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Soil nematode communities in jujube (*Ziziphus jujuba* Mill.) rhizosphere soil under monoculture and jujube/wheat (*Triticum aestivum* Linn.) intercropping systems, a case study in Xinjiang arid region, northwest of China

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ABSTRACT

Soil nematode community in jujube (*Ziziphus jujuba* Mill.) rhizosphere soil under monoculture and jujube/wheat (*Triticum aestivum* Linn.) intercropping systems were investigated for three years in Hetian arid area, Xinjiang Uygur Autonomous Region, northwest of China. The results showed that the density of soil nematodes in jujube orchards became larger when wheat was planted between the lines of jujube trees, mainly due to the higher numbers of *Rhabditis* and *Acrobeloides*. The bacterivores of *cp-1* and *cp-2* (*c–p*, colonizer–persister) guilds, and fungivores of *cp-2* guilds were much more in jujube/wheat intercropping system than those in jujube monoculture system, while other nematode groups had no significant difference between the two ecosystems. Although Shannon–Weaver index (*H′*), genus dominant index (*Ig*) and species richness (*SR*), showed no differences between the two systems, still lower maturity index (*MI*) and modified maturity index ($\sum MI$) with higher *PPI*/*MI* presented enriched but unstable soil food web in jujube/wheat intercropping system. Higher nematode channel ratio (*NCR*) and Wasilewska index (*WI*) in the intercropping system indicated that bacterial decomposition channel was dominant channel with higher level of soil total nitrogen content in both layers but lower organic matters in surface layer. We concluded that jujube/wheat intercropping system is good for young tree growing, but jujube monoculture system is preferred if cultivated land is sufficient.

1. Introduction

Xinjiang Uygur Autonomous Region in China exhibits unique light and heat resources with arid desert climate. On this 17% national territory, only 5% arable land has been used since external inputs were very low, although the irrigation water is available [1]. Jujube (*Ziziphus jujuba* Mill.) tree, which could adapt to lower fertile input and limited rainfall, grows well in this area. In order to fully utilize the limited arable land and get quickly economical returns, jujube/wheat (*Triticum aestivum* Linn.) intercropping were employed in this area, by planting wheat between the lines of jujube trees when jujube trees are young. Jujube and wheat were staggered in the aspect of phenological periods, thus the demand contradiction was small and the land equivalent ratio was greater than 1.0 in the intercropping system, which indicated that the jujube/wheat intercropping system was advantageous in this region [2,3]. Apart from the enhanced ability of soil respiration and water retaining capacity, soil organic matter, nitrogen, together with total number of bacteria and actinomycetes were increased in jujube/wheat intercropping system in compared with those in wheat monoculture system [4,5]. Due to its good ecological, social and economic benefits, Jujube/wheat intercropping system became one of the most widely applied agro-forestry systems in Xinjiang, northwest China [6,7].

However, there was, until now, little knowledge of soil environment changes in jujube rhizosphere, which response to soil food web diversity and structure impacted by wheat plants in jujube monoculture system, and also lack of determination of dominated

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decomposition channels for an enriched soil food web under monoculture and jujube/wheat intercropping systems.

Soil environment changes can be indicated by analyses of *in situ* nematode faunal assemblages or community structure [8]. Interpretation of nematode community structure offer excellent opportunities to assess the condition of soils or soil health and to monitor the changes in the structure and function of the detritus food web of cultivation and land use [9–11]. Besides of the most influential and sensitive, there are many other aspects of advantage superiority on using soil nematodes as bio-indicators of soil health. Moreover, soil nematode is ubiquitous and its diversity and density in soil is high enough to reflect disturbances rapidly. They can directly contact with dissolved compounds in the soil water through their permeable cuticle, also can be easily isolated and identified, and can be easily allocated to trophic groups [12,13]. In addition, soil nematodes play a significant role in the decomposition of soil organic matter, mineralization of plant nutrients and nutrient cycling [10].

Thus, in this paper, the two cultivation systems (jujube monoculture and jujube/wheat intercropping) were chosen to investigate their different effects on soil properties and nutrient levels, as well as soil nematode community structure, aiming to evaluate the rationality of jujube/wheat intercropping system, and provide guidance on the choice of a suitable development model for local jujube cultivation. The aims of this study in further points were: (1) Characterize the vertical distribution patterns and trophic composition of soil nematode community differences between monoculture and intercropping jujube system in Xinjiang arid region. (2) Determine the dominant nematode genera as central character of the two cropping systems in Xinjiang arid region. (3) Evaluate jujube rhizosphere nematode biodiversity and ecosystem functions by ecological indices under monoculture and intercropping systems.

2. Materials and methods

2.1. Site description and experimental design

Field experiments were set up in 2009 at Agro-Tech Extension and Service Center of Hetian Agricultural Scientific Research Institute (37°12′ N, 79°94′ E), Hetian Prefecture, Xinjiang Uygur Autonomous Region, China (Fig. 1). It is a typical arid climate region with annually 35 mm rainfall only, the forest-free period is 200–220 days. Annual average temperature is 13.7 °C. Total annual solar radiation is 6627 MJ/m^2. The soil at the site is classified as an Arenosol in the classification system of the Food and Agriculture Organization (FAO). Some basic physical and chemical properties of the soil are presented in Table 1.

The experimental design was a single-factor field experiment with three replicates, comprising jujube monoculture and jujube/wheat intercropping systems respectively with 2-year-old same age jujube trees. Wheat was sown in late October and harvested in June next year, while Jujube was harvested in early October. Intercropping system was designed as a replacement series, including 7 rows of wheat in 0.15 m inter-row distance, plus 2 rows of 2-year-old jujube trees, the distance between jujube trees and nearest wheat row was 0.55 m. Jujube monoculture was planting in 2-m-wide rows and 1.0 m lengthways between plants. All the three pairs of the treatments plots (12 m × 40 m) have undergone the same management consistently. All plots were applied identical amount of urea (N) at 450 kg/ha and diammonium phosphate (P) at 30 kg/ha. All P fertilizer and a half of the N were broadcast evenly and incorporated into the top 20 cm of the soil prior to wheat sowing. The remaining half of the N fertilizer was applied at wheat elongation stage. Irrigation was carried out on six occasions since late March to June for wheat. Each irrigation application consisted of 90 mm (900 m^3/ha) well water.

2.2. Sampling and procedures

Soil samples were collected in May 23, 29 and 25, respectively in the year of 2011, 2012 and 2013 during growing season of jujube in sprouting-leaf unfolding stage and wheat in booting stage.

In jujube monoculture or jujube/wheat intercropping plot (12 m × 40 m), 27 soil cores (3 subplots/replicates × 9 cores) were collected in jujube tree rhizosphere, with diagonal-line sampling method. Three soil cores were taken around the jujube tree within 0.5 m, using soil auger (I. d. 25 mm) down to two depths, i.e. surface layer (0–20 cm) and sub-surface layer (20–40 cm). Thus, a total of 162 soil samples (3 sub-plots × 9 cores × 2 layers × 3 times) were collected every year for each treatment (plot), and collected soil samples were mixed thoroughly to form a composite sample and reduce the variance associated with aggregated spatial patterns of nematodes in soil. Soil samples were stored in individual plastic bags, and immediately transferred to a 4 °C cold storage. All samples were processed within 7 days of collection.

The soil nematodes were extracted from 100 g free soil by the method of sugar flotation and centrifugation [14]. Extracted nematodes were killed at 60 °C and fixed in 5% FA (Formalin acetic acid) for genus identification. The number of nematodes was counted and individuals were identified to genus level, according to the Soil and Fresh Water Nematodes [15], Pictorial Keys of Soil Animals in China [16], and Taxonomy of Plant Nematodes [17], using an upright differential interference microscope (LEICA) [18].

Soil moisture was determined by drying the samples at 105 °C for 48 h. Soil pH value was measured in a paste of air-dried soil to solution at a ratio of 1:2 in KCl (1 mol/L) by glass electrode. Soil organic matter content was determined by burning dried soil in a muffle furnace at 490 °C for 8 h. Total nitrogen was measured following micro-Kjeldahl digestion. Available P were determined by colorimetry [19].

2.3. Nematode community

The classification of nematode trophic groups was assigned to: 1) Bacterivores, 2) Fungivores 3) Herbivores, and 4) Omnivores-Predators, based on known feeding habits or stoma and esophageal morphology [20–23]. The classification of nematode colonizer–persister (c–p) values based on life strategies according to the reports of Bongers [8,23,24].

The characteristics of nematode communities were described by the following approaches: 1) Diversity index: a) Shannon–Weaver index (H'): $H' = -\sum Pi \ln Pi$, where pi is the proportion of each taxon in the total population [25]; b) Genus dominance index (Ig): $Ig = \sum Pi^2$, where pi is the proportion of individuals in the i-th taxon [26]; c) Evenness index (J'): $J' = H'/\ln(S)$ [27]; d) Species richness index (SR): $SR = (S-1)/\ln(N)$, where S is the number of taxa and N is the number of individuals identified [28]; and e) Trophic diversity index (TD): $TD = 1/\sum Ti^2$, where Ti is the proportion of the trophic group i in the nematode community [29]. 2) Function index: a) Nematode channel ratio (NCR): $NCR = \mathrm{BF}/(\mathrm{BF}+\mathrm{FF})$ [30]; b) Channel index (CI), basal index (BI), structure index (SI), enrichment index (EI) according to Ferris et al. [31,32]; c) Wasilewska index (WI): $WI = (\mathrm{BF}+\mathrm{FF})/\mathrm{PP}$, the ratio of bacterial feeders (BF) plus fungal feeders (FF) to plant parasites (PP) [33]. 3) Maturity index: a) Plant parasites index (PPI): $PPI = \sum vi\, fi'$, where vi is the c–p value for the plant-parasitic nematodes to the i-th nematode genus and fi' is the proportion of genus in the plant-parasitic nematode community [23,34]; b) Maturity index (MI): $MI = \sum vi\, fi$, where vi is the c–p value for free-living nematodes to the i-th nematode genus and fi is the proportion of the genus in the nematode community