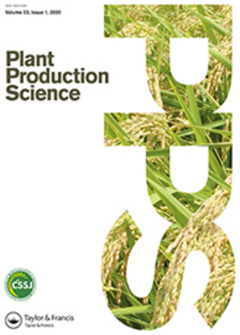

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Plant Production Science

ISSN: 1343-943X (Print) 1349-1008 (Online) Journal homepage: https://www.tandfonline.com/loi/tpps20

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To cite this article: Yan Wang, Yu Zhang, Zhen-Zhou Li, Quan Zhao, Xiao-Yan Huang & Kai-Feng Huang (2020) Effect of continuous cropping on the rhizosphere soil and growth of common buckwheat, Plant Production Science, 23:1, 81-90, DOI: 10.1080/1343943X.2019.1685895

To link to this article: https://doi.org/10.1080/1343943X.2019.1685895

Published online: 31 Oct 2019.

PLANT PRODUCTION SCIENCE
2020, VOL. 23, NO. 1, 81–90
https://doi.org/10.1080/1343943X.2019.1685895

SHORT REPORT

Effect of continuous cropping on the rhizosphere soil and growth of common buckwheat

Yan Wang[a], Yu Zhang[a], Zhen-Zhou Li[a], Quan Zhao[b], Xiao-Yan Huang[a] and Kai-Feng Huang[a]

[a]Research Center of Buckwheat Industry Technology, Guizhou Normal University, Guiyang, Guizhou Province, China; [b]The first middle school of Fenggang County, Zunyi, Guizhou Province, China

ABSTRACT
Common buckwheat is a health-care crop, and continuous cropping is one of the main factors restricting its high-yielding. In order to clarify the mechanism of continuous cropping of buckwheat, 4, 5and 6 years continuous cropping treatments were set up. We obtained the following results. The available nutrients content in rhizosphere soil, soil enzyme activity, leaf area, chlorophyll and soluble protein content, the peroxidase(POD) activity of leaves, agronomic traits, root index (except average diameter) of Fengtian1(FT1) decreased significantly with the increase of continuous cropping years. While, soil pH and the number of fungi in rhizosphere soil increased significantly, the number of bacteria in rhizosphere soil and the activity of catalase (CAT) and superoxide dismutase(SOD) in leaves first increased and then decreased. The yields of continuous cropping for 6 years were 12 times lower than the control crop. In conclusion, continuous cropping has certain effects on growth and yields of buckwheat.

ARTICLE HISTORY
Received 29 June 2018
Revised 25 July 2019
Accepted 15 October 2019

KEYWORDS
Common buckwheat; continuous cropping years; rhizosphere soil; plant traits; root system; yield

1. Introduction

Buckwheat belongs to the genus *Fagopyrum* Mill. of family Polygonaceae (Lin, 1994). Buckwheat is one of the most significant minor crops in China and offers a high economic value. Buckwheat provides a very high nutritional value and is an important functional crop. In China, buckwheat, oats, legumes, black rice, millet, maize, wheat bran, and rice bran are called 'the eight health foods' (Zhang & Ou, 2000). The multispecies of *Fagopyrum* can be classified into two types, namely, common buckwheat (*Fagopyrum esculentum*) and tartary buckwheat (*Fagopyrum tataricum*) (Lin, 1994). Common buckwheat has high economic value, and also provides many health benefits, such as low glycemic index, hypolipidemic activity, cardiovascular protection, and cancer prevention and treatment (Huang & Song, 2011; Liu, Han, Cui, Zhu & Lv, 2003; Wu & Lu, 1988; Yi, Lei, Wang, Wang & Yan, 2009). Given the high health value of common buckwheat, the demand for this crop is high in the international market and rapidly increasing in the local market as well.

Continuous cropping obstacle refers to the continuous cultivation of the same or allied species plant in the same soil; even under normal cultivation and management conditions, the growth potential will become weak, the disease will be aggravated, and the yield and quality will decline (Gao, Meng & Yu, 2006).In recent years, several scholars have studied the change of physicochemical properties of the soil, soil nutrient content, soil microbial community structure, soil enzyme activity, plant agronomic traits and physiological and biochemical indexes with continuous cropping of forest plants, grain crops, forage plants and horticultural plants, and they found that continuous cropping obstacle is the result of interaction between soil environment and plant two systems(Zhang et al., 2011; Wang, Li, Xu & Gu, 2013; Sun at al. 2015; Hou et al., 2016).

Continuous cropping is one of the main reasons that restrict the high yield of buckwheat. Buckwheat requires minimal fertilizer for cultivation, which leads not only to the decline of soil fertility but also to the gradual accumulation of bacteria, thereby eventually causing disease production (Chen 2008).At present, some scholars have studied the continuous cropping obstacle of tartary buckwheat, but it has not revealed the essence of the continuous cropping obstacle of tartary buckwheat (Gao et al. 2014; Gao, 2015; Zhao et al., 2015), and the study about the continuous cropping obstacle of common buckwheat was seldom reported, which restricts the proposal of effective regulation methods for the continuous cropping obstacle of common buckwheat. In this study, common buckwheat 'cv Fengtian1' (FT1), which is mainly cultivated in Guizhou, was selected as material to investigate the

CONTACT Kai-Feng Huang hkf1979@163.com

changes in rhizosphere soil properties, growth, and yield with continuous cropping for 4, 5, and 6 years. The results of this study would provide some theoretical basis for the continuous cropping mechanism and high-yield cultivation of common buckwheat.

2. Materials and methods

2.1. Plant materials and growth

The common buckwheat FT1 used in this experiment was provided by the Buckwheat Industry Technical Research Center of Guizhou Normal University. The experiment was conducted at Huangnitang's Cultivation Experiment Station of the Key Laboratory for Cultivation Physiology and Application of Buckwheat of Guizhou (in Bijie City of Guizhou Province, 922 m, 27°05′ N, 105°71′ E). On the basis of continuous cropping for 3 years, three treatments of 4, 5, and 6 stubbles were established in the years 2014–2016, respectively, which were represented by 4a, 5a, and 6a, respectively. In '4a' treatment, common buckwheat was cropped continuously for 4 years, and it was harvested in 2014. In '5a', it was cropped continuously for 5 years, and it was harvested in 2015. In '6a', it was cropped continuously for 6 years, and it was harvested in 2016. In this experiment, the continuous cropping of buckwheat varieties was all FT1. New soil was collected from the same point as that of the treatment group, and FT1 was planted for the first time as control, which was represented by CK, the data was obtained in 2016. Common buckwheat was cultivated in cement pools. The area for each test plot was 2 m × 10 m × 0.3 m, and the spacing for each row was 33 cm. Approximately 1000 reserved plants were available for each plot. All treatments were repeated three times.

Common buckwheat seeds were sown at the beginning of September and harvested in early November during the three growing seasons in 2014, 2015, and 2016. No fertilization was applied during the entire growth period. Normal agricultural practice was implemented during the three growing seasons.

2.2. Sample preparation

The rhizosphere soil of approximately 10–15 plants for each plot with uniform growth was sampled at the seedling, flowering, grain-filling, and maturity periods (every year from 2014 to 2016) of common buckwheat. Half-sampled rhizosphere soil of every treatment was dried to a constant weight with natural air drying for measuring soil available nutrient and pH value. The other half of rhizosphere soil was stored at 4°C and used to analyze soil microbial biomass and soil enzyme activity.

Leaves in the 4–6 internodes from the bottom to top of 10 tagged plants with uniform growth from each plot were sampled every 7 days from 7 days after flowering (sampling 4 times altogether, every year from 2014 to 2016). The sampled leaves were frozen in liquid nitrogen for 1 min and then stored at −80°C for reserve.

Approximately 10 plants for each plot with uniform growth were sampled with complete root in the maturity period (every year from 2014 to 2016) of common buckwheat. The roots were rinsed off the soil and then cut to determine the root morphology. The leaves in the 4–6 internodes from bottom to top were sampled to determine the leaf area.

2.3. Determination

The pH value of rhizosphere soil was determined using a precise pH instrument (MP511, China), and the available nutrients in the rhizosphere soil were determined by using a soil nutrient rapid analyzer (OK-Q3, China).The urease, alkaline phosphatase, CAT, and sucrase activity of rhizosphere soil were determined according to the method used by Guan (1986). The soil microbial biomass in rhizosphere soil was determined by dilution plate method (Zhao & He, 2002). The chlorophyll content, soluble protein content, and SOD, CAT, and POD activity in the leaves of FT1 were determined according to the method used by Zou (1995). A root scan analysis system (GXY-A, Zhejiang Tuopu Instrument Co., Ltd., China) was used to determine the root morphology and leaf area of FT1. Plant height, the branch and node numbers of the main stem, and 1- to 2-internode diameter were determined according to the method of Zhang and Lin (2007). The yield of each plot was determined at maturity and converted per hectare yield. (The output in the article is the mean of the two quarter).

2.4 Statistical analysis

All data were classified using MS Excel. The means and variance of the data from three replications were determined by SPSS17.0 (SPSS Inc., Chicago, IL, USA). Error bars represent standard deviation.

3. Results

3.1. Effect on the nutrient, enzyme activitiy, and microorganisms of rhizosphere soil

3.1.1. Effect on the rhizosphere soil available nutrient and pH

The contents of available nitrogen, available phosphorus, available potassium, and organic matter in rhizosphere soil decreased significantly with the increase in years of continuous cropping, and the difference among treatments reached a significant level (Table 1). The pH of rhizosphere soil increased significantly with the increase in years of continuous cropping, and the differences among different treatments reached a significant level.

3.1.2. Effect on the rhizosphere soil enzyme activitiy

The urease activity of rhizosphere soil in every growth period decreased with the increase of continuous cropping years, and the urease activity of rhizosphere soil initially increased and then decreased with the growth of common buckwheat (Figure 1).The urease activity of rhizosphere soil at the filling period was the highest, whereas that in the maturity period was the lowest.

Table 1. Changes in rhizosphere soil nutrient and pH with continuous cropping for different years.

Treatment	Available nitrogen (mg/kg)	Available phosphorus (mg/kg)	Available potassium (mg/kg)	Organic matter (‰)	pH
2016(CK)	90.8 a	72.1 a	114.7 a	39.81 a	5.96 d
2014(4a)	71.3 b	36.3 b	88.1 b	37.23 b	6.32 c
2015(5a)	68.5 c	35.4 c	87.2 c	37.19 b	6.41 b
2016(6a)	67.1 d	34.0 d	79.7 d	36.58 c	6.67 a

Note: there are significant differences in continuous cropping at different levels on the 0.05 level in the same column.

The CAT activity of rhizosphere soil in every growth period decreased with the increase of continuous cropping years, and the CAT activity of rhizosphere soil at the mature period had no significant difference between CK and 4 years of continuous cropping. The CAT activity of rhizosphere soil at the seeding period with CK, 5 and 6 years of continuous cropping was the highest, whereas that in the maturity period with 4 years of continuous cropping was the lowest.

The phosphatase activity of rhizosphere soil in every growth period decreased with the increase of continuous cropping years, and the phosphatase activity of rhizosphere soil had no significant difference between 4 and 5years of continuous cropping. The phosphatase activity of rhizosphere soil initially increased and then decreased with the growth of common buckwheat.

The sucrase activity of rhizosphere soil in every growth period decreased with the increase of continuous cropping years. Treated with CK and 4 years of continuous cropping, the sucrase activity initially increased and then decreased with the growth of common buckwheat, and the sucrase activity of rhizosphere soil at the filling period was the highest, whereas that in the maturity period was the lowest. Treated with 5 and 6 years of continuous cropping, the sucrase activity of rhizosphere soil at the mature period was the highest.

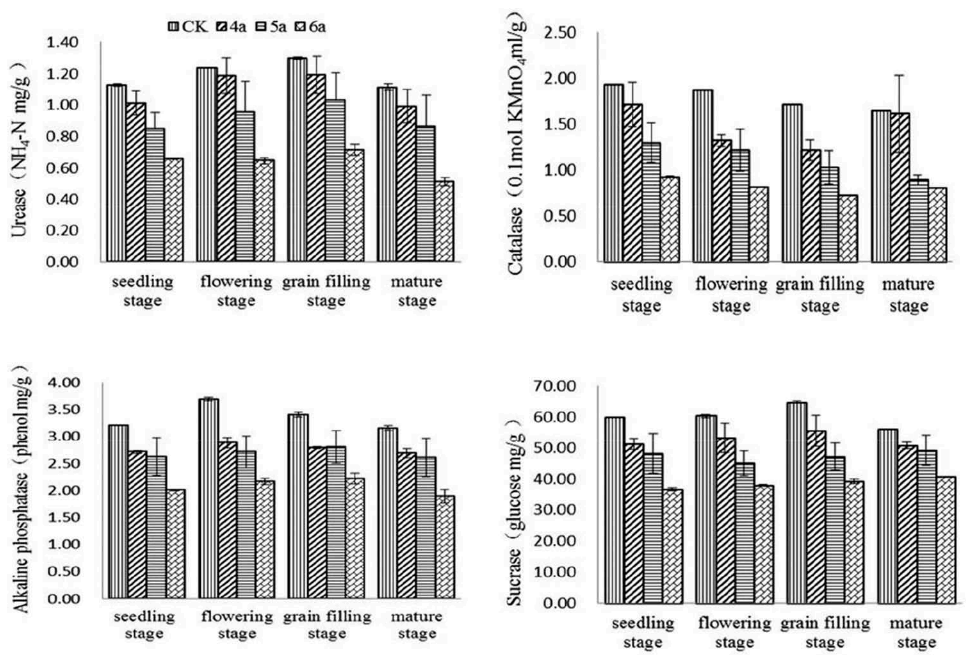

Figure 1. Rhizosphere soil enzyme activity of common buckwheat.

Note: ‘CK’ means blank control, the data was obtained in 2016. In ‘4a’ treatment, common buckwheat was cropped continuously for 4 years, and it was harvested in 2014. In ‘5a’, it was cropped continuously for 5 years, and it was harvested in 2015. In ‘6a’, it was cropped continuously for 6 years, and it was harvested in 2016. The same below.

3.1.3. Effect on the rhizosphere soil microorganism

The number of bacteria in rhizosphere soil at the seedling, flowering, and maturity periods initially increased and then decreased with the increase of continuous cropping years (Figure 2), and the number of bacteria at the seedling and maturity was the highest with 5 years of continuous cropping, whereas at the flowering period, the number of bacteria was the highest with 4 years of continuous cropping. The number of bacteria in rhizosphere soil at the filling period exhibited decreasing, increasing, and decreasing trend with the increase in years of continuous cropping. For those with 5years of continuous cropping, the number of bacteria in rhizosphere soil was the highest, whereas that with 6 years of continuous cropping was the lowest. The number of bacteria in rhizosphere soil initially increased and then decreased with the growth of common buckwheat, and the number of bacteria at the flowering period was the highest.

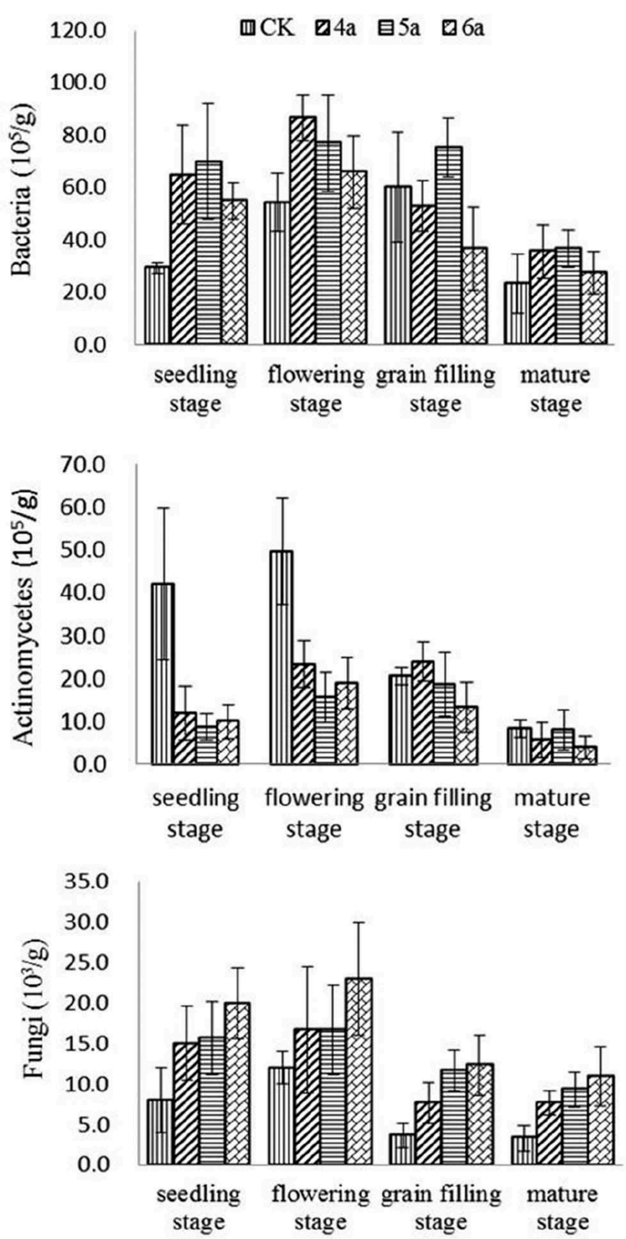

Figure 2. Rhizosphere soil microorganism of common buckwheat.

For CK treatment, the number of actinomycetes at the seedling, flowering and mature periods were significantly higher than that in the other three treatments. At the filling period, the number of actinomycetes was the highest with 4 years of continuous cropping. The number of actinomycetes at the filling period was the highest with 4 years of continuous cropping. The number of actinomycetes in rhizosphere soil at the flowering period was the highest, whereas that in the maturity period was the lowest.

The fungal biomass in rhizosphere soil in every growth period increased with the increase in years of continuous cropping. At the seedling and flowering periods, the fungal biomass in rhizosphere soil showed a slowly increasing trend with 4 and 5 years of continuous cropping. The fungal biomass in rhizosphere soil was the highest with 6 years of continuous cropping. The fungal biomass in rhizosphere soil initially increased and then decreased with the growth of common buckwheat, and the fungal biomass at the flowering period was the highest.

3.2. Effect on physiological and biochemical indexes in the leaves

The chlorophyll content in FT1 leaves generally showed a significant downward trend with the increase of continuous cropping years (Table 2). The content of CK was significantly higher than that in the other three treatments. The chlorophyll content in FT1 leaves exhibited a rapidly decreasing trend with the growth of common buckwheat. The chlorophyll content in the leaves reached the minimum, 28 d after flowering.

The contents of soluble proteins significantly decreased with continuous cropping. The contents reached the minimum with 6 years of continuous cropping. The contents of soluble proteins initially increased and then decreased with the growth of common buckwheat. At 28 d after flowering, the contents of soluble proteins in leaves reached the minimum.

For CK treatment, the POD activity at 7and 14 d after flowering were significantly higher than the other continuous cropping treatments, and they significantly decreased with the increase in years of continuous cropping. The POD activity at 21 d after flowering initially increased and then decreased with the increase in years of continuous cropping. For 5 years of continuous cropping treatment, the POD activity was significantly higher than that in the other treatments. For 6 years of

Table 2. Changes in chlorophyll and soluble protein contents, POD, CAT and SOD activity with continuous cropping for different years.

Contents	Treatment	7 d	14 d	21 d	28 d
Chlorophyll content (mg/g FW)	2016(CK)	1.71a	1.70a	1.03a	0.53a
	2014(4a)	1.69ab	1.43c	0.12c	0.02b
	2015(5a)	1.69ab	1.67b	0.21b	0.03b
	2016(6a)	1.67b	1.42c	0.11c	0.01b
Soluble proteins (mg/g)	2016(CK)	3.55a	6.84a	5.97a	3.21a
	2014(4a)	3.34c	6.36b	5.35c	1.82b
	2015(5a)	3.42b	6.22c	5.76b	1.45c
	2016(6a)	3.12d	5.97d	5.13d	1.62d
POD ($U \cdot g^{-1} \cdot min^{-1}$ FW)	2016(CK)	15.33a	19.69a	36.57c	56.63d
	2014(4a)	12.30b	16.40b	40.30ab	63.47b
	2015(5a)	10.03c	15.27c	45.43a	61.47c
	2016(6a)	9.23d	15.63c	40.07b	67.43a
CAT ($U \cdot g^{-1} \cdot min^{-1}$ FW)	2016(CK)	45.30a	47.96b	50.90c	60.21d
	2014(4a)	39.55b	48.52ab	70.92d	89.90c
	2015(5a)	38.44b	46.88c	85.90a	113.88a
	2016(6a)	38.48b	51.12a	80.50b	99.65b
SOD ($U \cdot g^{-1}$ FW)	2016(CK)	163.25d	169.56d	157.67d	99.66d
	2014(4a)	229.59c	299.67c	213.61c	146.85a
	2015(5a)	312.01a	355.78a	287.67a	106.90c
	2016(6a)	255.31b	325.30b	266.89b	112.19b

Note: Different small letters indicate the significant difference ($P \leq 0.05$) among the same multispecies analyzed by LSD using SPSS 17.0

continuous cropping treatment, the POD activity at 28 d after flowering were significantly higher than the other continuous cropping treatments. The POD activity in FT1 leaves increased continually with the growth of common buckwheat.

The CAT activity at 7 d after flowering decreased significantly with continuous cropping. The CAT activity was the maximum with CK treatment, and there were not significant among the other continuous cropping treatments. For 6 years of continuous cropping, the CAT activity at 14 d after flowering were significantly higher than the other continuous cropping treatments, whereas that was the lowest for 5 years of continuous cropping. The CAT activity at 21d and 28 d after flowering were significantly higher with 5 years of continuous cropping than the other continuous cropping treatments. The CAT activity in FT1 leaves increased continually with the growth of common buckwheat.

The SOD activity at 7, 14 and 21 d after flowering initially increased significantly and then decreased significantly with the increase in years of continuous cropping. The SOD activity was the maximum with 5 years of continuous cropping, whereas that with CK was the minimum. The SOD activity at 28 d after flowering were significantly higher with 4 years of continuous cropping than those in the other treatments, and CK was the minimum. The SOD activity at 21 d and 28 d after flowering were significantly higher with 5 years of continuous cropping than those in the other treatments, and that of CK was the minimum. The SOD activity initially increased and then decreased with the growth of common buckwheat, and the SOD activity in leaves reached the minimum, 14 d after flowering.

3.3. Effect on the plant morphology and yield

3.3.1. Effect on root morphology, agronomic traits, and yield

The root length was significantly decreased with the increase in years of continuous cropping, and the root length had no significant difference between 4 and 5 years of continuous cropping (Table 3). The root superficial area was significantly decreased with the increase in years of continuous cropping, and the root superficial area had no significant difference between 5 and 6 years of continuous cropping. The root volume was significantly decreased with continuous cropping, and no significant difference was found among 4, 5, and 6 years of continuous cropping. The root average diameter of 6 years was significantly higher than the other three treatments.

The plant height and branch number of main stem of FT1 were significantly decreased with the increase in years of continuous cropping. The plant height and branch number of main stem with CK treatment was the highest, whereas that with 6 years of continuous cropping was the lowest. The number of main stem node had no significant difference among CK, 4 and 5 years of continuous cropping, whereas significant higher than 6 years of continuous cropping. The 1- to 2-internode diameter was significantly decreased with continuous cropping, and no significant difference was found among 4, 5, and 6 years of continuous cropping. The leaf area and hundred grain weight of FT1 were decreased significantly with the increase in years of continuous cropping. The yield of FT1 was significantly decreased with the increase in years of continuous cropping, and the yields of 4, 5, and 6 years of

Table 3. Changes in plant morphology and yield with continuous cropping for different years.

	Agronomic traits and yield							Root index			
Treatment	Plant height (cm)	Branch number of main stem	Main stem node number	One- to two-internode thickness	Leaf area (cm^2)	Hundred grain weight (g)	Yield (kg/ha)	Length (cm)	Superficial area (cm^2)	Volume (cm^3)	Average diameter (mm)
2016(CK)	72.67 a	4.67 a	6.67 a	4.62 a	106.04 a	2.27 a	1828.92 a	114.14 a	15.08 a	0.24 a	0.38 b
2014(4a)	44.67 b	3.33 b	6.33 a	2.34 b	57.15 b	2.13 b	172.48 b	55.56 b	10.03 b	0.09 b	0.36 bc
2015(5a)	37.33 c	2.00 c	6.00 ab	1.97 b	28.60 bc	2.13 b	164.92 c	51.19 b	5.09 c	0.09 b	0.33 c
2016(6a)	33.67 c	1.67 d	5.33 b	1.80 b	22.32 c	1.87 c	153.00d	14.20 c	2.58 c	0.06 b	0.69 a

Note: Different small letters indicate the significant difference (P ≤ 0.05) among the same multispecies analyzed by LSD using SPSS 17.0.

continuous cropping decreased by 10.6, 11.1, and 12.0 times compared with the production control, respectively.

3.3.2. Relativity between the plant morphology, yield with continuous cropping years

The years of continuous cropping had a remarkably significant negative correlation with yield, plant height, the branch number of main stem, 1- to 2-internode diameter, leaf area, hundred grain weight, root length and root surface area, and the correlation coefficients reached −0.954, −0.984, −0.866, −0.964, −0.916, −0.842, −0.847, and −0.817, respectively (Table 4). The years of continuous cropping had a significant negative correlation with main stem node number and root volume, and the correlation coefficients reached −0.672 and −0.686, respectively.

The yield of FT1 had a remarkably significant positive correlation with plant height, the branch number of main stem, 1- to 2-internode diameter and leaf area, and the correlation coefficients reached 0.955, 0.769, 0.962 and 0.851, respectively. The yield of FT1 had a significant positive correlation with hundred grain weight, root length and root surface area, and the correlation coefficients reached 0.685, 0.683 and 0.648, respectively.

The plant height of FT1 had a remarkably significant positive correlation with the branch number of main stem, 1- to 2-internode diameter, leaf area, hundred grain weight, root length, and root surface area, and the correlation coefficients reached 0.874, 0.975, 0.878, 0.797, 0.804 and 0.791, respectively. The plant height of FT1 had a significant positive correlation with main stem node number and root volume, and the correlation coefficients reached 0.701 and 0.672, respectively.

The branch number of the main stem of FT1 had a highly significant positive correlation with 1- to 2-internode diameter, leaf area, hundred grain weight, root length, and root surface area, and the correlation coefficients reached 0.812, 0.818, 0.766, 0.832, 0.852 and 0.797, respectively. The branch number of the main stem had a significant positive correlation with main stem node number, and the correlation coefficients reached 0.698.

The main stem node number of FT1 had a highly significant positive correlation with hundred grain weight, root length, root surface area, and root volume, and the correlation coefficients reached 0.768, 0.779, 0.789 and 0.727, respectively. The main stem node number of FT1 had a significant positive correlation with 1- to 2-internode diameter and leaf area, and the correlation coefficients reached 0.661 and 0.626, respectively.

One- to two-internode diameters had a considerably significant positive correlation with leaf area, hundred grain weight, root length, and root surface area, and the correlation coefficients reached 0.888, 0.757, 0.753 and 0.751, respectively. One- to two-internode diameters had a significant positive correlation with root volume, and the correlation coefficients reached 0.611.

Leaf area had a remarkably significant positive correlation with hundred grain weight, root length, root surface area, and root volume, and the correlation coefficients reached 0.759, 0.905, 0.891 and 0.743, respectively.

Hundred grain weight of FT1 had a highly significant positive correlation with root length, root surface area, and root volume, and the correlation coefficients reached 0.874, 0.818 and 0.708, respectively. Hundred grain weight had a remarkably significant negative correlation with root mean diameter, and the correlation coefficients reached −0.761.

Root length of FT1 had a highly significant positive correlation with root surface area, and root volume, and the correlation coefficients reached 0.976 and 0.872, respectively. Root length had a significant negative correlation with root mean diameter, and the correlation coefficients reached −629.

Root surface area had a highly significant positive correlation with root volume, and the correlation coefficients reached 0.943.

4. Discussion

The soil available nutrients including available nitrogen, available phosphorus, available potassium and organic matter, and the soil available nutrients is the direct source

Table 4. Correlation analysis between agronomic traits and root morphology and continuous cropping.

Correlation coefficient	Continuous cropping number	Yield (kg/hm^2)	plant height (cm)	Branches per mainstem	nodes per mainstem	1- to 2-internode diameter	leaf area (cm^2)	Hundred grain weight(g)	Root length (cm)	root surface area (cm^2)	Root volume (cm^3)	Root mean diameter (mm)
Yield(kg/hm^2)	−0.954**	1										
plant height (cm)	−0.984**	0.955**	1									
Branches per mainstem	−0.866**	0.769**	0.874**	1								
nodes per mainstem	−0.672*	0.532	0.701*	0.698*	1							
1- to 2-internode diameter	−0.964**	0.962**	0.975**	0.812**	0.661*	1						
leaf area(cm^2)	−0.916**	0.851**	0.878**	0.818**	0.626*	0.888**	1					
Hundred grain weight(g)	−0.842**	0.685*	0.797**	0.766**	0.768**	0.757**	0.759**	1				
Root length (cm)	−0.847**	0.683*	0.804**	0.832**	0.779**	0.753**	0.905**	0.874**	1			
root surface area (cm^2)	−0.817**	0.648*	0.791**	0.852**	0.789**	0.751**	0.891**	0.818**	0.976**	1		
Root volume (cm^3)	−0.686*	0.477	0.672*	0.797**	0.727**	0.611*	0.743**	0.708*	0.872**	0.943**	1	
Root mean diameter (mm)	0.428	−0.228	−0.354	−0.420	−0.501	−0.278	−0.363	−0.761**	−0.629*	−0.518	−0.432	1

** $P < 0.01$.
Note:**significance respectively at 0.01 probability levels.
* $P < 0.05$.
Note:*significance respectively at 0.05 probability levels

of crop nutrients required for life activity. The content of soil available nutrients is an important indicator of soil fertility classification and fertility level, and it is the comprehensive performance of soil nutrient supply capacity (Chen, Xiao, Yu & Gong, 2009; Wang, Zhan, Xie, Qiu & Ke, 2009; Xu, 2004).The study found that soil available phosphorus, available phosphorus and available potassium had a significant positive correlation with crop yield(Liu & Hu, 2015). On the basis of continuous non-fertilization, the contents of soil available nitrogen and available phosphorus decreased with the increase of continuous cropping years, while the pH value increased. The activity of soil urease, alkaline phosphatase, sucrase and catalase decreased with the increase of continuous cropping years, and this phenomenon decreased faster with the increase of continuous cropping years. (Miao, Li, Zhou, Gao & Gao, 2016). The study found that the contents of available nitrogen, available phosphorus, available potassium, and the soil alkaline phosphatase, sucrase and catalase activity of tartary buckwheat with no fertilization decreased significantly with the increase in years of continuous cropping (Gao, 2015). In this study, the contents of available nitrogen, available phosphorus, available potassium, organic matter and enzyme activity of the rhizosphere soil and chlorophyll content and soluble proteins decreased significantly with the increase in years of continuous cropping, The comparison between CK and 6a is obvious. which was consistent with that observed by above scholars. Microorganisms are one of the most active soil fertility factors (Insam, Mitchel & Dormaar, 1991), and they are changed to a certain extent with plant transformation and absorption of nutrients in soil (Fu, Li & Fu, 2009). In this study, the number of bacteria initially increased and then decreased with the increase in the years of continuous cropping, and the number of fungi increased substantially with the increase in years of continuous cropping. These results were consistent with those of other scholars (Chen, Yang, Yuan, Yang & Liu, 2014; Ma et al., 2013). Continuous cropping of common buckwheat promoted the transformation of rhizosphere soil from the high fertility soil of bacteria type to the low fertility of fungi-type soil (Zou et al. 2005). In this study, available nitrogen, available phosphorus, available potassium, and organic matter in the rhizosphere soil of common buckwheat decreased significantly with the increase in years of continuous cropping. These findings suggested that continuous cropping could reduce soil fertility and deteriorate the soil properties of rhizosphere soil. The formation of specific soil and rhizosphere conditions thus affected the soil and rhizosphere microorganism and reproductive activity, thereby resulting in decreased number of beneficial microorganisms, increased pathogenic microorganisms, increased pests and diseases, and formation of continuous cropping obstacle.

The content of chlorophyll reflects the capability of plants to synthesize organic matter to a certain extent (Hoffmann-Benning et al. 1992; Lichtenthaler, Babani & Navratil et al., 2013). Soluble proteins are important osmotic-regulating substances and nutrients in plant cells. They have protective effects on cell life substances and biological membranes, and they are among the indexes of plant resistance. The content of chlorophyll in leaves of peanut was significantly decreased with continuous cropping (Li et al., 2012). The content of chlorophyll and soluble proteins of kidney bean significantly decreased with continuous cropping (Ma, 2014). The content of chlorophyll and soluble proteins of tartary buckwheat were significantly decreased with the increase in years of continuous cropping (Gao et al., 2016). In this study, the chlorophyll and soluble protein contents in the leaves of common buckwheat showed a significant downward trend with the increase in the years of continuous cropping, which was consistent with those obtained by above scholars. These results showed that the injury of common buckwheat increased with the increasing years of continuous cropping. SOD, CAT, and POD were important protective enzymes for plant stress resistance and anti-aging (Kalir, 1981; Stewart et al. 1980). Under normal conditions, enzymes were in a dynamic equilibrium state; under stress, the activity of antioxidant enzymes in plants increased rapidly (Li et al., 2013). In this study, POD activity significantly decreased with the increase in the years of continuous cropping, whereas that SOD and CAT activity initially increased and then decreased, which was similar with the observation in another research (Gao et al., 2016; Li et al., 2016).The results showed that the enzymatic defense system was activated in the leaves of common buckwheat under continuous cropping, and the activity of protective enzymes increased rapidly to remove the accumulation of activated oxygen and avoid the damage of continuous cropping stress.

As an important metabolic organ for crops, root system not only can absorb nutrients and water, but also can synthesize many important physiological active substances, so it plays a very important role in the growth and development of crops (Wang, Inukai & Yamauchi, 2006; Zhang, Tan, Yang, Yang & Zhang, 2009), and its growth directly affects crop growth and development, nutrition status, and yield level (Chu, Liu, Zhao & Yang, 2014). In this study, continuous cropping not only could significantly reduce the root length, root surface area, and root volume, but also could significantly reduce plant height, the number of main stem nodes, the number of main stem, 1- to 2-internode diameter, and leaf area, which was consistent with that observed by other scholars (Gao, 2015; Li et al., 2012).The results from this experiment implied that continuous cropping significantly reduced the yield of FT1 and decreased by 10.6, 11.1 and 12.0 times with continuous cropping for 4, 5, and 6 years compared with CK, respectively. Thus, the comparison of yield between CK and 6a is obvious. Combining the results of above findings, it was concluded that continuous cropping declined the nutrients of rhizosphere soil of common buckwheat, and continuous cropping seriously affected the growth of overground part, and root growth of common buckwheat, thereby affecting the absorption of nutrients and dry matter accumulation and resulting in a significant decline in yield. The results from this experiment also showed that the yield of common buckwheat decline was greater than tartary buckwheat with continuous cropping (Gao, 2015). This may be related to the plant of tartary buckwheat was far greater than common buckwheat, and dry matter accumulation of tartary buckwheat was greater than common buckwheat, what lead to tolerance of continuous cropping stress was greater than the common buckwheat.

5. Conclusions

From what has been mentioned above, we can come to the conclusion that, the tillage methods of continuous cropping declined the nutrients of rhizosphere soil of common buckwheat, and continuous cropping seriously affected the growth of overground part, and root growth of common buckwheat, thereby affecting the absorption of nutrients and dry matter accumulation and resulting in a significant decline in yield.

Acknowledgments

We are grateful to the National Natural Science Foundation of China (31560358), the Science and Technology Support Plan of Guizhou province, China (QianKeHe ZhiCheng [2018]2297)and [2019]2297), the Major Research Projects of Innovation Groups of Guizhou (QianJiaoHe KY Zi [2017]033) and[2018]015), Joint Project of Natural Science Foundation of China and Guizhou Provincial Government Karst Science Research Center (U1812401), the Earmarked Fund for China Agricultyre Research System (CARS-07-A5).

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the The Science and Technology Support Plan of Guizhou province, China [QianKeHe ZhiCheng [2018]2297)and[2019]2297];The Major Research Projects of

Innovation Groups of Guizhou [QianJiaoHe KY Zi [2017]033) and[2018]015];The National Natural Science Foundation of China [31560358];Joint Project of Natural Science Foundation of China and Guizhou Provincial Government Karst Science Research Center [U1812401];The Earmarked Fund for China Agricultyre Research System [CARS-07-A5];

ORCID

Yan Wang http://orcid.org/0000-0002-6991-4076

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