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RESEARCH ARTICLE

Effects of seven different companion plants on cucumber productivity, soil chemical characteristics and *Pseudomonas* community

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Abstract

Companion cropping can influence cucumber productivity by altering soil chemical characteristics and microbial communities. However, how these alterations affect the growth of cucumber is still unknown. In this study, seven different plant species were selected as companion plants for testing their effects on cucumber productivity. The effects of different companion plants on changes in soil chemical properties such as electrical conductivity (EC) and contents of essential nutrients as well as the structure and abundance of the soil *Pseudomonas* community were evaluated. The results showed a higher cucumber yield in the wheat/cucumber companion system than that in the cucumber monocultured and other companion cropping systems. The lowest phosphorus (P) and potassium (K) contents in the soil were found in the cucumber monocultured system, and the highest NO_3^+-N and NH_4^+-N contents were observed in the rye/cucumber companion system. PCR-denaturing gradient gel electrophoresis (DGGE) and real-time PCR analysis showed that the trifolium/cucumber companion system increased the diversity of the soil *Pseudomonas* community, while the chrysanthemum/cucumber companion system increased its abundance. Interestingly, plant-soil feedback trials revealed that inoculating the soil of the wheat/cucumber companion system increased the growth of cucumber seedlings. In conclusion, the effects of different companion plants on cucumber productivity, soil chemical characteristics and the soil *Pseudomonas* community were different, and wheat was a more suitable companion plant for increasing cucumber productivity. In addition, the altered microbial community caused by companion cropping with wheat contributed to increased cucumber productivity.

Keywords: cucumber, companion plants, soil chemical characteristics, *Pseudomonas* community

1. Introduction

Cucumber (*Cucumis sativus* L.) is a major greenhouse vegetable in many countries. In recent years, soil sickness has become a major obstacle for sustainable development of cucumber production. Decreased cucumber productivity that due to continuous monocropping deserves attention (Zhou *et al*. 2014). This phenomenon may be mainly due to poor soil quality caused by soil secondary salinization and nutrition imbalance (Zhou and Wu 2015), reduced diversity of soil microbial communities (Yao *et al*. 2006), and accumulation

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of phenolic autotoxins from cucumber root exudates (Yu *et al*. 2000). Various soil management practices have been used to minimize soil sickness, such as proper rotation and intercropping, management of soil and plant residue, introduction of beneficial microbes, physical removal of phytotoxins, and sterilization of the soil (Huang *et al*. 2013).

Intercropping is a cropping system in which two or more crop species are planted in the same field at the same time (Vandermeer 1992; Cong *et al*. 2015). Companion cropping is a special intercropping system that uses the special effects of companion plants on each other as well as on the soil ecological environment, pests and pathogens. Several plants have been used as companion plants for different purposes (Tringovska *et al*. 2015), such as the enhancing growth and yield of one crop and decreasing soil electrical conductivity (EC) (Colla *et al*. 2006). In our previous study, wheat as a companion plant increased watermelon growth, soil enzyme activities and microbial biomass (Xu *et al*. 2013, 2015), and garlic or onion as companion crops increased cucumber productivity and improved the soil environment (Zhou *et al*. 2011).

The community structure and diversity of soil microbes are vital to the function and sustainability of agroecosystems (Doran and Zeiss 2000; Singh *et al*. 2004; Helgason *et al*. 2010). Among the free-living microorganisms, plant growth-promoting rhizobacteria (PGPR) have received much attention. *Pseudomonas* is one of the widely distributed PGPR and plays a vital role in improving mineral nutrition, increasing the nitrogen cycle (Wackett 2003), promoting plant growth (Lifshitz *et al*. 1987), and controlling soil-borne plant pathogens (Garbeva *et al*. 2004). Several studies have shown that the imbalance of soil microbial community structure and the reduction of soil microbial diversity can both result in soil sickness (Zhou and Wu 2015). In addition, the deterioration of soil chemical characteristics is also thought to account for soil sickness (Zhou and Wu 2015). Thus, management practices that could improve the soil microbe community and soil chemical characteristics would contribute to the alleviation of soil sickness.

Different plants species have been used as companion plants. For example, white mustard (*Sinapis alba* L.) belongs to the Cruciferae, and white mustard intercropped with tomato can suppress the development of *Meloidogyne* spp. (Tringovska *et al*. 2015). Crimson clover (*Trifolium incarnatum* L.), which belongs to the Leguminosae, enhanced the growth of eggplant (*Solanum melongena* L.) as a companion plant. Companion cropping with wheat, which belongs to the Gramineae, increased watermelon growth, soil enzyme activities and microbial biomass (Xu *et al*. 2013, 2015). Therefore, in this study, we selected seven plant species that belong to the Gramineae, Leguminosae, Cruciferae and Compositae as companion plants with cucumber to examine their effects on cucumber productivity and the soil environment. Furthermore, plant diversity could affect soil microbial diversity; in turn, the changed soil community may subsequently affect plant performance, which is known as plant-soil feedback (van der Putten *et al*. 1993; Bever 1994). Thus, the goals of this study were to: 1) assess the effects of seven companion plants on the cucumber productivity, soil chemical characteristics and *Pseudomonas* community, and 2) examine the effects of soil microbes on cucumber growth using plant-soil feedback trials.

2. Materials and methods

2.1. Plant and soil materials

The cucumber (*C. sativus* L.) variety Jinzao 1 and seven companion plants, wheat (*Triticum aestivum* L.), rye (*Secale cereale* L.), trifolium (*Trifolium repens* L.), alfalfa (*Medicago sativa* L.), rape (*Brassica rapa* L.), mustard (*Brassica juncea* L.) and crown daisy chrysanthemum (*Chrysanthemum coronarium* L.), were chosen as companion plants in this study. The seeds of cucumber, trifolium, alfalfa, rape, mustard and chrysanthemum were purchased from Huawei Seed Company, Harbin, China. Wheat and rye seeds were obtained from the Laboratory of Vegetables, Physiological and Ecology, Northeast Agricultural University, China. The basic chemical characteristics of the soil used in this study were as follows: soil NH_4^+ content, 13.32 mg kg^{-1}; soil NO_3^- content, 253.04 mg kg^{-1}; available phosphorus (P) content, 277.62 mg kg^{-1}; available potassium (K) content, 359.03 mg kg^{-1}; EC (1:2.5, w/v), 0.88 mS cm^{-1}; pH, 6.64.

2.2. Greenhouse experiment

A greenhouse experiment was conducted in a plastic greenhouse at the experimental station of the Northeast Agricultural University from April 26th to July 25th on 2014. The field soil consisted of a kind of mollisol, which had been continuously used for cucumber production for 3 years. Cucumber seeds were washed for a few minutes with sterilized water and then soaked in water at 55°C for 20 min for sterilization. Then, the seeds were sown in autoclaved sand in darkness at 28°C for 2 days in an incubator for germination. After germination, the cucumber seedlings with three true leaves were transplanted into the field in rows, with 12 cucumber seedlings per row. The experiment was carried out in a randomized block design with three blocks. There were 12 cucumber seedlings per treatment in each block, and each block contained 8 treatments.

The cucumber seedlings growing alone constituted