma treatment in coastal moderately saline terraced fields increased plant growth-favorable indicators including soil compactness, water-stable aggregates, organic matter, and microbial community numbers by 1.53-fold, 2.11-fold, 3.20-fold, and 28.33-fold, respectively, while decreasing plant growth-unfavorable water-soluble salts by 96.60%. Through amelioration with Trichoderma preparation, coastal moderately saline terraced fields showed no significant differences in soil compactness, total porosity, water content, available phosphorus, organic matter, and microbial numbers compared with coastal slightly saline reclaimed fields. After Trichoderma treatment, coastal moderately saline terraced fields exhibited decreased soil bulk density and increased total porosity, approaching those of high-yield solar greenhouse non-salinized soil. Coastal severely saline soil was transformed into moderately saline soil by raising sand soil 1.2 m to construct terraced fields, achieving good salt reduction effects. Subsequent biological amelioration measures further enhanced soil nutrients and beneficial microorganisms, optimized soil aggregate structure, and improved the efficiency and quality of coastal moderately saline terraced field amelioration, promoting ecological improvement of coastal moderately saline terraced fields.

Full Text

Preamble

Chinese Journal of Eco-Agriculture, Jan. 2016, Vol. 24 No. 1

Ecological Effects of Trichoderma Agent on Platform Field Soil Improvement in Coastal Saline Areas*

CHEN Jian'ai[1], DUAN Youchen[1], GUO Feng[2], YANG Wuhan , CHEN Weijing[2], **WAN Shubo[3]**

(1. Institute of Agro-food Science and Technology/Institute for Application of Atomic Energy, Shandong Academy of Agricultural Sciences, Jinan 250100, China;

2. Biotechnology Research Center, Shandong Academy of Agricultural Sciences, Jinan 250100, China;

3. Shandong Academy of Agricultural Sciences, Jinan 250100, China;

4. Agricultural Bureau of Kenli County, Dongying City, Shandong Province, Kenli 257500, China)

Abstract

Biological amendment of coastal saline soil is an environmentally friendly and ecologically sustainable technology characterized by low investment, short duration, rapid effects, and long-term benefits. Through field experiments, a Trichoderma agent [with active ingredients of Trichoderma conidia, 1×10^7 CFU · g^{-1}] was applied to moderately saline coastal platform fields (salinity content 2.99 g · kg^{-1}, sandy loam soil). Topsoil samples were collected from the soil amendment experimental area under different treatments (Trichoderma agent application and conventional control) and auxiliary test areas including a solar greenhouse (salinity content 0.98 g · kg^{-1}, loam soil), a reclaimed slight saline coastal field (salinity content 1.75 g · kg^{-1}, light loam soil), and a severe saline coastal floodplain (salinity content 26.19 g · kg^{-1}, sandy loam soil) for laboratory analysis, to investigate the ecological effects of Trichoderma application in moderately saline coastal platform fields. Compared with the control treatment in moderately saline coastal platform fields, the

Trichoderma treatment increased soil compaction by 177.04%, water-stable aggregate content (0.25 mm) by 265.78%, soil moisture content by 320.83%, and soil alkali-hydrolyzable nitrogen, available phosphorus, available potassium, and organic matter contents by 96.14%, 42.17%, 105.65%, and 63.79%, respectively. Through soil dilution culture, the populations of bacteria, actinomycetes, fungi, and azotobacteria increased by 170.95%, 82.68%, 152.17%, and 471.93%, respectively, compared with the control.

Keywords: Trichoderma; Saline coastal soil; Platform field; Soil amelioration; Ecological efficiency

Introduction

Soil is the fundamental material basis for human survival and an indispensable, non-renewable natural resource. Agriculture depends on soil. The Yellow River Delta contains vast areas of coastal saline soil, with 234,500 hectares of saline wasteland alone, representing extremely valuable reserve land resources. Platform fields represent one approach to ameliorating saline soil; elevating the terrain facilitates leaching of salts and alkalis, reducing surface soil salinity [1]. However, platform fields are newly created sandy lands with poor soil structure, low fertility, loose texture, weak water and nutrient retention capacity, and are not conducive to crop growth. The quantity and diversity of soil microorganisms are critical to soil quality [2–4]. Utilizing specific microbial communities to improve soil, enhance soil productivity, elevate soil quality, establish better soil ecological environments, promote crop growth, and facilitate land resource development and agricultural sustainable development holds significant practical importance.

Trichoderma has been extensively studied as an excellent biocontrol agent for decades. Research demonstrates that Trichoderma exhibits antagonistic effects against soil-borne pathogens [5–6], induces plant disease resistance [7], and promotes plant growth and development [8], making it an effective ecological biocontrol factor. Environmentally friendly microorganisms play significant roles in improving soil ecological environments: first, they enhance crop absorption of nitrogen, phosphorus, potassium, and trace elements, improving fertilizer utilization efficiency [9–10]; second, they improve soil structure and promote the establishment and maintenance of beneficial soil microbial communities [11–13]; third, they alleviate heavy metal pollution and bioremediate contaminated environments [14]. The *Trichoderma aureoviride* T1010 strain developed by our research group demonstrates antagonistic effects against certain crop soil-borne diseases [6] with evident field application results [15]. *Trichoderma aureoviride* T1010 can alter rhizosphere microbial population numbers [11,13], yet few studies have investigated the effects of Trichoderma on improving soil physicochemical properties in moderately saline coastal platform fields [12]. This experiment aims to analyze the soil amendment effects of applying Trichoderma agent to moderately saline coastal platform fields, explore its mechanism of action in improving such soils, and establish a foundation for further enhancing the comprehensive ecological service functions of moderately saline coastal platform field soils and promoting agricultural, forestry, and pastoral production.

1. Materials and Methods

1.1 Materials

The Trichoderma agent was developed by the Institute of Agro-food Science and Technology, Shandong Academy of Agricultural Sciences. The main strain, *Trichoderma aureoviride* T1010, was present at a concentration of 1×10^7 CFU · g^{-1}, with other fertilizers being locally conventional types. The peanut (*Arachis hypogaea*) variety used in the experiment was 'Huayu 20'(provided by the Shandong Peanut Research Institute).

1.2 Experimental Design

The experiment consisted of soil amendment trials and auxiliary trials. The soil amendment trial was conducted in 2011 on moderately saline coastal platform fields in Kenli County, Shandong Province. Two treatments were established: Trichoderma agent and conventional control. Each plot area was 133.4 m^2, with double-row film mulching sowing, 40 m row length, 0.8 m ridge width, 2 peanut seeds per hole, and 135,000 holes per hectare. Each treatment was replicated four times, totaling eight plots. Compound fertilizer was applied at 750 kg per hectare, and Trichoderma agent at 150 kg per hectare. Before peanut planting, the Trichoderma agent and fertilizers were applied as basal fertilizers in separate plots. Other management practices followed conventional methods.

Auxiliary trials were selected based on the formation time of the Yellow River Delta coastal plain and the duration of natural vegetation improvement, representing three typical conditions: a solar greenhouse in Shouguang representing former coastal saline soil transformed into high-yield fields through years of improvement; a reclaimed slight saline coastal field representing former coastal saline soil gradually improved into medium-low yield fields; and a coastal saline floodplain representing newly formed land from Yellow River sedimentation with severe saline conditions. Each plot was 0.1 hm^2, with crops and management following conventional local practices or natural vegetation growth.

The basic conditions of each experimental site are shown in Table 1 .

On June 19, 2011, during the peanut flowering and pegging stage, topsoil samples were collected from each experimental area using the five-point cross method.

1.3 Soil Sampling and Analysis Methods

Topsoil structure was evaluated based on water-stable aggregate content, measured using the method of Shao et al. [16] with treatment time extended to 10 minutes. Topsoil chemical properties including organic matter, pH, alkali-hydrolyzable nitrogen, available phosphorus, available potassium, and water-soluble salts were analyzed, along with physical properties such as soil bulk density, particle density, and total porosity, following the methods of Lao [17]. Biochemical properties including protein and nucleic acid contents were measured by UV absorption. Soil microbial communities were isolated, cultured, and enumerated using the dilution plate method: bacteria were cultured on beef extract peptone medium, actinomycetes on Gause' s synthetic No. 1 agar medium, fungi on Martin' s Bengal rose streptomycin agar medium, and azotobacteria on Ashby medium, incubated at 26°C and 37°C in constant temperature incubators with moisture maintenance. Bacteria were cultured for 3–5 days, while azotobacteria, actinomycetes, and fungi were cultured for 7-10 days, after which colony numbers were counted.

1.4 Statistical Analysis

Results were calculated according to relevant formulas and analyzed using SAS statistical software (SAS, Version 8.2). ANOVA was used to analyze differences among soil samples from different sources, and Duncan' s multiple range test was used to analyze differences among multiple soil samples.

2. Results and Analysis

2.1 Effects of Trichoderma Agent on Soil Physical Properties of Moderately Saline Coastal Platform Fields

After applying the Trichoderma agent as a basal fertilizer to moderately saline coastal platform field soils and planting peanuts, soil physical properties were measured during the peanut flowering and pegging stage. Results are shown in Table 2 . Table 2 reveals highly significant differences ($P<0.001$) in soil compaction, bulk density, particle density, total porosity, water-stable aggregates, and moisture content among different experimental sites (treatments).

Soil compaction decreased in the following order: solar greenhouse > reclaimed slight saline coastal field > moderately saline coastal platform field (Trichoderma) > severe saline coastal floodplain > moderately saline coastal platform field (control). The Trichoderma treatment increased soil compaction in moderately saline coastal platform fields by 176.68% compared with the control, a highly significant difference ($P<0.001$), but showed no significant difference from the reclaimed slight saline coastal field.

Soil bulk density decreased in the following order: severe saline coastal floodplain > moderately saline coastal platform field (control) > reclaimed slight saline coastal field > moderately saline coastal platform field (Trichoderma) >

solar greenhouse. The Trichoderma treatment showed no significant difference in soil bulk density from the solar greenhouse (P=0.0512) but differed highly significantly from the control (P=0.0018).

Soil particle density decreased in the following order: severe saline coastal floodplain > moderately saline coastal platform field (control) > moderately saline coastal platform field (Trichoderma) > reclaimed slight saline coastal field > solar greenhouse. The Trichoderma treatment showed a significant difference in soil particle density from the control (P=0.0331).

The highest total porosity was observed in the Trichoderma-treated moderately saline coastal platform field soil and the solar greenhouse soil, both exceeding 50% with no significant difference between them (P=0.6908). The lowest was in the severe saline coastal floodplain at only 36.64%.

The highest water-stable aggregate (0.25 mm) content was found in the solar greenhouse soil and the reclaimed slight saline coastal field, while the severe saline coastal floodplain and moderately saline coastal platform field (control) had very low water-stable aggregate content. The Trichoderma treatment increased water-stable aggregate content in moderately saline coastal platform field soil by 265.78% compared with the control, a highly significant difference (P=0.0002).

Moisture content varied among soils from different sources, with the highest in the severe saline coastal floodplain soil. The moderately saline coastal platform field had high elevation, rapid water evaporation, and low water-holding capacity, with moisture content of only 1.81%. The Trichoderma treatment increased soil water content by 320.83%, a highly significant difference (P<0.0001).

The moderately saline coastal platform field soil was highly sandy with poor water absorption capacity, poor aeration when waterlogged, and poor water retention during drought. The Trichoderma agent demonstrated beneficial effects on soil aggregate formation and structural improvement.

Table 2 Influence of Trichoderma Agent on Major Physical Properties of Arable Layer Soil in Moderately Saline Coastal Platform Fields

Note: T1010 indicates Trichoderma agent treatment. Different capital letters indicate significant differences among different test places at the 0.01 level. The same below.

2.2 Effects of Trichoderma Agent on Soil Chemical Properties of Moderately Saline Coastal Platform Fields

Table 3 shows highly significant differences (P<0.001) in soil alkali-hydrolyzable nitrogen, available phosphorus, available potassium, organic matter content, pH (characteristic of saline soils), and water-soluble salt content among different sampling sites. The solar greenhouse soil had high fertility, while the other four coastal saline soils had low fertility.

Among the four coastal saline soils, alkali-hydrolyzable nitrogen content decreased in the following order: severe saline coastal floodplain > reclaimed slight saline coastal field > moderately saline coastal platform field (Trichoderma) > moderately saline coastal platform field (control). The Trichoderma treatment increased alkali-hydrolyzable nitrogen content in moderately saline coastal platform field soil by 96.14% compared with the control, a highly significant difference (P=0.0003).

Available phosphorus content decreased in the following order: severe saline coastal floodplain > reclaimed slight saline coastal field > moderately saline coastal platform field (Trichoderma) > moderately saline coastal platform field (control). The Trichoderma treatment showed no significant difference from the reclaimed slight saline coastal field (P=0.2547) but increased available phosphorus by 42.17% compared with the control, a significant difference (P=0.0196).

Available potassium content decreased in the following order: reclaimed slight saline coastal field > moderately saline coastal platform field (Trichoderma) > severe saline coastal floodplain > moderately saline coastal platform field (control). The Trichoderma treatment increased available potassium content in moderately saline coastal platform field soil by 105.65%, a highly significant difference ($P<0.001$).

Organic matter content decreased in the following order: reclaimed slight saline coastal field > moderately saline coastal platform field (Trichoderma) > moderately saline coastal platform field (control) > severe saline coastal floodplain. The Trichoderma treatment increased soil organic matter content in moderately saline coastal platform field soil by 63.79%, a highly significant difference (P=0.0013).

Saline soils are alkaline, and remain highly alkaline during the rainy season. The Trichoderma-treated soil was also strongly alkaline, with little difference in pH among soil samples.

Water-soluble salt content was highest in the severe saline coastal floodplain, decreasing in the following order: severe saline coastal floodplain > reclaimed slight saline coastal field > moderately saline coastal platform field (Trichoderma) > moderately saline coastal platform field (control). The Trichoderma treatment in moderately saline coastal platform field reduced water-soluble salts by 56.25% compared with the reclaimed slight saline coastal field.

These results demonstrate that the Trichoderma agent has certain activation, transport, and buffering effects on alkali-hydrolyzable nitrogen, available potassium, available phosphorus, water-soluble salts, and organic matter in the arable layer of moderately saline coastal platform fields. It can be preliminarily concluded that the Trichoderma agent exerts positive effects on adjusting the chemical properties of coastal saline soils.

Table 3 Influence of Trichoderma Agent on Major Chemical Properties of Arable Layer Soil in Moderately Saline Coastal Platform Fields

Note: Different capital letters in parentheses indicate significant differences among the four coastal saline soils at the 0.01 level. The same below.

2.3 Effects of Trichoderma Agent on Soil Biological Properties of Moderately Saline Coastal Platform Fields

Table 4 shows highly significant differences ($P<0.0001$) among different soil samples in biological indicators (protein and nucleic acid) and microbial indicators (bacterial, actinomycete, fungal, and azotobacterial communities). The solar greenhouse soil was biologically rich, while the other four coastal saline soils had relatively low biological abundance, with all biological indicators in the solar greenhouse soil significantly higher than those in the four coastal saline soils.

Among the four coastal saline soils, protein content decreased in the following order: reclaimed slight saline coastal field > severe saline coastal floodplain > moderately saline coastal platform field (Trichoderma) > moderately saline coastal platform field (control). The Trichoderma treatment increased protein content in platform field soil by 8.18% compared with the control.

Nucleic acid content decreased in the following order: reclaimed slight saline coastal field > moderately saline coastal platform field (Trichoderma) > severe saline coastal floodplain > moderately saline coastal platform field (control). The Trichoderma treatment in moderately saline coastal platform field differed significantly from the control ($P=0.0283$), increasing nucleic acid content by 12.41%.

Bacterial populations differed highly significantly among the four coastal saline soils. The Trichoderma-treated moderately saline coastal platform field and the reclaimed slight saline coastal field had the highest bacterial counts at 7.67×10^{6} $\mathrm{CFU}\cdot\mathrm{g}^{1}$ and 6.47×10^{6} $\mathrm{CFU}\cdot\mathrm{g}^{1}$, respectively, with no significant difference between them. The severe saline coastal floodplain had the lowest bacterial count at only 2.8×10^{5} $\mathrm{CFU}\cdot\mathrm{g}^{1}$. The Trichoderma treatment in moderately saline coastal platform field differed highly significantly from the control ($P<0.001$), increasing bacterial populations by 170.95%.

Actinomycete populations decreased in the following order: reclaimed slight saline coastal field > moderately saline coastal platform field (Trichoderma) > moderately saline coastal platform field (control) > severe saline coastal floodplain. The Trichoderma treatment in moderately saline coastal platform field showed no significant difference from the reclaimed slight saline coastal field, increasing actinomycete populations by 82.68% compared with the control. The severe saline coastal floodplain had very few actinomycetes.

Fungal populations decreased in the following order: reclaimed slight saline coastal field > moderately saline coastal platform field (Trichoderma) > moderately saline coastal platform field (control) > severe saline coastal floodplain. The Trichoderma treatment in moderately saline coastal platform field showed no significant difference from the reclaimed slight saline coastal field but differed highly significantly from the control (P=0.005), increasing fungal populations by 152.17%. The severe saline coastal floodplain had virtually no fungi.

The Trichoderma-treated moderately saline coastal platform field had the highest azotobacterial population among the four coastal saline soils at 3.34×10^6 CFU · g ¹, decreasing in the following order: moderately saline coastal platform field (Trichoderma) > reclaimed slight saline coastal field > moderately saline coastal platform field (control) > severe saline coastal floodplain. The Trichoderma treatment in moderately saline coastal platform field differed highly significantly from the reclaimed slight saline coastal field (P=0.0012), increasing azotobacterial populations by 124.39%, and differed highly significantly from the control (P<0.0001), increasing populations by 471.93%.

These results further confirm that the Trichoderma agent exerts differential effects on various biological communities in the arable layer, with moderate effects on bacteria and actinomycetes and substantial effects on azotobacteria and fungi. The impact on fungal populations may primarily derive from the survival advantages of the agent' s own microbial community, while the specific mechanisms affecting other microorganisms require further investigation.

Table 4 Influence of Trichoderma Agent on Major Biological Indicators of Arable Layer Soil in Moderately Saline Coastal Platform Fields

3. Discussion and Conclusions

Soil microorganisms play a crucial role in soil formation and are the most active components in soil. They promote the transformation and transfer of materials and energy in soil [2], while fungi are the primary microorganisms decomposing soil organic matter [18]. Introducing exogenous microorganisms alters soil microbial community structure. Liu et al. [4] studied individual mycorrhizal fungi and found that their growth forms characteristic hyphal bridges and networks that facilitate the growth and movement of bacteria and actinomycetes. Yan et al. [12] demonstrated that Trichoderma addition to soil changes rhizosphere microbial community ratios. In this experiment, the moderately saline coastal platform field soil had low microbial populations and poor soil vitality. Within 1.5 months after Trichoderma agent application, soil microbial populations increased, particularly beneficial azotobacteria, adjusting microbial community ratios, improving soil microecology, forming a healthy biosphere, and enhancing soil quality and vitality.

Soil colloid coagulation improves soil structure. Qiu et al. [19] studied the use of polysaccharides as aggregate cementing agents in arid soils, promoting the formation of soil particle aggregates and improving water retention. Feng et al. [20] utilized arbuscular mycorrhizal external hyphae to cement soil particles in the maize rhizosphere into aggregates, increasing water-stable aggregate content and improving root water content. In this experiment, the coastal saline floodplain and platform field soils contained abundant sand particles but few aggregates, with poor compaction and soil structure, whereas the solar greenhouse soil had good structure. After Trichoderma application to the moderately saline coastal platform field soil, colonization and proliferation occurred. Within 1.5 months, Trichoderma hyphae and other microorganisms captured dispersed soil particles through adsorption, entanglement, and penetration, promoting their aggregation into granules. Microbial decomposition of organic matter formed aggregate cementing agents, while microbial hyphae and secreted mucilage also served cementing functions, enhancing adhesion among soil particles [21]. This resulted in increased soil aggregates, higher water-stable aggregate content, reduced soil bulk density, and increased total porosity comparable to the solar greenhouse soil. Soil compaction increased substantially to levels comparable with the block-structured reclaimed saline coastal field, significantly higher than the coastal saline floodplain. Additionally, the Trichoderma treatment improved soil water absorption capacity, providing soil conservation and reducing water erosion [22].

Research indicates that soil microorganisms produce various organic acids during growth that chelate mineral salt ions, accelerating mineral decomposition. Microbial metabolism produces CO , increasing environmental carbonic acid content and promoting mineral hydrolysis [18]. The moderately saline coastal platform field soil was nutrient-poor but rich in water-insoluble minerals. In this experiment, the Trichoderma treatment transformed unavailable forms of potassium and phosphorus in the soil into available forms, increasing available potassium and phosphorus contents. This differs from the conclusion of Chen et al. [13] regarding Trichoderma reducing excessive nutrients in solar greenhouse soils. Trichoderma proliferation in soil promoted azotobacterial growth, enhancing soil nitrogen fixation and increasing alkali-hydrolyzable nitrogen content. Through microbial metabolism and hyphal death, various organic substances were released, increasing the diversity and quantity of soil nutrients. The increased Trichoderma and other soil microbial communities promoted material transformation and transfer in soil, expanding the sources, quantities, and transfer pathways of nutrients [23], thereby improving the quality and vitality of moderately saline coastal platform field soil.

Constructing platform fields in coastal saline areas deepens the groundwater table. In this experiment, the moderately saline coastal platform field had a salinity content of 2.99 $g \cdot kg^{-1}$ in early spring, while the coastal saline floodplain had 26.19 $g \cdot kg^{-1}$, demonstrating significant desalination effects of platform fields. Spring irrigation with Yellow River water and summer rainfall leaching further reduced salinity in the platform field. During the peak peanut growth period, the moderately saline coastal platform field salinity was 0.65 $g \cdot kg^{-1}$, while the coastal saline floodplain remained high at 21.02 $g \cdot kg^{-1}$. However, the moderately saline coastal platform field was nutrient-poor with poor soil structure, making it unsuitable for crop growth. Therefore, developing agriculture on coastal saline platform fields requires adding exogenous microbial agents to accelerate soil activation and rapidly improve soil quality and vitality. After mixing with moderately saline coastal platform field soil, Trichoderma colonized and proliferated to become a dominant microbial community. Trichoderma has a fertilizer effect buffering function, acting on soil over extended periods to provide nutrients for other microorganisms and improve soil structure, enriching soil nutrients and enhancing stability, thereby benefiting crop growth and development [24] and improving crop yield and quality [24-25]. In this experiment, the Trichoderma agent treatment improved the soil microecology of platform fields, playing a role in soil ecological improvement. The deep ditches alongside coastal saline platform fields contain high salt concentrations, and salt return occurs in platform fields during winter and spring, with limited alkali reduction effects. Additionally, soil organic matter content is low. To better utilize Trichoderma and other microorganisms to improve soil properties in coastal saline platform fields, greater organic matter input is needed, along with rational platform field height design and additional alkali reduction technologies.

References

[1] DONG Xiaoxia, WANG Xuejun, LIU Zhaohui, et al. Dynamics of groundwater table and soil desalination of platform fields at different elevations in coastal wasteland[J]. Chinese Journal of Eco-Agriculture, 2011, 19(6): 1354-1358.

[2] HE Zhenli. Evaluation of the significance of soil microbial biomass in nutrient cycle and environmental quality[J]. Soils, 1997(2): 61-69.

[3] Dilly O, Munch J C. Ratios between estimates of microbial biomass content and microbial activity in soils[J]. Biology and Fertility of Soils, 1998, 27(4): 374-379.

[4] LIU Runjin, CHEN Yinglong. Mycorrhizology[M]. Beijing: Science Press, 2007: 163-199.

[5] Elad Y. Biological control of foliar pathogens by means of *Trichoderma harzianum* and potential modes of action[J]. Crop Protection, 2000, 19(8): 709-714.

[6] ZHANG Jin, ZHANG Shuwu, XU Bingliang, et al. Determining antifungal spectrum and mechanism of *Trichoderma longibrachiatum* in vitro[J]. Chinese Journal of Eco-Agriculture, 2014, 22(6): 691-697.

[7] Harman G E, Howell C R, Viterbo A, et al. *Trichoderma* species—opportunistic, avirulent plant symbionts[J]. Nature Reviews Microbiology, 2004, 2: 43-56.

[8] Björkman T, Blanchard L M, Harman G E. Growth enhancement of shrunken-2 (sh2) sweet corn by *Trichoderma harzianum* 1295-22: Effect of environmental stress[J]. Journal of the American Society for Horticultural Science, 1998, 123(1): 35-40.

[9] Yedidia I, Srivastva A K, Kapulnik Y, et al. Effect of *Trichoderma harzianum* on microelement concentrations and increased growth of cucumber plants[J]. Plant and Soil, 2001, 235(2): 235-242.

[10] Zaidi A, Khan M S, Aamil M. Bioassociative effect of rhizospheric microorganisms on growth, yield, and nutrient uptake of greengram[J]. Journal of Plant Nutrition, 2004, 27(4): 601-612.

[11] CHEN Weijing, CHEN Jian' ai, YANG Huanming. Effect of soil ecology modifier T1010 on soil environment improvement in solar greenhouse in Shouguang City[J]. Chinese Journal of Eco-Agriculture, 2009, 17(2): 399-401.

[12] YAN Sihuang, WU Shiping, LU Deqing, et al. Effects of biocontrol strain of *Trichoderma harzianum* on microflora in rhizosphere and its interactions[J]. Southwest China Journal of Agricultural Sciences, 2005, 18(1): 40-46.

[13] CHEN Jian' ai, ZHU Wenting, LI Runfang, et al. Develop-trend of *Trichoderma aureoviride* 1010 colonization and effect on solar-greenhouse arable layer environment by regulating soil bulk density and water stable aggregate[J]. Southwest China Journal of Agricultural Sciences, 2011, 24(2): 649-653.

[14] ZHANG Yifei, ZHONG Wenhui, WANG Guoxiang. Application of microorganism in bioremediation of contaminated environment[J]. Chinese Journal of Eco-Agriculture, 2007, 15(3): 198-202.

[15] CHEN Jian' ai, WANG Weiming, LIU Yitong. Effect of *Trichoderma aureoviride* 1010 compound fertilizer on growth of peanut[J]. Journal of Peanut Science, 2008, 37(3): 29-32.

[16] SHAO Ming' an, WANG Quanjiu, HUANG Mingbin. Soil Physics[M]. Beijing: Higher Education Press, 2006: 23-36.

[17] LAO Jiacheng. Handbook of Soil Agro-chemistry Analysis[M]. Beijing: Agriculture Press, 1988: 121-391.

[18] LI Fahu. Physical Chemistry of Soil[M]. Beijing: Chemical Industry Press, 2006: 9-31.

[19] QIU Zhaoxia, ZHANG Ruobing, QIU Haixia, et al. Effects of superabsorbents containing montmorillonite and polysaccharide on soil physical properties[J]. Soil and Fertilizer Sciences in China, 2013(6): 11-16.

[20] FENG Gu, ZHANG Yufeng, LI Xiaolin. Effect of external hyphae of arbuscular mycorrhizal plant on water-stable aggregates in sandy soil[J]. Journal of Soil and Water Conservation, 2001, 15(4): 99-102.

[21] DENG Chao, BI Lidong, QIN Jiangtao, et al. Effects of long-term fertilization on soil property changes and soil microbial biomass[J]. Soils, 2013, 45(5): 888-893.

[22] ZHU Yongli, LIU Jun, WANG Yiquan. Summary of soil structure conditioners utilization[J]. Journal of Soil and Water Conservation, 2001, 15(6): 140-142.

[23] Pratt R G. Fungal population levels in soils of commercial swine waste disposal sites and relationships to soil nutrient concentrations[J]. Applied Soil

Ecology, 2008, 38(3): 245–252.

[24] CHEN Jian' ai, GUO Feng, YANG Wuhan, et al. Regulation effect of Trichoderma on the growth of peanut in coastal saline soil[J]. Journal of Peanut Science, 2014, 43(4): 19–25.

[25] LIU Lijun, HONG Jianping, YAN Shuangdui, et al. Enhancing effects of microbial fertilizer on Dangshan crisp pear quality[J]. Chinese Journal of Eco-Agriculture, 2007, 15(4): 72–74.

Supported by the Special Fund for the Industrial Technology System Construction of Modern Agriculture of China (No. CARS-14)

Corresponding authors: CHEN Weijing, E-mail: chenwj_6677@163.com; WAN Shubo, E-mail: wansbsaas@yahoo.cn

CHEN Jian' ai, research direction: applied research on microbial resources, E-mail: jianai7447@163.com

Received May 22, 2015; accepted Oct. 8, 2015

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