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Communication

The Effects of Catch Crops on Properties of Continuous Cropping Soil and Growth of Vegetables in Greenhouse

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Abstract: Continuous cropping has become a key factor limiting the sustainable development of greenhouse vegetables. It is a matter of great importance to maintain and improve the effective fertility of greenhouse soil. Catch crops planted as green manure is an effective method to improve soil quality. In order to determine the effects of catch crops on soil characteristics and the growth of afterculture vegetables, onion, corn, wheat, soybean and cabbage were planted as catch crops for two years during the summer fallow season, with no catch crop as CK. The results showed that the total porosity and organic matter content of the soil, with corn and wheat as catch crops, was significantly increased by 2.93%, 5.25% and 21.32%, 51.61%, respectively, while pH was decreased, compared with CK. The urease, sucrase, invertase, catalase and FDA enzyme activity of the soil with corn and wheat as catch crops was significantly increased by 30.14% and 30.21%, 14.81% and 25.31%, 15.43% and 15.21%, 29.37% and 28.69%, 46.32% and 44.23%. Meanwhile, the enzyme activity of the soil was increased with each catch crop planted. The amount of culturable bacteria and actinomycetes in the soil with corn and wheat as catch crops was increased by 33.42% and 38.12% at the period of 150dayII, while fungi was decreased by 59.95%. The yield of vegetables with corn and wheat as catch crops significantly increased by 5.59~13.33% and 4.35~11.18% compared with CK. Overall, catch crops could improve the soil quality as well as the growth of afterculture vegetables.

Keywords: catch crops; soil properties; soil enzymatic activity; soil microbial quantity; yield of vegetables

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1. Introduction

China has the largest greenhouse area in the world, since greenhouse vegetable cultivation has developed rapidly for whole-year production for economic benefit [1,2]. Greenhouses generate much more yield and income than open-field cultivation because of their more favorable environment for vegetable growth [3]. However, continuous cropping, a common practice in greenhouses, has caused obstacles to plant growth, such as secondary salination, imbalance in the soil's nutrient supply and a serious environmental problem [4,5]. Meanwhile, the excessive application of mineral fertilizer leads to decreased soil quality [6,7] and reduced food quality [8]. In northern vegetable greenhouses, planting cover crops with the addition of catch crops in the summer fallow season (the high temperature is not suitable for growing vegetables), to a certain extent, can retain the original planting system, improve the soil environment and reduce continuous cropping obstacles [9].

The physical and chemical properties of soil are crucial for agricultural production and the sustainable use of agricultural land [10]. The incorporation of catch crops into soil increase its organic matter and total porosity, change the C/N and decrease the soil bulk density [11–13]. Soil enzymatic activity is an essential parameter of the soil quality [14], which can be enhanced by catch crops [12,15]. Meanwhile, catch crops affect the richness and diversity of soil microbial communities [16]. Soil microorganisms have crucial roles in the maintenance of soil health, sustainability, nutrient cycling and thus crop production [17,18].

Catch crops are important for sustainable agricultural development [19]. The effects of different catch crops are various. Sweet corn as a summer catch crop significantly increases nitrogen retention and reduces nitrogen leaching in protected vegetable production systems [5]. Exogenous N is added to the agroecosystem through atmospheric N2 fixation from legumes [20]. Wheat as a catch crop can increase soil fertility and plant yield [21]. Mustard, buckwheat and common cabbage as catch crops inhibit soil-borne diseases [22]. Root exudates of onion can directly affect the soil fungi and bacteria [23].

In this experiment, onion, corn, wheat, soybean and cabbage as catch crops were planted in the summer fallow season of the greenhouse. We hypothesized that catch crops could enhance the yield of vegetables by altering soil physicochemical properties. Our aim is to explore the change in soil physicochemical properties, enzyme activities, microbial biomass and the yield of afterculture vegetables through different catch crops. This study will provide theoretical support for improving greenhouse soil.

2. Materials and Methods

2.1. Materials and Experiment Design

A protected cultivation experiment was conducted from July 2015 to June 2017 at the vegetable base of Dasima Manor, Qingxian County, Cangzhou City, Hebei Province (38°63′ N, 116°82′ E). The greenhouse was used to continuously plant vegetables for 20 years. The soil was saline, and the surface soil (0–20 cm) properties are shown in Table 1.

Table 1. The basic soil properties.

pH	Bulk Density g cm^{-1}	Electric Conductivity mS cm^{-1}	Organic Matter g kg^{-1}	Total N g kg^{-1}	Alkali Hydrolyzed Nitrogen mg kg^{-1}	Available Phosphorus mg kg^{-1}	Available Potassium mg kg^{-1}
8.12	1.30	1.32	18.56	1.40	158.50	109.27	169.00

Seeds of five catch crops including onion (yellow onion), corn (zhengdan 958), wheat (hengmai 29), soy (zhonghuang 30) and cabbage (jinpin) were bought from the market. The seeds of cherry tomato (qianxi CL032), melon (boyang 61), eggplant (zilui 4) and pumpkin (beifen F1) were provided by the base.

The greenhouse in the experiment was built in 2005, which consisted of a common wall structure, with a length of 60 m, a width of 6.2 m and a total area of 372 m^2. Six treatments were set up: onion, corn, wheat, soy and cabbage were five of the catch crops, with CK as a blank control (with no catch crop). Each treatment was set up with three repetitions, and each repetition's area was 6 × 1.5 m with random block arrangement. The seed amount of each catch crop was 30 kg·ha^{-1}, uniformly sewn for each repetition. The catch crops were planted from July to August in 2015 and July to August in 2016 at the same plot, respectively. Then, the overground part of the catch crops was crushed and overturned into the soil in August. Cherry tomato, melon, eggplant and pumpkin were planted from September to December 2015, January to June 2016, September to December 2016 and January to June 2017, respectively. The plant density of the vegetable species was 35 × 40 cm, with consistent management. The 300 kg ha^{-1} compound fertilizer (NPK (15:15:15)) was uniformly applied each time before the vegetable planting.

2.2. Determination Index and Method

There were four periods: the first and second periods, 30 days and 150 days after the catch crops were crushed and overturned into the soil, in 2015, are named 30dayI and 150dayI, respectively. The third and fourth periods, 30 days and 150 days after the catch crops were crushed and overturned into the soil, in 2016, are named 30dayII and 150dayII. Fresh soils were determined for soil enzyme activity and the soil cultivable microbial count. Air-dried and sieved (<2 mm) soils were used for chemical properties analyses.

Soil pH and electrical conductivity (EC) were determined by mixing soil with deionized water at 1:5 and 1:2.5 (w/v), respectively. The mixture was manually shaken for 30 min, and the reading was taken using pH meters (pH-400, Spectrum Technologies, Inc., Aurora, IL, USA) and an electrical conductivity meter (DDS-307A, Shanghai Yoke Instrument Co., Ltd., Shanghai, China) [24]. Bulk density, total porosity and organic matter content of the soil were detected using the methods of Bao [25]. The activities of soil urease (expressed as mg NH_4^+-N g^{-1} soil d^{-1}) and neutral phosphates (expressed as mg phenol g^{-1} soil d^{-1}) were determined by indophenol blue colorimetric method and benzene disodium phosphate colorimetric method, respectively [25]. Sucrase activities (expressed as mg glucose g^{-1} soil d^{-1})and catalase (expressed as mg H_2O_2 g^{-1} soil d^{-1}) were determined by 3, 5-dinitrosalicylic acid colorimetric method and potassium permanganate colorimetric method [26]. FDA (fluorescein diacetate, expressed as μg fluorescein g^{-1} soil h^{-1}) activity was determined using the method described by Taylor [27].

The amounts of soil cultivable bacteria, fungi and actinomycetes were detected using the standard 10-fold dilution plating method. Specifically, beef extract medium was used for the characterization of total bacteria population, Martin medium for fungi and Gause NO. 1 medium for actinomycetes [28]. The data were expressed as the number of per gram dry soil.

Six plants were randomly selected from uniform plants in each plot in order to measure plant height, stem diameter, maximum leaf length and width of cherry tomato, melon, eggplant and pumpkin. The yields of the vegetables were the weight of all ripe fruits throughout the growing period.

2.3. Statistical Analysis

Data analyses were performed using SPSS software (SPSS, Chicago, IL, USA) and Microsoft Excel 2010. The significance of differences between treatments was evaluated by Duncan's new multiple range test (different small letters represented significant difference at 0.05, $p < 0.05$).

3. Results

3.1. Soil Physical and Chemical Properties

The physical and chemical properties of soil with different treatments were different (Figure 1). When the catch crops were planted, the pH, EC and bulk density of the soil showed a trend of decreasing, except with CK. At the period of 150dayII, the pH, EC and bulk density of the soil with corn and wheat as catch crops was the lowest, 4.68% and, 4.74%, 15.41% and 16.66%, 12.41% and 13.34%, significantly lower than CK, respectively. On the contrary, when the catch crops were planted, the organic matter content and total porosity of the soil showed a trend of increasing, except with CK. At 150dayII period, the soil organic matter content and total porosity of corn and wheat as catch crops was the highest, at 56.98%, 57.61%, 5.36% and 5.25%, significantly higher than CK. This showed that the physical and chemical properties of soil were improved by catch crops, particularly corn and wheat as catch crops.

3.2. Soil Enzyme Activities

The soil sucrase, neutral phosphates, catalase and FDA enzyme activities of CK all decreased, except urease (Figure 2). With the catch crops planted, urease, sucrase, neutral phosphates, catalase and FDA enzyme activities of the soil showed a trend of increasing. At the period of 150dayII, the five soil enzymes, urease, sucrase, neutral phosphates, catalase and FDA enzyme activities of the soil with corn and wheat as catch crops were the highest, at 30.14% and 30.21%, 14.81% and 25.31%, 15.43% and 15.21%, 29.37% and 28.69%, 46.32% and 44.23%, significantly higher than CK.

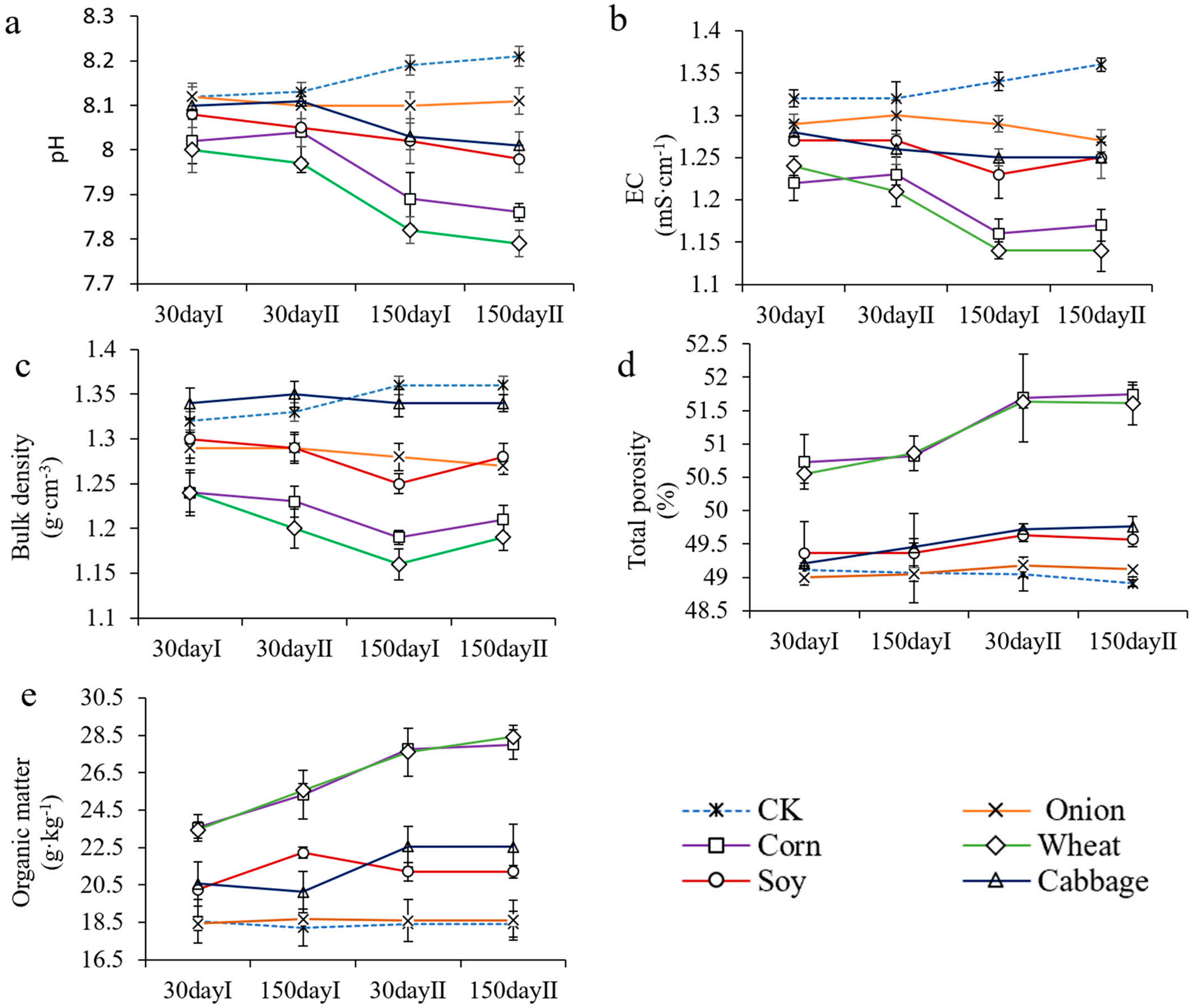

Figure 1. Effects of different catch crops on soil physical and chemical characters. pH (**a**), EC (**b**), Bulk density (**c**), Total porosity (**d**), Organic matter (**e**). CK–blank control with no catch crop.

3.3. The Amounts of Soil Cultivable Bacteria, Actinomycetes and Fungi

All the treatments increased the amount of soil cultivable bacteria (Figure 3). The soil-cultivable bacteria amount of corn and wheat as catch crops was the highest. At the period of 30dayI, this was 17.15% and 17.33%, significantly higher than CK, and at the period of 150dayII, it was 33.42% and 38.12% significantly higher than CK. The amount of soil-cultivable actinomycetes increased with the catch crops planted. At the period of 150dayII, the soil cultivable actinomycetes amounts of corn and wheat as catch crops were the highest. At the period of 30dayI, the amount of soil-cultivable fungi with the treatment of wheat as a catch crop was the highest and was 28.02% higher than CK. At the period of 150dayII, the amounts of soil-cultivable fungi with all treatments were significantly lower than CK, of which corn as the catch crop was the lowest, 59.95% lower than CK. The soil-cultivable fungi amount with all treatments, at the period of 150dayII, was lower than at the period of 30dayI. This showed that cultivable bacteria and actinomycetes amounts were increased by catch crops; on the contrary, the amount of soil cultivable fungi was decreased, particularly the treatment of corn and wheat as catch crops.

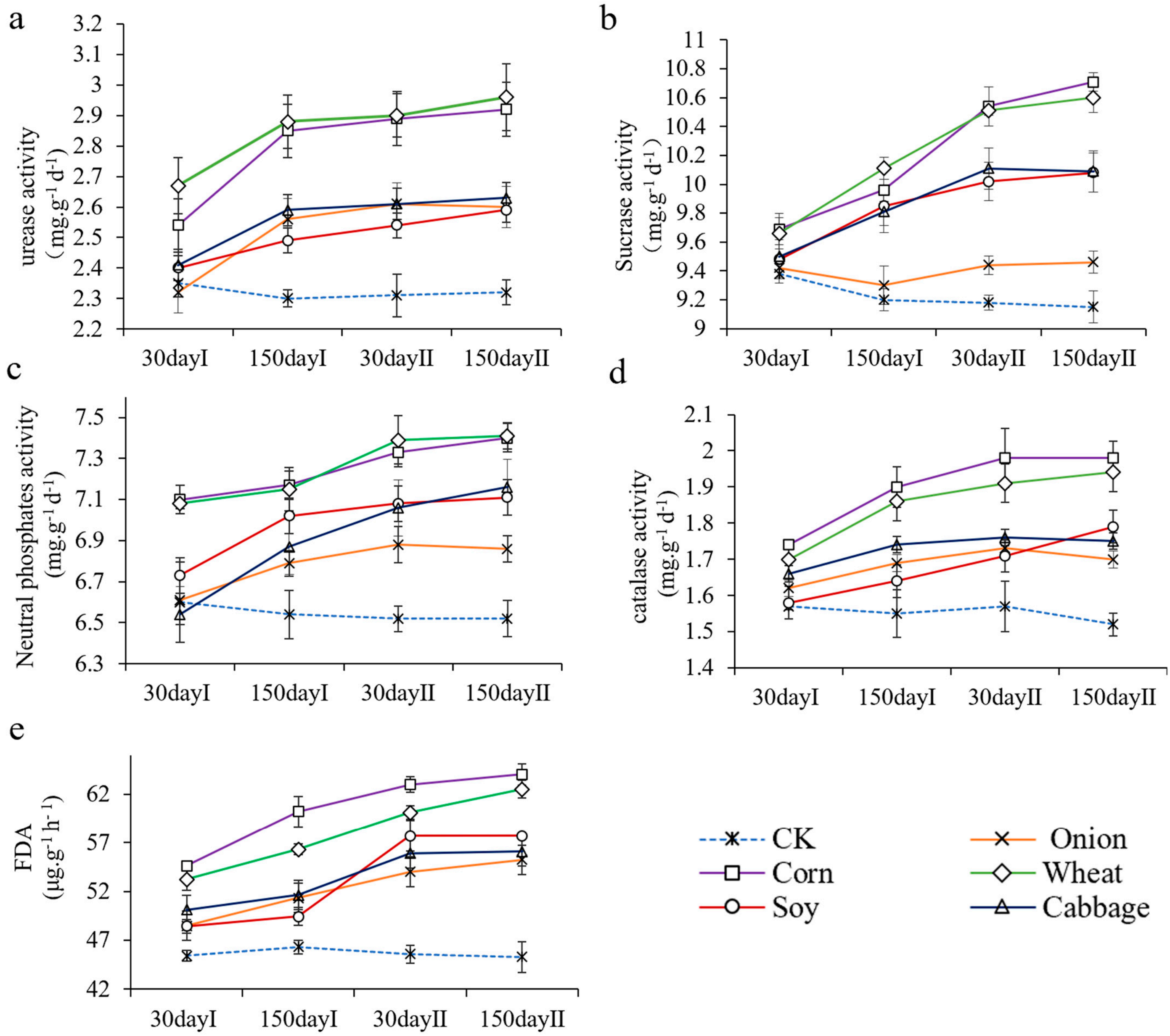

Figure 2. Effects of different catch crops on soil-enzyme activities. Urease activity (**a**), Sucrase activity (**b**), Neutral phosphates activity (**c**), Catalase activity (**d**), Organic matter (**e**). FDA–fluorescein diacetate, expressed as μg fluorescein g^{-1} soil h^{-1}.

3.4. The Growth and Yield of the Vegetables

Catch crops could promote the growth and yield of vegetables (Table 2, Figure 4). The plant height and stem diameter of the four vegetables with corn and wheat as catch crops was significantly higher than CK. The yields of cherry tomato, melon, eggplant and pumpkin were 13.33% and 11.66%, 5.59% and 4.35%, 12.94% and 11.18%, 12.94% and 11.18% with the treatment of corn and wheat as catch crops, significantly higher than CK. There was no significant difference between other treatments.

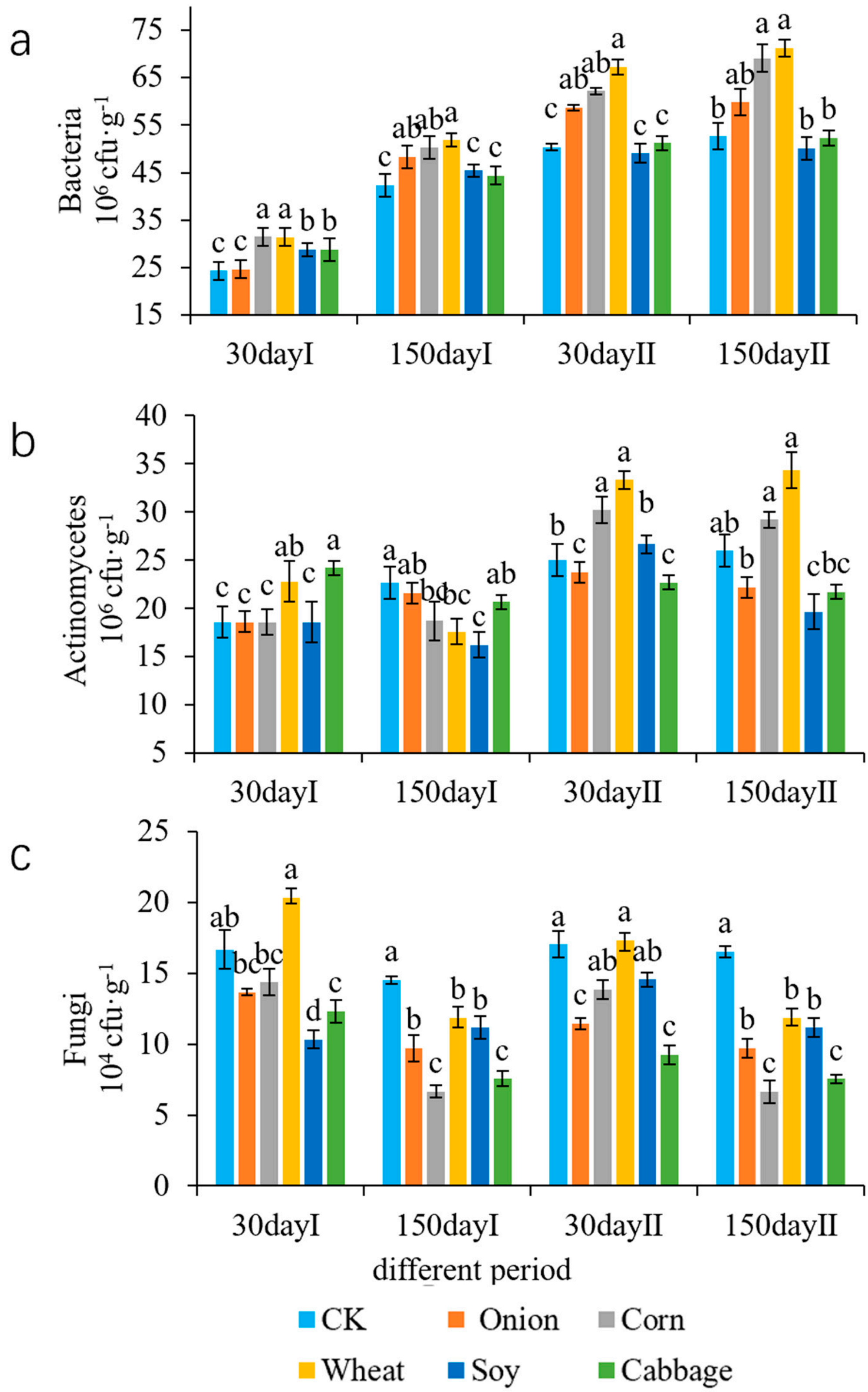

Figure 3. Effects of different catch crops on amounts of soil cultivable bacteria, actinomycetes and fungi. Bacteria (**a**), Actinomycetes (**b**), Fungi (**c**). Different small letters represent significant difference at 0.05 level by Duncan's test.

Table 2. Effects of different catch crops on the growth of vegetables.

Vegetable	Treatment	Plant Height cm	Stem Diameter mm	Leaf Length cm	Leaf Width cm
Tomato	CK	137.46 ± 4.31 b	9.08 ± 0.74 c	48.15 ± 2.12 b	43.30 ± 2.01 b
	Onion	139.15 ± 3.20 b	10.24 ± 0.85 b	49.10 ± 2.01 ab	43.67 ± 1.87 b
	Corn	141.2 ± 1.28 b	10.31 ± 0.65 ab	50.25 ± 2.98 a	44.73 ± 3.45 a
	Wheat	158.15 ± 5.71 a	10.89 ± 0.41 ab	48.90 ± 3.01ab	44.85 ± 2.01 a
	Soy	122.9 ± 3.04 c	10.33 ± 0.88 ab	45.21 ± 1.98 c	43.13 ± 1.80 b
	Cabbage	142.35 ± 1.87 b	11.24 ± 1.07 a	45.85 ± 2.07 c	42.03 ± 2.75 c
Melon	CK	212.12 ± 5.87 b	10.76 ± 0.65 b	32.95 ± 1.65 b	23.50 ± 1.02 ab
	Onion	215.27 ± 8.71 b	10.74 ± 0.47 b	33.04 ± 1.98 b	24.03 ± 0.87 ab
	Corn	226.53 ± 7.12 a	11.28 ± 0.87 ab	33.16 ± 1.21 b	23.37 ± 1.44 ab
	Wheat	226.15 ± 4.34 a	11.75 ± 0.24 a	34.17 ± 1.74 a	24.31 ± 2.00 a
	Soy	218.50 ± 4.17 ab	10.89 ± 0.87 ab	33.36 ± 2.09 b	23.60 ± 1.81 ab
	Cabbage	219.14 ± 4.21 ab	10.72 ± 0.74 b	33.86a ± 0.98 b	22.63 ± 0.87 b
Eggplant	CK	109.12 ± 2.07 b	15.10 ± 0.89 b	39.99 ± 2.01 b	29.97 ± 0.54 c
	Onion	109.24 ± 3.21 b	15.03 ± 1.45 b	39.80 ± 2.34 b	29.91 ± 1.54 c
	Corn	112.08 ± 2.01 a	15.64 ± 1.89 a	41.22 ± 2.78 a	31.02 ± 1.55 a
	Wheat	113.19 ± 2.22 a	15.62 ± 1.98 a	41.64 ± 1.87 a	30.97 ± 1.95 a
	Soy	109.48 ± 2.14 b	15.17 ± 1.64 b	40.11 ± 1.02 b	30.41 ± 1.74 b
	Cabbage	109.01 ± 0.87 b	14.96 ± 1.44 b	40.03 ± 1.12 b	29.89 ± 1.07 c
Pumpkin	CK	195.32 ± 4.54 c	9.10 ± 0.85 b	27.06 ± 0.87 c	25.50 ± 0.87 b
	Onion	194.11 ± 4.78 c	9.40 ± 0.65 b	27.80 ± 1.02 b	25.37 ± 1.47 b
	Corn	212.03 ± 5.67 a	10.21 ± 0.79 a	28.22 ± 1.32 a	26.58 ± 2.07 a
	Wheat	210.34 ± 7.43 a	10.35 ± 1.26 a	28.34 ± 0.96 a	26.66 ± 2.14 a
	Soy	205.28 ± 4.21 b	9.12 ± 0.87 b	27.61 ± 1.01 b	25.49 ± 1.54 b
	Cabbage	197.06 ± 3.23 c	9.06 ± 0.80 b	27.08 ± 0.88 c	25.61 ± 1.12 b

Note: Different small letters represented significant difference at 0.05 level by Duncan's test.

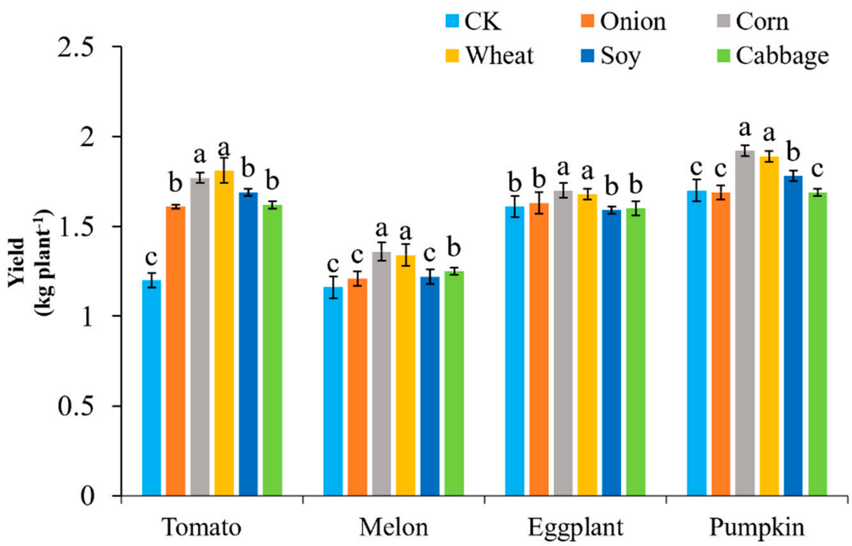

Figure 4. Effects of different catch crops on the yield of vegetables. Different small letters represent significant difference at 0.05 level by Duncan's test.

4. Discussion

In the vegetable greenhouse during the summer fallow season, catch crops cultivation reduced nitrate leaching, decreased soil bulk density and increased soil C and N content [6,8,11]. When being incorporated into the soil, catch crops biomass become the organic matter precursor, enhance the intensity of microbiological processes and improving the soil enzymatic activity [29,30]. Furthermore, soil enzyme activity is positively correlated with soil organic matter content [10]. Catch crops contributed to the formation of the soil's organic matter, which, in turn, induced greater soil loosening (soil bulk density, soil total porosity and soil compaction) [13]. Analyzing the results of our research, we note that the soil's total porosity and soil organic matter content treated by catch crops, particularly corn and wheat, were significantly enhanced compared with CK. In contrast, the pH was decreased (Figure 1). Meanwhile, the pH, EC and bulk density of the soil made a trend of decreasing with the number of catch crops that were planted. Total porosity and organic matter showed a trend of increasing. It could be seen that the effect of catch crops on soil was sustainable. Catch crops improve soil moisture and thermal conditions, while these, in turn, determine soil enzymatic activity [31]. Harasim et al. [13] found that catch crops mixed with legumes (faba bean + spring vetch) promoted improved soil structure, soil particle-size distribution, soil bulk density and soil moisture content, and the activities of soil urease and catalase enzymes significantly increased. Qian et al. [32] found that straw returning significantly increased soil urease, catalase and phosphates activity. The study showed that all five catch crops could increase the soil enzyme activity. At the period of 150dayII, urease, sucrase, neutral phosphates, catalase and FDA enzyme activities of the soil with corn and wheat as catch crops were the highest. Meanwhile, the soil enzyme increased with the number of catch crops planted (Figure 2).

Soil microorganisms are the key factors associated with soil quality, fertility and productivity [33,34]. Accordingly, the amount and species of soil microorganisms affect the growth, development and health status of plants [35]. Tian et al. [36] found that planting Welsh onion as a cover crop in the summer fallow period and rotating vegetable chrysanthemum and tomato could increase the amount of bacteria and decrease the amounts of fungi. Zhang et al. [37] found that the continuous cropping of cucumber in a greenhouse for 30 years accumulates a lot of nutrients in soils, and green soybean and peanut increase the microbial diversity and reduce NO_3-N contents. In the experiment, we noted that corn and wheat as catch crops significantly increased the amounts of soil cultivable bacteria and actinomycetes compared with CK (Figure 3). At the period of 150dayII, the amount of soil-cultivable fungi with all treatments was significantly lower than in CK. However, we only studied the amounts of soil culturable bacteria, fungi and actinomycetes. The effects of different catch crops on soil microbial diversity would be studied in the next step.

Wheat as a catch crop increased soil fertility and crop yield [21,38]. Sweet corn significantly increased nitrogen retention and reduced nitrogen leaching as summer catch crop in protected vegetable production systems [5]. Analyzing the results of our own research, we note that catch crops could promote the growth and yield of vegetables (Table 2, Figure 4). The yield of cherry tomato, melon, eggplant and pumpkin with the treatments of corn and wheat as catch crops significantly increased compared with CK. Catch crops appear to increase the physicochemical properties of soil, enhance the soil enzyme activity and ultimately provide a favorable environment for the growth of vegetables. Previous research has shown that root exudates of catch crops promote the increase in soil microbial biomass and diversity, as well as the growth of plants [39–41]. Meanwhile, we found that the effect of catch crops was persistent, and the growth of multiple plants was affected by catch crops. Similar results were reported by Acua and Villamil [42] and Wu et al. [9].

In the experiment, we studied the effects of different catch crops on the soil quality of greenhouses and the growth of vegetables, systematically. Catch crops increased the quality of soil and the growth of vegetables, particularly with corn and wheat as catch crops. Organic matter content was increased, pH was decreased and the amounts of culturable bacteria and actinomycetes of the soil were increased. Thus, the activities of soil enzymes was increased, and ultimately, the growth of vegetables was promoted by catch crops. Ideal catch crops possess the capacity of a short growth period, rapid growth rates, high biomass and strong absorbability of soil mineral N [43]. Corn and wheat as catch crops exactly fit the requirements. Possibly, this was the reason for corn and wheat being the best choice for catch crops.

5. Conclusions

Onion, corn, wheat, soybean and cabbage as catch crops, particularly corn and wheat, could enhance the yield of vegetables by altering soil physicochemical properties. Organic matter content and total porosity were increased, while pH, EC and bulk density were decreased. Additionally, corn and wheat as catch crops significantly increased the activities of soil urease, sucrase, invertase, catalase and FDA enzyme. The amounts of culturable bacteria and actinomycetes of the soil were increased by catch crops, and in contrast, fungi decreased. Overall, corn and wheat as catch crops have potential; they could increase the quality of greenhouse soil and promote the growth of vegetables. This study will provide theoretical support for improving greenhouse soil and the effects on soil microbial diversity should be studied in the next step.

Author Contributions: Y.Q. and L.N. designed the experiments. Y.Q. performed the experiments. Y.Q. analyzed the data. Y.Q. wrote the manuscript. R.Z., F.J., M.S. and X.W. gave valuable comments on the manuscript. All authors have read and agreed to the published version of the manuscript.

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