Improvement of red pepper yield and soil environment by summer catch aquatic crops in greenhouses

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Abstract. To investigate effects of the rotation of summer catch crops on remediation retrogressed soils in continuous cropping, a field experiment was conducted. Rice, water spinach, or cress were selected as summer catch crops; bare fallow during summer fallow was used as the control group. Results showed that aquatic crops grown in summer fallow period could effectively reduce soil bulk density and pH, facilitate soil nutrient release, and improve soil physical and chemical properties compared with those grown in fallow period. Paddy-upland rotation could improve soil microbial members and increase bacterial and actinomycete populations; by contrast, paddy-upland rotation could reduce fungal populations and enhance bacterium-to-fungus ratio. Paddy-upland rotation could also actively promote activities of soil enzymes, such as urease, phosphatase, invertase, and catalase. The proposed paddy-upland rotation significantly affected the growth of red pepper; the yield and quality of the grown red pepper were enhanced. Summer catch crops, such as rice, water spinach, and cress significantly increased pepper yield in the following growing season by 15.4%, 10.2% and 14.0%, respectively, compared with those grown in fallow treatment. Therefore, the proposed paddy-upland crop rotation could be a useful method to alleviate continuous cropping problems involved in cultivating red pepper in greenhouses.

1. Introduction
Vegetable supply is a very important matter in China with the largest human population [1]. Greenhouse environments are suitable for vegetable growth throughout the year; as such, vegetable yield is usually higher in greenhouses than in open fields [2] As commercial demands for vegetables
increase, growing vegetables in greenhouses has been recognized as a thriving industry in China. Moreover, greenhouse vegetable cropping has been increasingly popular in China; the total area allotted for greenhouse vegetable cropping reached $5 \times 10^6$ ha in 2012 [3]. Land areas for the greenhouse industry increase by 10% annually. Modern greenhouse facilities, planting modes, and technical systems have been designed and applied in particular regions for various crops. For instance, red pepper (Capsicum annuum L.) is considered as an important horticultural crop worldwide and commonly consumed in various ways in China. This crop is of economic and nutritional importance[4-7]. Furthermore, red pepper is one of the main crops in the greenhouse industry in China because this crop produces a high yield and economic profits. “Huai’an red pepper” has been considered as a national geographical trademark because this crop occupies an important position in the national red pepper market. The cultivation area of red pepper in the core region of Qingpu District in Huai’an city of Jiangsu province covers $2.7 \times 10^4$ hm$^2$; growing red peppers is a leading industry and source of income of local farmers [8]. However, continuous cropping has been associated with serious problems similar to those in other greenhouse industries; these problems severely cause soil retrogression, such as soil hardening, acidification, secondary salination, and nutrient imbalance, thereby leading to a decline in crop yield and quality [9-12]. Hence, remediation of retrogressed soils were one of the major goals of the greenhouse industry. Low-cost, highly efficient, and environmentally friendly remediation techniques should be developed to remediate retrogressed soils [13].

Drawbacks related to continuous cropping can be resolved by implementing agricultural practices. Crop rotation is one of the most simplest and efficient methods to prevent such problems [14-17]. As a worldwide trend, growing crops in monoculture has been developed, and this method is affected by several factors, such as plant habits, mechanization, economic market trends, government policies, and chemical inputs [18]. Phytoremediation by crop rotation during summer fallow to remediate retrogressed soils has been performed as an effective measure to solve problems associated with the greenhouse industry [19-21]. One of the pivotal steps in phytoremediation involves the selection of suitable catch crops for summer fallow. Scallion (Allium fistulosum var. gigantum), sweet corn (Zea mays L.), common bean (Phaseolus vulgaris L.), Garland chrysanthemum, and edible amaranth (Amaranthus mangostanus L.) have been selected as ideal summer catch crops in greenhouse soil remediation. Summer catch crops can improve microflora, increase the number of bacteria and actinomycetes, decrease the number of fungi, enhance bacterium-to-fungus ratio (number of bacteria/number of fungi; B/F), and reduce the number of Fusarium, as well as prevent nutrient loss in soils [22]. Wu et al. [23] also reported that summer catch crops, such as wheat (Triticum aestivum L.), rye (Lolium perenne), sudangrass (Sorghum sudanense (Piper) Staff), sage (Salvia officinalis), basil (Ocimum basilicum), and rape (Brassica campestris L.), can reduce electrical conductivity (EC) and available N and K contents in soils but effectively improve available P content and soil enzyme activities in soils. Rotation with Garland chrysanthemum during summer fallow also increases the yield of cucumber fruits by affecting the biomass and population of rhizosphere soil microbes in cucumbers [21]. Thus, planting crops in summer fallow positively affects soil rhizosphere microflora compared with growing crops in bare fallow; in this process, retrogressed soils can also be remediated by changing soil environment [24-27]. However, information regarding the long-term effects of
planting summer crops on soil nutrients, microbial communities, and soil enzyme activities is limited; the relationship of these parameters with the yield and quality of red pepper in greenhouses remains unclear. As such, we aim to determine the mechanism by which soil environments are affected by planting summer catch aquatic crops in the fallow period under greenhouse conditions. Gu et al. [28] found that flooding with added wheat straw for 20 d not only increases ammonium nitrogen, available phosphorus, and available potassium contents but also effectively reduces the incidence of chili pepper blight; as a result, pepper growth is promoted and chili pepper yield is enhanced. These results suggest that paddy-upland rotation may be an effective method to alleviate problems related to continuous cropping.

In this study, rice (Oryza sativa L.), water spinach (Ipomoea aquatica), and cress (Oenanthe clemuncens) were used as summer catch crops to investigate their effects on red pepper yield and quality, soil nutrients, microbial communities, and enzyme activities in greenhouses with problems related to continuous cropping. This study aimed to screen optimum summer catch crops for crop rotation in red pepper planted in greenhouses; this study also aimed to provide a theoretical basis to cultivate red pepper and establish soil micro-ecological environments.

2. Materials and methods

2.1. Materials
The pepper cultivar ‘Huai pepper 1108’ was obtained from Vegetable Research Center of Huaiyin Institute of Agricultural Sciences in Xuhuai, Jiangsu Province. The seeds were sterilized in 10% hydrogen peroxide for 15 min and washed thoroughly with distilled water, then bud-forced in a germinating box at 28 °C in a culture dish with single filter paper. Uniform sprouted seeds were chosen and sown in a 70-hole seedling tray with vegetable seedling substrates on September 10, 2012 and transplanted on October 24, 2012 with a planting space of 30 cm × 50 cm. The transplanted samples were irrigated regularly. After the plants were transplanted, the greenhouse was ventilated 9 h daily and shaded with straws.

2.2. Experimental design
This study was conducted in greenhouses at the Horticultural Experimental Station, Huai’an, Jiangsu, China, from October 2012 to June 2013. Pepper was planted in the greenhouses for four consecutive years, and the experiment was performed on the fifth year of pepper cultivation. The soil texture in the greenhouse was sandy loam with pH 7.6, and the soil layer at depths between 0 and 200 mm contained 26.61 g kg⁻¹ total organic matter, 147 mg kg⁻¹ available N, 45.4 mg kg⁻¹ available phosphate, and 302 mg kg⁻¹ available potassium. Four treatments were prepared: planting rice, water spinach, or cress during summer fallow, and fallow as the control.

2.3. Plant sampling and measurements
Plant height and stem diameter of red pepper were measured in different growth stages, including early fruiting stage (December 15, 2012), middle fruiting stage (February 18, 2013), and late fruiting stage (April 15, 2013). The fruits were harvested when red pepper reached maturity; fruit yields per plot were recorded. The total yield of each plot was calculated and converted to kg per ha.
Red pepper fruits were collected in the middle fruiting stage (February 18, 2013) to determine quality. Vitamin C, soluble sugar, soluble protein, and nitrate contents were determined through 2,6-dichlorophenolindophenol titration, anthrone colorimetry, Coomassie brilliant blue G-250 staining, and salicylic acid colorimetry, respectively. These procedures were described in details in a previous study of Li [29]. Each treatments were replicated three times.

2.4. Soil sampling
Soil samples were collected by Liu et al. [30]. Soil samples (at depths between 2 and 25 cm) were collected before aquatic crops were planted (June 10, 2012), after aquatic crops were harvested, and before pepper was transplanted (October 15, 2012). Pepper rhizosphere soils in each test plot was collected in different growth stages, including early fruiting stage (December 15, 2012), middle fruiting stage (February 18, 2013), and late fruiting stage (April 15, 2013). At each sampling site, soil samples (at depths between 2 and 25 cm) at pepper rhizosphere were collected from five spots. The collected samples were combined into a sterilized polyethylene bag and transported to the laboratory at 4 °C. One portion of each sample was stored at -40 °C for microbial analysis, and the remainder was air-dried at room temperature (25 °C to 30 °C) and sifted using a 1 mm sieve to analyze physicochemical properties and enzyme activity.

2.5. Analysis of soil enzyme activity
Soil urease (EC 3.5.1.5) activity was determined by incubating 10 g of soil with 10 mL of 10% urea solution for 24 h at 37 °C. Ammonium formation was spectrophotometrically determined at 578 nm, and ammonium activity was expressed as NH₄-N mg•g⁻¹ soil 24 h⁻¹ [31]. Soil invertase (EC 3.2.1.26) activity was determined by incubating 5 g of soil with 15 mL of 8% sucrose solution for 24 h at 37 °C. The suspension was allowed to react with 3,5-dinitrosalicylic acid, and absorbance was detected at 508 nm. Activity was expressed as glucose mg•g⁻¹ soil 24 h⁻¹ [31]. Soil catalase (EC 1.11.1.6) activity was detected by incubating 5 g of soil with 5 mL of 0.3% H₂O₂ for 30 min at 30 °C. The suspension was titrated with 0.1 mol•L⁻¹ KMnO₄ solution. Activity was expressed as 0.1 mol•L⁻¹ KMnO₄ mL•g⁻¹ soil 30 min⁻¹ [31]. Soil natural phosphatases were determined using phenylphosphate as a substrate, which was incubated in citrate buffer (pH 7.0) at 37 °C for 3 h [31]. Each sample was subjected to analysis in triplicate; data were the average of the three determined values expressed on the basis of oven-dried soils.

2.6. Evaluation of soil microorganism population
Bacterial, fungal, and actinomycete populations in the soil samples were determined via the standard dilution plate method in terms of colony forming units (cfu) [31]. A portion (5 g) of the soil samples was weighed and placed in a 200 mL shaking bottle containing 45 mL of sterile distilled water and agitated for 15 min. The homogeneous solution was then serially diluted to 10⁻² to 10⁻⁵ to inoculate bacterial, fungal, and actinomycete cultures. The bacteria extracted from the soil sample were incubated in beef broth peptone substrate. The fungi extracted from the soil sample were incubated in potato dextrose agar (PDA) substrate (3 mL of lactic acid was added per 1000 mL of substrate to control bacterial growth). The actinomycetes extracted from the soil sample were incubated in a Gause No. 1 substrate (1 mL of 3% potassium bichromate was added per 1000 mL of substrate to suppress
bacterial growth). Bacterial, fungal, and actinomycete populations were counted at 2, 3, and 7 d after these microorganisms were incubated at 28 °C, respectively. Three plates in each treatment were counted in each replicate.

2.7. Statistical analysis
The experiments were conducted in a completely randomized design. Analysis of variance (ANOVA) was performed with DPS v14.10 statistical software; means were compared by the least significant difference, tested at a significance level of $P < 0.05$.

3. Results

3.1. Effect of planting aquatic crops during summer fallow on the growth of red pepper in greenhouses

| Treatments | Early fruit stage | Middle fruit stage | Late fruit stage |
|------------|------------------|--------------------|-----------------|
|            | Plant height (cm) | Stem diameter (mm) | Plant height (cm) | Stem diameter (mm) | Plant height (cm) | Stem diameter (mm) |
| RP         | 60.18±2.42a       | 10.37±0.22b        | 81.75±3.26a      | 12.67±0.76a        | 83.17±2.95a       | 13.96±0.47a        |
| WSRP       | 59.76±1.78a       | 9.48±0.62c         | 80.19±3.16a      | 11.98±0.91b        | 81.96±1.88a       | 13.15±0.58b        |
| CRP        | 60.23±1.26a       | 10.84±0.31a        | 81.66±2.43a      | 12.05±0.86b        | 82.55±1.77a       | 14.18±0.83a        |
| FRP        | 52.87±2.56b       | 8.24±0.41d         | 70.15±2.18b      | 9.18±0.72c         | 71.69±2.86b       | 10.92±0.64c        |

RRP: rice-red pepper; WSRP: water spinach-red pepper; CRP: cress-red pepper; FRP: fallow-red pepper.

Values (mean± standard error) with different small letters in the column are not significantly different at 0.05 levels according to least significant difference (LSD) test ($n = 3$).

Plant height and stem diameter are two main indexes of plant vegetative growth. Table 1 shows that different aquatic crops planted during summer fallow could significantly improve the growth of red pepper. In the whole fruiting stage of red pepper, plant height and stem diameter in each treatment were larger than those in the control group. The largest plant height and stem diameter of CRP (the treatment of planting cress during summer fallow) were observed in early fruiting stage; these parameters increased by 7.36 cm and 2.6 mm, respectively, compared with plants grown via fallow treatment. By contrast, the largest plant height and stem diameter of RRP (the treatment of planting rice during summer fallow) were in the middle fruiting stage; these parameters increased by 11.6 cm and 3.49 mm, respectively. The largest plant height of RRP was observed in the late fruiting stage, but the largest stem diameter of red pepper was observed in CRP. The results indicated that planting aquatic crops during summer fallow could effectively promote the growth of red pepper.
3.2. Effect of planting aquatic crops during summer fallow on the quality of red pepper in greenhouses

Compared with the control group, the three aquatic crops planted in the fallow period significantly improved the quality of red pepper by increasing vitamin C, soluble sugar, and soluble protein contents and by reducing nitrate content (Table 2). The four treatments significantly increased vitamin C content and significantly reduced nitrate content; by contrast, soluble sugar and soluble protein contents did not significantly increase. Rice was subjected to crop rotation with red pepper and most significantly affected red pepper quality; vitamin C, soluble sugar, and soluble protein contents increased by 15.4%, 3.0%, and 4.7%, respectively. As a negative index of pepper quality, fruit nitrate content decreased by 37.0% in rice-red pepper rotation.

**Table 2.** Effect of planting aquatic crops in summer fallow period and fallow on nutritive quality of the following red pepper in greenhouse.

| Treatments | Vitamin C content (mg·kg⁻¹ FW) | Soluble sugar content (mg·g⁻¹ FW) | Soluble protein content (mg·kg⁻¹ FW) | Nitrate content (mg·kg⁻¹ FW) |
|------------|---------------------------------|-----------------------------------|-------------------------------------|-----------------------------|
| RRP        | 347.75±10.78a                   | 11.15±0.58a                       | 2.89±0.24a                         | 141.78±10.43d              |
| WSRP       | 323.58±11.49c                   | 10.58±0.67b                       | 2.78±0.21a                         | 178.62±12.37b              |
| CRP        | 334.41±12.65b                   | 10.96±0.88a                       | 2.91±0.41a                         | 159.71±10.98c              |
| FRP        | 301.29±10.23d                   | 10.83±0.49ab                      | 2.76±0.36a                         | 225.16±11.25a             |

RRP: rice-red pepper; WSRP: water spinach-red pepper; CRP: cress-red pepper; FRP: fallow-red pepper; FW: fresh weight. Values (mean± standard error) with different small letters in the column are not significantly different at 0.05 levels according to least significant difference (LSD) test (n = 3).

3.3. Effect of planting aquatic crops during summer fallow on soil nutrients of red pepper in greenhouses

Table 3 shows that the nutrients in the soil sample were fairly enriched. Soil density, pH, total N, and available N, P, and K were also high because an expired compound fertilizer was used in previous growing seasons in the greenhouse; by contrast, planting aquatic crops and fallow could improve soil microenvironment by reducing soil density, pH, total N, and available N, P, and K. The three aquatic crops significantly decreased soil density, pH, total N, and available N, P, and K compared with the control crop because no fertilizer was applied during rotations. Planting rice during summer fallow was the most effective among the four treatments. After the fallow period was completed, treatment by planting rice significantly improved soil microenvironment compared with the base soil of the control group; as a result, soil density, pH, total N, and available N, P, and K decreased by 7.43%, 3.96%, 12.12%, 50.48%, 21.47%, and 15.17%, respectively.

**Table 3.** Effect of planting aquatic crops in summer fallow period and fallow on soil nutrients of the following red pepper in greenhouse.

| Sampling | Density | pH | Total N | Available | Available | Available K |
|----------|---------|----|---------|-----------|-----------|-------------|
In the whole growing season of red pepper, the same patterns were observed among the dynamic changes in soil density, pH, total N, and available N, P, and K in the four treatments (Table 3). Soil density, pH, total N, and available N, P, and K increased in the early fruiting stage; afterward, these parameters decreased in the middle fruiting stage until the end of the growing season. By contrast, soil pH initially decreased in the early fruiting stage, increased in the middle fruiting stage, and remained constant until the end of the growing season. In the late fruiting stage of red pepper, the lowest soil density, pH, and available N, P, and K in RRP were observed in the four treatments. Compared with those of the control base soils, these parameters decreased by 6.61%, 1.8%, 22.03%, 18.22%, and 12.52%, respectively. However, total N in CRP was lower than that in the base soils, and the decrease was 13.94%. These results indicated that paddy-upland rotations could improve soil environment, and this trend could also be observed in crops planted in the next growing season.

| Time         | Treatments | (g•cm⁻³) | (g•kg⁻¹) | N (mg•kg⁻¹) | P (mg•kg⁻¹) |
|--------------|------------|----------|----------|-------------|-------------|
| Before fallow| Before treatment | 1.21±0.02 | 7.82±0.45 | 1.65±0.02 | 186.6±5.5 | 65.3±2.1 | 425.8±10.3 |
| RRP          | 1.12±0.01c | 7.51±0.38b | 1.45±0.03d | 92.4±2.1c | 51.2±1.2c | 361.2±11.6d |
| WSRP         | 1.13±0.02bc | 7.56±0.41b | 1.52±0.01b | 89.3±1.6d | 53.6±1.5b | 375.8±9.8b |
| CRP          | 1.14±0.01b | 7.69±0.52a | 1.48±0.02c | 96.8±1.5b | 52.3±1.6c | 368.4±10.2c |
| FRP          | 1.20±0.00a | 7.72±0.46a | 1.58±0.03a | 124.6±3.9a | 58.4±1.5a | 411.6±14.6a |
| After fallow | WSRP       | 1.18±0.02d | 7.49±0.32a | 1.83±0.03b | 218.6±3.3c | 70.5±1.9b | 498.5±13.5c |
| Early fruit stage | WSRP   | 1.20±0.01b | 7.52±0.28a | 1.79±0.01d | 235.6±4.1b | 72.5±1.8b | 510.3±11.4b |
| CRP          | 1.19±0.01c | 7.58±0.35a | 1.81±0.02c | 220.9±5.3c | 70.2±2.1b | 491.9±12.1d |
| FRP          | 1.23±0.01a | 7.61±0.44a | 1.85±0.01a | 245.2±6.6a | 78.6±2.5a | 551.4±13.8a |
| RRP          | 1.16±0.01c | 7.62±0.51a | 1.61±0.02c | 168.5±2.9c | 62.3±1.4c | 441.6±10.5c |
| Middle fruit stage | WSRP | 1.17±0.01bc | 7.63±0.48a | 1.68±0.03b | 194.2±3.5b | 65.4±1.3b | 461.2±9.6b |
| CRP          | 1.16±0.00c | 7.63±0.23a | 1.62±0.01c | 170.6±5.2c | 62.6±1.5c | 441.9±10.3c |
| FRP          | 1.18±0.01a | 7.73±0.45a | 1.72±0.00a | 201.4±5.5a | 68.9±2.1a | 491.6±11.5a |
| RRP          | 1.13±0.01b | 7.68±0.22a | 1.45±0.00c | 145.5±4.5c | 53.4±1.1d | 372.5±9.8c |
| Late fruit stage | WSRP   | 1.14±0.00b | 7.71±0.41a | 1.48±0.01b | 165.8±3.8b | 55.7±1.3b | 384.2±10.8b |
| CRP          | 1.14±0.01b | 7.72±0.26a | 1.42±0.01d | 146.3±5.4c | 54.6±1.1c | 378.7±9.7bc |
| FRP          | 1.16±0.01a | 7.83±0.43a | 1.52±0.02a | 192.5±6.8a | 59.5±1.2a | 422.1±11.5a |

RRP: rice-red pepper; WSRP: water spinach-red pepper; CRP: cress-red pepper; FRP: fallow-red pepper. Values (mean± standard error) with different small letters in the column are not significantly different at 0.05 levels according to least significant difference (LSD) test (n = 3).
3.4. Effect of planting aquatic crops during summer fallow on soil microbial community of red pepper in greenhouses

Quantity was closely related to composition changes in soil microbial flora, absorption, and soil nutrient transformation. Compared with those grown in the base soils, crops grown in three paddy-upland rotations increased bacterial population and reduced fungal and actinomycete populations. However, fallow reduced all of the tested soil microbial communities (Table 4). The planted aquatic crops were plowed and irrigated to increase soil permeability and microbial populations. In the late fruiting stage, RRP yielded the highest bacterial and actinomycete populations and the lowest fungal population. Fallow treatment resulted in the highest fungal population. Therefore, different aquatic crops rotated with pepper could significantly affect soil microflora, effectively improve community structure, and enhance soil remediation (Table 4).

After the summer fallow period, bacterial, fungal, and actinomycete populations initially increased and then decreased in the whole growing season of red pepper (Table 4); dynamic changes in single microorganism did not differ among the four treatments. Bacterial population significantly increased and significantly differed among the four treatments. The highest quantity of RRP was detected in the early fruiting stage of red pepper. The quantity of RRP also increased by 10.71% compared with that of the control group. Soil bacterial populations in WSRP (the treatment of planting water spinach during summer fallow) and CRP were higher than those in the control group; in particular, soil bacterial populations in WSRP and CRP increased by 5.31% and 6.76% in the early fruiting stage, respectively.

Table 4. Effect of planting aquatic crops in summer fallow period and fallow on soil microbial community of the following red pepper in greenhouse.

| Sampling time | Treatments | Bacteria $(10^7 \text{cfu•g}^{-1})$ | Fungi $(10^4 \text{cfu•g}^{-1})$ | Actinomyces $(10^6 \text{cfu•g}^{-1})$ |
|---------------|------------|----------------------------------|-------------------------------|---------------------------------|
| Before fallow | Before treatment | 3.35±0.13                       | 2.86±0.09                     | 2.65±0.11                      |
|               | RRP        | 3.96±0.16a                      | 2.25±0.05c                    | 2.01±0.07d                     |
|               | WSRP       | 3.88±0.12b                      | 2.36±0.04b                    | 2.16±0.05c                     |
|               | CRP        | 4.01±0.15a                      | 2.19±0.10d                    | 2.31±0.06b                     |
|               | FRP        | 3.15±0.09c                      | 2.49±0.06a                    | 2.49±0.05a                     |
|               | RRP        | 4.55±0.14a                      | 2.65±0.08d                    | 3.78±0.07a                     |
| After fallow  | WSRP       | 4.36±0.10b                      | 2.86±0.07b                    | 3.56±0.05c                     |
| Early fruit stage | CRP        | 4.42±0.12b                      | 2.77±0.03c                    | 3.68±0.06b                     |
|               | FRP        | 4.14±0.18c                      | 3.16±0.10a                    | 3.25±0.04d                     |
|               | RRP        | 4.23±0.16a                      | 2.45±0.03c                    | 4.15±0.14a                     |
| Middle fruit stage | WSRP      | 4.12±0.11b                      | 2.64±0.05b                    | 3.99±0.10b                     |
|               | CRP        | 4.22±0.14a                      | 2.41±0.12c                    | 4.11±0.14a                     |
|               | FRP        | 3.65±0.08c                      | 3.46±0.10a                    | 3.78±0.11c                     |
|          | RRP | WSRP | CRP | FRP |
|----------|-----|------|-----|-----|
| Late fruit stage | 4.1±0.11a | 2.12±0.05d | 3.46±0.15a |     |
| WSRP     | 3.98±0.09c | 2.23±0.06b | 3.28±0.12c |     |
| CRP      | 4.02±0.08b | 2.19±0.04c | 3.34±0.11b |     |
| FRP      | 3.41±0.08d | 3.11±0.08a | 2.92±0.14d |     |

RRP: rice-red pepper; WSRP: water spinach-red pepper; CRP: cress-red pepper; FRP: fallow-red pepper. Values (mean± standard error) with different small letters in the column are not significantly different at 0.05 levels according to least significant difference (LSD) test (n = 3).

The fungal population in the soils of three aquatic crop rotations significantly decreased in the whole growing season of red pepper; fungal populations also significantly differed among the three treatments. The number of fungi of RRP was lower than that of the control group; in particular, the number of fungi decreased by 16.14%, 29.19%, and 31.83% in early, middle, and late fruiting stages of red pepper, respectively. The number of fungi in CRP was also lower than that of WSRP and the control group.

Soil actinomycete populations in the four treatments increased in the early fruiting stage and reached the maximum number; soil actinomycete populations decreased in the late fruiting stage. Compared with the control group, the treatments of RRP, WSRP, and CRP significantly increased the number of soil actinomycetes. The number of soil actinomycetes in RRP was higher than that of the control group; in particular, the number of soil actinomycetes in RRP increased by 16.3%, 9.79%, and 18.49% in early, middle, and late fruiting stages of red pepper, respectively.

### 3.5. Effect of planting aquatic crops during summer fallow on soil enzyme activity of red pepper in greenhouses

Soil enzymes are important factors of soil ecosystem metabolism, and these enzymes can affect soil biological and chemical processes [32]. Soil enzyme activities varied among the treatments (Table 5). The highest activity in the soil of each treatment varied in terms of enzymes and soil samples from a specific growing season. Compared with those grown in the control soil, the three aquatic crops planted in the fallow period could significantly increase soil urease, phosphatase, invertase, and catalase activities. However, the effects of the fallow treatment were not significant. The results showed that the dynamic changes in different soil enzyme activities did not differ in individual treatments; by contrast, these changes significantly differed among the four treatments. Soil urease, phosphatase, and catalase activities in individual treatments increased in the early fruiting stage and decreased in the middle fruiting stage. Soil invertase activity in each treatment increased until the middle fruiting stage and decreased in the late fruiting stage. Compared with the control group, the three aquatic crops planted during fallow could significantly increase soil urease, phosphatase, invertase, and catalase activities in the growth stage of red pepper. Soil urease and catalase activities of RRP and phosphatase activity of CRP were the highest in the early fruiting stage; soil invertase activity of RRP peaked in the middle fruiting stage. Therefore, aquatic crop rotations could help improve soil activity and fertility.
Table 5. Effect of planting aquatic crops in summer fallow period and fallow on soil enzyme activities of the following red pepper in greenhouse.

| Sampling time | Treatments  | Urease (NH₃-N mg·g⁻¹·d⁻¹ DS) | Neutral phosphatase (Phenol mg·g⁻¹·d⁻¹ DS) | Invertase (Glucose mg·g⁻¹·d⁻¹ DS) | Catalase (0.1mol·L⁻¹ KMnO₄ mL·g⁻¹·h⁻¹ DS) |
|---------------|-------------|-------------------------------|---------------------------------------------|----------------------------------|---------------------------------------------|
| Before fallow | Before treatment | 1.75±0.09                     | 3.26±0.13                                   | 1.78±0.22                        | 1.45±0.04                                   |
| RRP           | 2.98±0.08a   | 3.82±0.12b                   | 2.89±0.13a                                 | 1.78±0.09a                       |                                             |
| WSRP          | 2.76±0.10c   | 3.66±0.14c                   | 2.57±0.11b                                 | 1.65±0.03b                       |                                             |
| CRP           | 2.87±0.08b   | 3.96±0.09a                   | 3.11±0.09a                                 | 1.81±0.06a                       |                                             |
| FRP           | 1.98±0.11d   | 3.41±0.08d                   | 2.21±0.06c                                 | 1.51±0.01c                       |                                             |
| After fallow  | RRP          | 3.97±0.12a                   | 4.78±0.11a                                 | 4.42±0.12a                       | 2.89±0.11a                                 |
| WSRP          | 3.66±0.13c   | 4.48±0.09b                   | 3.54±0.09b                                 | 2.35±0.08b                       |                                             |
| CRP           | 3.86±0.15b   | 4.82±0.06a                   | 4.37±0.13a                                 | 2.85±0.05a                       |                                             |
| FRP           | 2.98±0.12d   | 4.16±0.05c                   | 3.12±0.21c                                 | 1.95±0.02c                       |                                             |
| RRP           | 3.69±0.17a   | 4.33±0.11b                   | 4.98±0.16a                                 | 1.76±0.03b                       |                                             |
| Early fruit stage | WSRP        | 3.57±0.15b                   | 4.06±0.04c                                 | 4.27±0.22c                       | 1.55±0.02c                                 |
| CRP           | 3.71±0.16a   | 4.47±0.12a                   | 4.79±0.21b                                 | 1.85±0.05a                       |                                             |
| FRP           | 2.45±0.11c   | 3.56±0.09d                   | 3.46±0.13d                                 | 1.41±0.10d                       |                                             |
| RRP           | 3.45±0.12b   | 3.96±0.10a                   | 4.76±0.21a                                 | 1.82±0.04a                       |                                             |
| Middle fruit stage | WSRP     | 3.42±0.11b                   | 3.82±0.11c                                 | 3.98±0.17c                       | 1.58±0.05c                                 |
| CRP           | 3.52±0.15a   | 3.88±0.09b                   | 4.55±0.15b                                 | 1.78±0.07b                       |                                             |
| FRP           | 2.28±0.08c   | 3.33±0.11d                   | 3.35±0.12d                                 | 1.44±0.08d                       |                                             |
| Late fruit stage | WSRP      | 3.42±0.11b                   | 3.82±0.11c                                 | 3.98±0.17c                       | 1.58±0.05c                                 |
| CRP           | 3.52±0.15a   | 3.88±0.09b                   | 4.55±0.15b                                 | 1.78±0.07b                       |                                             |
| FRP           | 2.28±0.08c   | 3.33±0.11d                   | 3.35±0.12d                                 | 1.44±0.08d                       |                                             |

RRP: rice-red pepper; WSRP: water spinach-red pepper; CRP: cress-red pepper; FRP: fallow-red pepper; DS: dry soils. Values (mean± standard error) with different small letters in the column are not significantly different at 0.05 levels according to least significant difference (LSD) test (n = 3).

3.6. Correlation between soil properties and enzyme activities in microbial communities

Soil properties were largely determined by enzymes and microbial communities in soils (Table 6). Soil bulk density was positively correlated with soil N and available N, P, and K; soil bulk density did not also significantly affect soil enzymes and abundance of soil-borne bacteria and actinomycetes. By contrast, soil bulk density is positively correlated with the abundance of fungi. This result indicated that a decrease in soil bulk density might be related to enhance nutrient amounts in soils. Soil pH negatively correlated with soil urease, neutral phosphatase, and catalase activities. Therefore, an increase in pH likely inhibits soil enzyme activities. pH was also negatively correlated with soil...
bacterial community; thus, an increase in soil pH could reduce soil-borne bacterial populations. Total N and available N, P, and K were positively correlated with soil-resident enzymes and soil microflora. Available N, P, and K were significantly correlated with fungal and actinomycete populations. Furthermore, soil nutrients could directly affect soil microflora and composition and soil-resident enzyme activities. Bacterial population in the soil of red pepper planted in the greenhouse was positively correlated with urease, phosphatase, invertase, and catalase activities. Fungi did not significantly affect soil enzymes; however, actinomycete population was positively correlated with urease, phosphatase, and invertase activities. These results showed that an increase in soil bacteria and actinomycetes could promote soil-resident enzyme activities. Therefore, appropriate soil pH and available N, P, and K contents are key factors to promote soil-resident enzyme activities and to create microbial communities.

Table 6. Correlation analysis among soil nutrients, enzyme activity and microbial community.

| Index | DS | pH | TN | AN | AP | AK | Uase | NPase | Inv | Cat | BC | FC |
|-------|----|----|----|----|----|----|------|-------|-----|-----|----|----|
| DS    | 1  |    |    |    |    |    |      |       |     |     |    |    |
| pH    | 0.06 | 6  | 1  |    |    |    |      |       |     |     |    |    |
| TN    | 0.82 | -0.37 | 1** | 4  |    |    |      |       |     |     |    |    |
| AN    | 0.74 | -0.05 | 0.82 | 4** | 8  | 9** | 1    |       |     |     |    |    |
| AP    | 0.86 | -0.22 | 0.96 | 0.91 | 7** | 2  | 3** | 8**  | 1   |     |    |    |
| AK    | 0.81 | -0.28 | 0.96 | 0.89 | 0.98 | 8** | 4    | 2**  | 9** | 8** | 1  |    |
| Uase  | -0.21 | -0.65 | 0.21 | 0.26 | 0.17 | 0.22 | 2    | 0**  | 5   | 9   | 0  | 4  |
| NPase | 0.12 | -0.73 | 0.53 | 0.42 | 0.44 | 0.48 | 0.89 | 1    |     |     |    |    |
| Inv   | -0.28 | -0.26 | 0.04 | 0.26 | 0.06 | 0.12 | 0.86 | 0.67 | 1   |     |    |    |
| Cat   | 0.21 | -0.68 | 0.57 | 0.42 | 0.44 | 0.46 | 0.66 | 0.86 | 0.38 | 1   |     |    |
| BC    | -0.09 | -0.75 | 0.37 | 0.32 | 0.30 | 0.34 | 0.94 | 0.93 | 0.71 | 0.76 | 1  |    |
| FC    | 0.71 | 0.18 | 0.69 | 0.71 | 0.76 | 0.76 | -0.32 | -0.10 | -0.24 | -0.00 | -0.20 | 1 |
| AC    | 0.25 | -0.12 | 0.48 | 0.67 | 0.54 | 0.57 | 0.64 | 0.59 | 0.80 | 0.31 | 0.54 | 0.24 |
3.7. Effect of planting aquatic crops during summer fallow on red pepper yield and economic benefit analysis

The three aquatic crops planted during fallow significantly improved the yield of red pepper in greenhouses (Table 7). RRP, WSRP, and CRP increased pepper yield by 15.4%, 10.2%, and 14.0%, respectively, compared with the fallow treatment (FRP). However, the final total income of CRP was the highest among all of the treatments; the final total income, which increased by 57%, significantly differed compared with that of the control group. The final total incomes of RRP and WSRP were significantly higher than those of the control group; the final total incomes also increased by 24.7% and 46.5%, respectively.

| Treatments                  | RRP  | WSRP | CRP           | FRP  |
|-----------------------------|------|------|---------------|------|
| Summer yield (kg·ha⁻¹)      | 9552 | 53514| 35677.5       | 0    |
| Summer incomes (Ұ·ha⁻¹)      | 13585.2 | 87040.8 | 101605.5    | 0    |
| Yield of red pepper         | 62683.5 | 59827.5 | 61884        | 54297|
| (kg·ha⁻¹)                   |      |      |               |      |
| Incomes of red pepper       | 308601 | 291465 | 303804       | 258282|
| (Ұ·ha⁻¹)                    |      |      |               |      |
| Total incomes (Ұ·ha⁻¹)       | 322186.2 | 378505.8 | 405409.5    | 258282|

RRP: rice-red pepper; WSRP: water spinach-red pepper; CRP: cress-red pepper; FRP: fallow-red pepper.

Values with different small letters in the same line are not significantly different at 0.05 levels according to least significant difference (LSD) test (n = 3).

4. Discussion

Continuous cropping with specific crops has been considered as the main factor that contributes to cropping limitations in greenhouses [33], resulting in soil nutrient loss and imbalance. These phenomena increase the prevalence of multiple soil-borne diseases and seriously affect the normal growth of protected vegetables by impairing yield and quality [34-35]. Our result revealed that paddy-upland rotation is an effective way to prevent continuous cropping problems in the red pepper industry. He et al. [36] used two aquatic vegetables with long life spans, namely, water chestnuts (*Eleocharis dulcis*) and arrowhead (*Sagittaria sagittifolia*), to replace rice for paddy-upland rotation in vegetable facilities; this treatment can overcome cropping obstacles and significantly improve the yield of subsequently planted crops. Qian et al. [37] applied a similar strategy to investigate strawberry (*Fragaria ananassa*) and *Ipomoea* rotation and their effects on water spinach yield; strawberry and *Ipomoea* rotation can also effectively overcome continuous
cropping problems, increase cropping land index, and improve land utilization. Thus, the economic value of water spinach increases.

In this study, several aquatic summer catch crops could effectively improve the quality and growth indicators of red pepper, which is a housekeeper crop in local greenhouses. Among these crops, rice and pepper rotation (RRP) most significantly improved the growth and quality of pepper in the following growing season, followed by cress and water spinach (Tables 1 and 2). This result suggested that rice, water spinach, and cress were rotated with pepper and could effectively alleviate the adverse effects of continuous cropping soils on the growth of pepper in the following growing season; crop rotation also increased plant height, stem thickness, leaf area, and chlorophyll content. Each treatment improved the quality of peppers by reducing nitrate content and by significantly increasing soluble sugar and protein contents of red pepper. Rice, water spinach, and cress planted during fallow significantly improved pepper yield in the following growing season. RRP showed the highest pepper yield in the following growing season. Cress provided the highest economic benefit when this crop planted during fallow, followed by water spinach and rice. The most economical combination is the rice-pepper rotation, followed by cress and water spinach (Table 7). Therefore, different aquatic crops planted during fallow could increase the total income of greenhouses.

Soil secondary salinization, nutrient imbalance, increased auto-toxicity, and soil-borne diseases are the main causes of continuous cropping problems, which seriously hamper crop growth and reduce yield and quality [38]. Paddy-upland crop rotation can alleviate continuous cropping problems. The results from xerophyte and aquatic crop rotation revealed that aquatic plants not only uptake excess nutrients in soils; however, agricultural measures help distribute topsoil nutrients through irrigation, which is necessary to maintain balance of soil nutrients and reduce soil salinization [39-40]. In this study, soil bulk density and pH of rice, water spinach, and cress were significantly lower than those of fallow treatment; thus, rice, water spinach, and cress planted during fallow not only actively reduced soil bulk density and pH but also increased soil permeability. In another treatment, rice was rotated with pepper and yielded optimum results. Rice, water spinach, and cress planted during fallow could significantly reduce total nitrogen and available N, P, and K of soils, particularly in rice-pepper rotation. The lowest reduction was caused by the fallow treatment (Table 3). Therefore, planting aquatic crops help maintain soil nutrient composition and nutrient balance through excess soil nutrition uptake caused by continuous cropping.

The type and population of soil microorganisms are mainly determined by plant root exudates [41]. A specific soil microflora of a particular ecosystem was determined by nutrient composition in soils and by plant root exudates and plant biomass degradation. In agricultural practice, different crops prefer various soil nutrients; paddy-upland rotation was considered as the most efficient technique in terms of improving soil properties, maintaining nutrient balance, and increasing diversity and stability of soil microbial populations. Moreover, crop rotations and fallow treatment are also effective ways to limit pathogen proliferation because of the lack of hosts and the changes in their living environment [42]. Our results showed that the selected aquatic crops planted during fallow could significantly affect soil microbial population and composition (Table 4). Rice, water spinach, and cress planted during summer fallow significantly increased bacterial populations; by contrast, fallow treatment slightly increased bacterial populations. Among the treatments,
Cress-pepper rotation is the most effective method to decrease soil fungal populations; rice-pepper rotation is the most effective mechanism to decrease soil actinomycete populations. Agricultural measures, such as plowing, fertilization, and irrigation, are implemented before or after crop planting is performed; these measures positively affect soil permeability and fertilizer availability. Fallow treatment did not significantly affect soils. Rice, water spinach, and cress planted during fallow significantly affected soil microflora structure. These crops were conducive to microbial growth; thus, the proliferation of pathogenic fungi was inhibited and the spread of soil-borne diseases was prevented. Therefore, paddy-upland rotation can improve soil microbial composition, maintain diversity and stability of soil microbial populations, and reduce the occurrence of cropping problems in greenhouses.

Soil enzymes mainly come from soil microbial metabolic processes [43], plant root exudates, and animal and plant decomposition. Crop rotation can increase microbial diversity and enzyme activity in soils [44]. Our data demonstrated that aquatic crops planted during fallow enhanced soil urease, phosphatase, invertase, and catalase activities compared with those planted on the control sample soil. The increase in urease and invertase activities indicated that soil biological activity, hydrolysis activity of soil enzymes, and available organic nitrogen increased after aquatic crops were rotated. Inorganic nitrogen content was also enhanced possibly because organic nitrogen was released from soils. Increased soil phosphatase activity could promote decomposition and transformation of soil organic phosphorus, as well as conversion and utilization of phosphate fertilizer. Increased soil catalase activities indicated that soil oxidation was enhanced; thus, this enzyme may protect plant roots against oxidation [45]. Our data showed that soil phosphatase and catalase activities were enhanced after rice-pepper rotation was completed; this result may explain the process by which available phosphorus accumulates in soils. Sun et al. [45] found that the proliferation of fungal population in peanut planted in continuous cropping soils can significantly inhibit soil alkaline phosphatase, invertase, and urease activities; by contrast, soil bacterial and actinomycete populations increase and promote soil alkaline phosphatase, invertase, and urease activities. Yang et al. [46] reported that soil invertase and urease activities are positively correlated with the number of bacteria and actinomycetes in the rotation of green Chinese onion and cucumber, along with waxy corn and cucumber. In our study, the number of soil bacteria and actinomycetes was positively correlated with urease, phosphatase, invertase, and catalase activities in the rotation of rice, water spinach, and cress with pepper; by contrast, the number of fungi was not correlated with soil enzyme activities. This result is consistent with the conclusions of Sun et al. [45] and Yang et al. [46]. Soil bulk density was also positively correlated with total nitrogen and available N, P, and K of soils. By contrast, soil bulk density was not significantly related to enzyme activities and bacterial and actinomycete titer in soils; nevertheless, soil bulk density was significantly positively correlated with fungal titer. However, soil pH was negatively correlated with soil urease, phosphatase, invertase, and catalase activities; soil pH was also negatively correlated with soil bacterial and actinomycete titer. Therefore, soil enzyme activities were closely related to soil nutrition. Furthermore, total N and available N, P, and K were positively correlated with soil enzyme activities and microbial communities; this result suggested that available N, P, and K contents in soils should be controlled to promote soil enzyme activities and to establish beneficial microbial communities.
Therefore, paddy-upland crop rotation can improve physical and chemical properties of soil and microbial community structures in greenhouses that experience continuous cropping problems; these properties are enhanced by increasing microbial populations, soil urease, phosphatase, invertase, and catalase activities, and soil fertility. Thus, the growth and development of red pepper in the following growing season could be facilitated.

5. Conclusions
This study showed that planting aquatic crops during summer fallow could balance soil nutrient, reduce salt accumulation, increase soil microbial populations, and promote soil ecological condition. As such, growth, yield, and quality of red pepper are improved. Therefore, appropriate paddy-upland crop rotation, such as rice-pepper rotation, could be a useful method to alleviate continuous cropping obstacles experienced when red peppers are grown in greenhouses. However, whether effects can be maintained after rotation is performed should be further analyzed.

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References
[1] Tian Y Q, Zhang X Y, Wang J G and Gao L H 2013 Soil microbial communities associated with the rhizosphere of cucumber under different summer cover crops and residue management: A 4-year field experiment Sci. Hortic. 150 100-9
[2] Gao L H, Qu M, Ren H Z, Sui X L, Chen Q Y and Zhang Z X. 2010 Structure, function, application, and ecological benefit of a single-slope, energy-efficient solar Greenhouse in China HortTechnology 20 626-31
[3] Yu J Q 2011 Progress in protected vegetable production and research during “The Eleventh Five-year Plan” in China China Vegetable 2 11-23 (in Chinese)
[4] Rodoni L M, Zaro M J, Hasperué J H, Concellón A and Vicente A R 2015 UV-C treatments extend the shelf life of fresh-cut peppers by delaying pectin solubilization and inducing local accumulation of phenolics LWT - Food Science and Technology 1 408-14
[5] Singh R, Giri S K and Kotwalwale N 2014 Shelf-life enhancement of green bell pepper (Capsicum annuum L.) under active modified atmosphere storage. Food Packaging and Shelf Life 2 101-12
[6] Ahamad I, Cheng Z H, Meng H W, Liu T J, Wu C N, Ali K M, Wasila H and Rehman K A 2013 Effect of intercropped garlic (Allium sativum) on chlorophyll contents, photosynthesis and antioxidant enzymes in pepper Pak. J. Bot. 6 1889-96
[7] Yang Y H 2009 Studies on the prevention effect of PGPR in the greenhouse pepper obstacles J. Hebei Univ. Eng. (Nat. Sci. Ed.) 2 103-105 (in Chinese)
[8] Wu C W,Du X F,Gu D L,Wen T G, Yang W F,Guo X S,Wang G L, Xie Z Y and Wang W Z 2015 Effects of mulching modes on soil environment and growth of red pepper in greenhouse Jiangsu J. Agric. Sci. 2 407-14 (in Chinese)
[9] Liu L,Huang B J,Sun J,Guo S R,Li L Q and Guo H W 2013 Relationship between soil
microbial quantity, enzyme activity and soil fertility in hot pepper greenhouse soils of different continuous cropping years *Soil and Fertilizer Sciences in China* 2 5-10 (in Chinese)

[10] Guo H W, Guo S R, Liu L, Sun J and Huang B J 2012 Effects of continuous cropping on physical and chemical properties of soil, physiological resistance and ion absorption of pepper *Soils* 6 1041-47 (in Chinese)

[11] Guo H W, Guo S R and Huang B 2011. Study on soil physical and chemical properties in pepper greenhouse of different continuous cropping years. *Jiangsu Agric. Sci.*, 5, 452-455 (in Chinese)

[12] Yao H Y, Jiao X D and Wu F Z 2006 Effects of continuous cucumber cropping and alternative rotations under protected cultivation on soil microbial community diversity *Plant Soil* 284 195-203

[13] Zhou X G, Gao D M, Liu J, Qiao P L, Zhou X L, Lu H B, Wu X, Liu D, Jin X and Wu F Z 2014 Changes in rhizosphere soil microbial communities in a continuously monocropped cucumber (*Cucumis sativus* L.) system *Eur. J. Soil Biol.* 60 1-8

[14] Congreves K A, Hayes A, Verhallen E A and Eerd V L L 2015 Long-term impact of tillage and crop rotation on soil health at four temperate agroecosystems. *Soil Till. Res.* 1 17-28

[15] Spencer J L, Hughson S A and Levine E 2014 Chapter 7-Insect Resistance to Crop Rotation. *Insect Resistance Management (Second Edition)* (Amsterdam: Elsevier) p 233-78

[16] Melero S, López-Bellido R J, López-Bellido L, Muñoz-Romero V, Moreno F and Murillo M 2011 Long-term effect of tillage, rotation and nitrogen fertiliser on soil quality in a Mediterranean Vertisol. *Soil Till. Res.* 2 97-107

[17] Lehuger S, Gabrielle B, Cellier P, Loubet B, Roche R, Béziat P, Ceschia E and Wattenbach M. 2010. Predicting the net carbon exchanges of crop rotations in Europe with an agro-ecosystem model. *Agric. Ecosyst. Environ.* 3, 384-395.

[18] Bennett A J, Bending G D, Chandler D, Hilton S and Mills P 2012 Meeting the demand for crop production: the challenge of yield decline in crops grown in short rotations *Biol. Rev. Camb. Philos. Soc.* 87 52-71

[19] Li W, Cheng Z H, Meng H W, Zhou J, Liang J and Liu X J 2012 Effect of rotating different vegetables on microbiomass and enzyme in tomato continuous cropped substrate and after culture tomato under plastic tunnel cultivation. *Acta Hortic.* 1 73-80 (in Chinese)

[20] Guo R Y, Li X L, Christie P, Chen Q, Jiang R F and Zhang F S 2008 Influence of root zone nitrogen management and a summer catch crop on cucumber yield and soil mineral nitrogen dynamics in intensive production systems *Plant Soil* 313 55–70

[21] Wu Y, Zhang X, Gao L, Yuan L and Wei W 2007 Effect of different cultivation patterns on continuous cropping soil environment and cucumber growth *Chin. J. Eco-agric. (ISHS)* 761 547-54

[22] Li Y, Gao L H, Wu Y F, Guo R Y and Zhang X Y 2006 Effect of Summer Catch Crops on Soil Environment in Solar Greenhouse *J. Shenyang Agric. Univ.* 3 531-4 (in Chinese)

[23] Wu F Z, Guo X, Liu S W, Zhou X G and Yi Z H 2014 Effect of summer catch mode on root zone soil enzyme activities and soil chemical properties of continuously monocropped cucumber *J. Northeast Agric. Univ. (English Edition)* 10 29-34

[24] Marinari S, Mancinelli R, Brunetti P and Campiglia 2015 Soil quality, microbial functions
and tomato yield under cover crop mulching in the Mediterranean environment. Soil Till. Res. 145 20-8

[25] Campiglia E, Radicetti E, Brunetti P and Mancinelli R 2014 Do cover crop species and residue management play a leading role in pepper productivity Sci. Hortic. 166 97-104

[26] Gabriel J L, Garrido A and Quemada M 2013 Cover crops effect on farm benefits and nitrate leaching: Linking economic and environmental analysis Agric. Systems 121 23-32

[27] Nair A and Ngouajio M 2012 Soil microbial biomass, functional microbial diversity, and nematode community structure as affected by cover crops and compost in an organic vegetable production system Appl. Soil Ecol. 58 45-55

[28] Gu Z G, Ma Y, An X, Wang G F, Sun D and Wang Q J 2014 Effects of wheat straw with flooding on soil properties and phytophthora blight control in continuous chili pepper cropping field J. Agro-Environ. Sci. 9 1762-9 (in Chinese)

[29] Li H S 2000 Experimental Principles and Techniques of Plant Physiology and Biochemistry (Beijing:Higher Education Press) p 123-125,184,185,195-197, 246-9 (in Chinese)

[30] Liu S W,Liu S Q,Pan K,Wang L L and Wu F Z 2011 Effects of different preceding crops on soil micro-ecological environment and yield of cucumber J. Northeast Agric. Univ. (English Edition) 4 6-14

[31] Li Z G, Luo Y M and Teng Y 2008 Research Method of Soil and Environmental Microbiology (Beijing: Science Press) p 90-99,395-413 (in Chinese)

[32] Cao H, Sun H, Yang H, Sun B and Zhao Q G 2003 A review: soil enzyme activity and its indication for soil quality Chin. J. Appl. Environ. Biol. 1 105-9 (in Chinese)

[33] Wu X, Liang Y L, Hao W L, Luo A R, Peng Q and Chen C 2011 Effect of mulching mode on growth and water use of greenhouse pepper during fruiting stage Chin. J. Eco-agric. 1 54-8 (in Chinese)

[34] Wu F Z, Zhao F Y and Gu S Y 2002 Effect of the continuous cultivating cucumber on the bio-chemical properties of soil in the plastic greenhouse System Sci. Comprehensive Studies in Agric. 18 20-2

[35] Liang Y L, Chen Z J, Xu F L, Yan Y G, Du S N, Zhang C E 2003The effect of continuous cropping year on physiological characteristics of cucumber in sunlight greenhouse Acta Botanica Boreali-occidentalia Sin. 23 1398-1401 (in Chinese)

[36] He S M, Yang Y J, Li B Y and Xu M F 2005 Application of an efficient planting mode of greenhouse vegetables and water chestnut rotation Jiangsu Agric. Sci. 1 74-5 (in Chinese)

[37] Qian Y M, Zhao M Z, Wu W M, Wang Z W, Wang J, Yu H M,Cai W J and Zhang Z 2012 Preliminary study on water spinach cultivation under the mode of greenhouse strawberry and water spinach rotation Jiangsu Agric. Sci. 12 167-8 (in Chinese)

[38] Yu J Q and Du X S 2000 Soil-sickness problem in the sustainable development for the protected production of vegetables J. Shenyang Agric. Univ. 2 124-6 (in Chinese)

[39] Xiong H Y, Li T X and Yu H Y. 2008. Amount of soil microorganism and influencing factor of different no-tillage years in “paddy-upland” rotation systems J. Wuhan Univ. (Nat.sci.ed.) 2 244-8 (in Chinese)

[40] Xiong H Y, Li T X, Yu H Y and Zhang X 2008 Microbial characters in no-tillage soil with paddy-upland rotation Plant Nutr. fertilizer Sci. 1 145-150 (in Chinese)

[41] Hu Y S, Wu K, Liu N, Chen H G and Jia X C 2004 Studies in microbial population dynamics
in the cucumber rhizospheres at different developmental stages *Sci. Agric. Sin.* **10** 1521-6 (in Chinese)

[42] Wang Y, Shen Q R and Shi R H 1996 Soil microbial biomass and its ecological effects *J. Nanjing Agric. Univ.* **4** 45-51 (in Chinese)

[43] Zimmermann S and Frey B 2002 Soil respiration and microbial properties in an acid forest soil: effects of wood ash *Soil Biol. Biochem.* **34** 1727-37

[44] Miller M and Dick R P 1995 The stability and activity of soil enzymes as influenced by crop rotations *Soil Biol. Biochem.* **27** 1161-6

[45] Sun X S, Feng H S, Wan S B and Zuo X Q 2001 Changes of main microbial strains and enzymes activities in peanut continuous cropping soil and their interactions *Acta Agro. Sin.* **5** 617-20 (in Chinese)

[46] Yang F J, Wu H T, Wei M and Shi Q H 2009 Effects of rotation and fallowing on the microbial communities and enzymes activities in a solar greenhouse soil under continuous cucumber cropping *Chin. J. Appl. Ecol.* **12** 2983-8 (in Chinese)