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Effects of Rice-duck Cropping Mode on Soil Enzyme Activities

Haixia Guo[1], Kang Li[2], Fuyuan Lai[3], Xie Wang[4,*]

[1]Key Laboratory of the Philosophy and Social Sciences of Sichuan Province on the Monitoring and Evaluation of the Utilization of Rural Land, Chengdu Normal University, Chengdu Sichuan 611130, China
[2]Sichuan Arts and Physical Education High School, Chengdu Sichuan 610203, China
[3]Fuyuan County Industrial Investment Group Co., Qujing Yunnan 655500, China
[4]Institute of Agricultural Resources and Environment, Sichuan Academy of Agricultural Sciences, Chengdu Sichuan 610066, China
*Corresponding author: wangxiechangde@hotmail.com

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Abstract Rice-duck farming is one of the emerging ecological cropping modes in paddy fields in China. Soil enzyme play an important catalytic role in nutrient transformation and organic matter decomposition in soil, and their activity is an important indicator of soil fertility and quality. In this study, the effect of rice-duck cropping on soil enzyme activities in paddy fields was analyzed, and the results show that: (1) soil catalase activity was significantly higher under rice-duck cropping model; (2)soil harvesting time had a significant effect on the activities of urease, alkaline phosphatase and catalase, in which soil urease activity showed a gradual increasing trend, with after rice harvesting (ARH) > before transplanting (BT) > before ducks releasing (BDR), soil alkaline phosphatase activity showed a tendency to increase and then decrease, with BT > ARH > BDR, and soil catalase showed a tendency of gradual decrease, with BT > BDR > ARH; (3) there was no significant difference in the activities of urease, alkaline phosphatase and catalase among different soil layers. Thus, this study concluded that rice-duck cropping mode optimizes the enzyme environment of paddy soil by enhancing catalase activity.

Keywords: *Rice-duck Cropping Model, Soil enzyme, Catalase*

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1. Introduction

Rice-duck co-cropping is a novel ecological planting mode in paddy fields in China. This ecological mode enables the organic integration of two different ecological economies--planting rice and breeding animals, and uses the same paddy field space for both farming and breeding. It makes full use of the resources of light, heat, and water in the paddy field, which increases economic outputs of the paddy ecosystems, and is good for environment [1,2]. Numerous studies have demonstrated that the activities of ducks in the rice-duck cropping model can enhance the field environment and increase organic fertilizer, which is conducive to the improvement of the rice field soil environment [3,4,5].

Soil enzymes play an important catalytic role in the transformation of nutrients and decomposition of organic matter in the soil, and their activity can not only be used as an important indicator for evaluating the fertility and quality of the soil, but also reflects the direction and intensity of the biochemical reactions in the soil [6]. Soil enzyme is one of the most active parts of the ecosystem by participating in the nutrient cycle and energy metabolism in the soil and linking the functions of the agro-ecosystem together [7].

Although current research on rice-duck cropping has pointed out that rice-duck cropping is favourable to the improvement of the soil environment, research on its mechanism of action is still insufficient. Based on this, the present study provides a scientific basis for exploring the mechanism of rice-duck cropping to improve the soil environment by analyzing the effects of the rice-duck cropping model on the activities of soil urease, alkaline phosphatase and catalase.

2. Materials and Methods

2.1. Study Area

The experimental site was situated in Boyatou Village, Fenghe Town, Linshui County District, Guang'an City, Sichuan Province, China (30.187N°, 107.06E°). The region exhibits a typical subtropical monsoon humid climate, characterized by a mild climate, and no frost period. The soils of the experimental site are deeply weathered loamy, exhibiting a poor quality colloidal structure, with a high proportion of loamy and clayey particles.

2.2 Design of Experimental

The experiment was designed with two modes: rice-duck co-cropping (Group A) and traditional rice cultivation (Group CK). Three sample plots were established in each mode, with the dimensions of the plots in Group A being 667m^2, 667m^2, and 534m^2, respectively, and the dimensions of the plots in Group CK being 467m^2, 534m^2, and 534m^2, respectively. A field of stalks was constructed with soil between each sample plot in order to prevent the cascading of fertiliser and water between different plots. The Group A was surrounded by a fence constructed from nylon mesh, 50 cm in height, in order to prevent the escape of ducks into the CK area during the entirety of the experimental period.

2.2.1. Varieties of Rice and Duck

The rice variety is Tianyou Huazhan (Beijing Golden Nonghua Seed Science and Technology Co., Ltd., State-approved rice 2011008, Qian-approved rice 2012009)

Test Duck Variety is a local variety of duck from Guang'an City, Sichuan Province, which is notable for its small size, robust foraging abilities, and rapid growth.

2.2.2. Harvest and Measurement

Samples were collected at varying soil depths (0-5 cm, 6-10 cm, 11-15 cm, 16-20 cm, 20-25 cm). Five samples were collected according to the diagonal method, with one sample taken from the centre of the plot and another from the midpoint of the diagonal midpoint to the midpoint of 4 vertices in each plot. Soil sample from one point was divided into different layers, and then mixed well with the soil of the same depth in each plot. The soil samples were brought back to the laboratory immediately after mixing and stored under refrigeration at 4°C.

The field experiment was conducted between September 2020 and October 2021. The experiment was divided into three phases: (1) from September to October 2020, at this phases the first batch of soil samples was collected (before duck releasing)(BDR) , and then the ducks were driven down to the field for the first release of ducks. (2) from October 2020 to April 2021, the first batch of ducks was recovered for the second soil sampling (before transplanting) (BT), subsequently, seedlings were transplanted and the second batch of ducks was released after the seedlings had set roots and tillers. (3) from April to October 2021, the second batch of ducks were recovered before rice harvest, thereafter, the third soil samples were collected after rice harvesting (after harvesting rice)(ARH).

Soil urease activity was quantified using the sodium phenol-sodium hypochlorite colourimetric method. Soil alkaline phosphatase activity was determined by the disodium benzene phosphate colourimetric method. Soil catalase activity was assessed using the potassium permanganate (concentration of 0.1 mol L^{-1}) titration method.

2.3. Statistical Analysis

Microsoft Excel was employed for the organization of data, while IBM SPSS Statistics 19 was utilised for the statistical analysis of the data.

3. Results

3.1. Responses of Soil Urease

The results of the analyses indicated that the impact of the rice-duck cropping model on soil urease activity was not statistically significant (P>0.05), nor was the soil layer (P>0.05), in comparison to the control treatment. However, there were highly significant differences (P<0.01) among different soil harvesting times. (Table 1)

Table 1. Effects of different influencing factors on Urease

Factors	F	Sig.
Cropping model	4.574	0.088
Soil harvesting time	57.482	< 0.001
Soil layer	1.053	0.452
Cropping model*Soil harvesting time	0.761	0.471
Soil harvesting time*Soil layer	0.793	0.611
Soil layer*Cropping model	0.264	0.900

Table 2. Changes of soil urease activity under different tillage methods (mg NH^3-N·g^{-1}·24 h^{-1})

Cropping model	Soil layer(cm)	BDR	BT	ARH
CK	0-5	0.0080±0.0009c	0.0218±0.0171b	0.1570±0.1203a
	6-10	0.0072±0.0023c	0.0180±0.0069b	0.1323±0.0428a
	11-15	0.0064±0.0026b	0.0118±0.0060b	0.1442±0.1068a
	16-20	0.0010±0.0006b	0.0199±0.0027b	0.1444±0.0650a
	21-25	0.0002±0.0001b	0.0209±0.0015b	0.0851±0.0632a
A	0-5	0.0080±0.0009b	0.0216±0.0015b	0.2475±0.1753a
	6-10	0.0072±0.0023b	0.0169±0.0009b	0.1207±0.0767a
	11-15	0.0064±0.0026b	0.0125±0.0078b	0.1358±0.0957a
	16-20	0.0010±0.0006b	0.0157±0.0038b	0.1861±0.1167a
	21-25	0.0002±0.0001b	0.0121±0.006b	0.1237±0.0383a

Note: the mean ± standard error was used to represent the soil activity in the table. Different lower letters indicates the difference of soil urease activity among different soil harvesting time (P = 0.05). (The same as below)

As illustrated in Table 2, overall, the activity of urease exhibited a gradual increasing trend, with ARH>BT>BR. For ARH, urease activities on all soil layers were found to be significantly higher than that observed in soil from BT and BR (P<0.05). In CK group, urease activity exhibited a 306.27% increase in BT and a 617.47% increase in ARH, in comparison to BDR. In A group, urease activity from BT was 246.60% higher than BDR, and ARH was 932.20% higher than BT. Before duck releasing, urease activity from CK group was 14.96% higher than that of A group. Conversely, after rice harvesting, the urease activity in the CK group was 14.96% lower than that in the A group.

A comparison of urease activity across different soil layers revealed no significant effect of soil layer on urease activity(P>0.05).However, the activity of soil urease in the shallow soil layer (0-10 cm) was found to be higher than that in the deep soil layer (11-25 cm). Furthermore, there was no consistent growth trend of soil urease in the soil layers of the CK group and A group. For example, after rice harvesting, on the 0-5 cm soil layer, the urease activity in the A group was greater than that in the CK group. However, on the 6-10 cm layer, the urease activity exhibited the reverse pattern, with that in the CK group had higher activity.

3.2. Responses of Soil Alkaline

The results showed that only the soil harvesting time, and the interaction between soil layer and harvesting time, had significant (P<0.05) effects on alkaline phosphatase activity (Table 3).

Table 3. Effects of different influencing factors on soil alkaline phosphatase

Factors	F	Sig.
Cropping model	0.265	0.609
Soil harvesting time	113.631	< 0.001
Soil layer	0.945	0.444
Cropping model*Soil harvesting time	1.593	0.212
Soil harvesting time*Soil layer	2.61	0.016
Soil layer*Cropping model	0.165	0.955

Table 4. Changes of alkaline phosphatase activity under different tillage methods （mg.g^{-1}.24 h^{-1}）

Cropping model	Soil layer(cm)	BDR	BT	ARH
CK	0-5	0.2217±0.0029b	0.2400±0.0173b	0.1000±0.0200a
	6-10	0.1900±0.0173ab	0.2700±0.0346b	0.1233±0.0425a
	11-15	0.2100±0.0563ab	0.2767±0.0251b	0.1133±0.0596a
	16-20	0.1650±0.0390ab	0.2650±0.0328b	0.0900±0.0360a
	21-25	0.1317±0.0189a	0.2950±0.0867b	0.1450±0.4330a
A	0-5	0.2217±0.0029ab	0.2583±0.088b	0.1067±0.0247a
	6-10	0.1900±0.0173ab	0.2800±0.0687b	0.0900±0.0304a
	11-15	0.2100±0.0563ab	0.2683±0.0510b	0.1083±0.0126a
	16-20	0.1650±0.0390ab	0.2633±0.0375b	0.0767±0.0670a
	21-25	0.1317±0.0189a	0.3417±0.0808b	0.0517±0.0275a

The soil alkaline phosphatase activity change pattern in relation to soil harvesting time was as follows: BT>ARH>BDR. Overall, the soil alkaline phosphatase activity demonstrated an increase and subsequent decrease, with the peak occurring before rice transplanting. After rice harvesting, the soil alkaline phosphatase activity was significantly smaller than that of BDR under both models (P<0.05).

A comparison of the urease activity of the two cropping models revealed that before seedlings transplanting the CK group was 4.83% lower than A group, while after rice harvesting the A group was 24.20% higher than A group.

Comparison among different soil layers revealed that, before seedlings transplanting, alkaline phosphatase activity in the deep soil layer (21-25 cm) in both group CK and group A were relatively higher than that from other layers. After rice harvesting, the enzyme activity in the deep soil layer (21-25 cm) of group CK was still higher than that of other soil layers, but the soil in group A had lower alkaline phosphatase activity in the deep soil layer (21-25 cm) than in the other soil layers.

3.3. Responses of Soil Catalase

As shown in Table 5, both of soil harvesting time and cropping model had significant effects (P<0.05) on soil catalase activity. However, the soil layer did not exert a significant influence (P> 0.05) on catalase activity.

Table 5. Effects of different influencing factors on Soil Catalase

Factors	F	Sig.
Cropping model	5.576	0.021
Soil harvesting time	4.486	0.015
Soil layer	0.549	0.7
Cropping model*Soil harvesting time	7.502	0.01
Soil harvesting time*Soil layer	0.238	0.982
Soil laye*Cropping model	0.319	0.864

Table 6. Changes of soil hydrogen peroxide activity under different tillage methods（mL $KMnO_4$·g^{-1}）

Cropping model	Soil layer(cm)	BDR	BT	ARH
CK	0-5	0.2328±0.0575a	0.2875±0.0856aA	0.1430±0.0302aA
	6-10	0.2773±0.0350a	0.2629±0.0808aA	0.1655±0.1226aA
	11-15	0.2581±0.0602ab	0.2998±0.0750bA	0.1357±0.0414aA
	16-20	0.2843±0.0404a	0.2925±0.0896aA	0.1956±0.0405aA
	21-25	0.2667±0.0467a	0.3570±0.1844aA	0.1042±0.0643aA
A	0-5	0.2328±0.0575a	0.0380±0.2614aA	0.3119±0.0813aB
	6-10	0.2773±0.0350a	0.2686±0.1074aA	0.2517±0.0552aA
	11-15	0.2581±0.0602a	0.2408±0.0473aA	0.2722±0.0243aB
	16-20	0.2843±0.0404a	0.3110±0.2237aA	0.2595±0.0423aA
	21-25	0.2667±0.0467a	0.3012±0.1752aA	0.3940±0.1797aB

Note: Different capital letters indicate significant differences in enzyme activities under different tillage practices in the same soil layer and at the same harvesting period (P<0.05).

In general, the following order of soil catalase activity was observed: BT > BDR > ARH, and BT was significantly higher than ARH (P< 0.05). When compared under different cropping model, the soil catalase activity showed the following change pattern: in CK group, soil from 6-10 cm, its catalase activity was BT > BDR > ARH, while the other layers were BDR > BT > ARH, but only on 11-15cm layer, the soil catalase activity showed significant difference among soil harvesting time, with ARH significantly higher than BDR; in the A group, the impact of soil harvesting time on soil catalase activity in all soil layers were not statistically significant, and soil catalase activity exhibited a distinct variation across the soil layers: on 0-5cm, 20-25cm layers, BDR>BT>ARH, on 6-10cm layer, BDR>BT>ARH, on 11-15cm layer, ARH>BDR>BT, and on 16-20cm layer, BDR<BT<ARH.

Comparisons among different cropping models revealed that, in general, rice-duck cropping significantly increased soil catalase activity. In particular, soil catalase activity in the 0-5, 11-15, and 21-25 cm soil layers of group A was significantly higher than that of group CK after rice harvesting (P<0.05). Among soil layers, there was no significant trend change in soil catalase activity (P>0.05).

4. Discussion

Soil urease is an important enzyme that catalyses soil nitrogen transformation, which can reflect the ability of the soil to transform nitrogen [8]. Variation of the urease activity with the soil harvesting time could provide advice for the urea fertiliser application in rice-duck farming. The changes in soil urease activity were not significant under the rice-duck cropping mode, which is consistent with the results of Ma Yunjun's study [9]. However, after rice harvest, urease was 27.84% higher in the rice-duck cropping mode than in the control group, indicating that the rice-duck cropping mode may have some effect on urease. Soil enzyme activity is influenced by a variety of factors, such as soil nutrient status, microbial activity and plant root activity [10,11]. The activities of ducks and their faeces may affect urease activity under the rice-duck cropping pattern, but the significance of their effect may take a longer time to become apparent [12].

In this study, soil alkaline phosphatase activity tended to increase and then decrease with sampling time. This is consistent with the trend of effective phosphorus during rice growth [13]. Before seedlings transplantation, soil alkaline phosphatase activity increased, accelerating phosphorus mineralisation and increasing effective phosphorus, but as rice grew, soil nutrients were gradually consumed, soil alkaline phosphatase activity decreased [14], which induced effective phosphorus decrease. In addition, soil alkaline phosphatase activity did not show a consistent trend of increasing or decreasing after rice-duck cropping in this study; it was higher than the control before ducks were released, but lower than the control after rice harvesting. This is similar to the results of effective phosphorus in the current study of rice-duck co-cropping. In the current studies, there is a large divergence in the changes in soil effective phosphorus after rice-duck co-cropping. For example, several studies by Zhang Yin et al. concluded that rice-duck cropping decreased soil effective phosphorus [12,13,15,16], whereas studies by Ji Li et al. found that soil effective phosphorus increased after rice-duck cropping [5, 17,18,19].

Soil catalase activity could improve the redox state of paddy soil and facilitates the mineralisation of organic matter. In this study, rice-duck farming significantly increased soil catalase activity, which is consistent with the findings of Ma Yunjun et al [9,10,20]. It can be seen that rice-duck farming can provide a better nutrient environment for rice growth by increasing the activity of catalase and accelerating the mineralisation of organic matter.

5. Conclusion

The results of this study indicate that rice-duck farming has a significant impact on soil catalase activity, with minimal effects on urease and alkaline phosphatase. Furthermore, the timing of soil harvesting has a notable influence on the activities of urease, alkaline phosphatase, and peroxidase. Finally, there were no discernible differences in the activities of urease, alkaline phosphatase, and catalase across different soil layers. Consequently, the present study concludes that rice-duck farming optimises the enzyme environment of paddy soil by enhancing peroxidase activity.

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