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RESEARCH ARTICLE

Effects of Continuous Cropping and Application of Bio-organic Fertilizers on Growth, Yield and Quality of Sugar Beet under Reduced Chemical Fertilizer Application

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Abstract

A major problem in the cultivation of sugar beet is continuous cropping cycle. A study was carried out in the 2019–2021 season at the Agriculture and Forestry Sciences of Ulanqab, Inner Mongolia, to assess the impacts on the growth, root yield, and sugar content of sugar beet of various continuous cropping years with bio–organic fertilizers. A split plot system with three replications was set up to carry out the field testing. The main plots had five planting years, with the non-continuous of each growing season serving as the control (CK) and continuous cropping for one, two, three, and four years (designated as C1, C2, C3, and C4, respectively). The subplots had two bio-organic fertilizer levels: 6000 kg ha^{-2} (Y) and 0 (N). The results demonstrated that continuous cropping stunted sugar beet growth and lowered yield and quality. The plant height, leaf area index, root volume, root yield, and sugar yield of sugar beet significantly decreased with the extension of continuous cropping years. Compared with CKN (CKY), plant height, leaf area index, root volume, and fresh weight of C1N (C1Y), C2N (C2Y), C3N (C3Y), and C4N (C4Y) all showed a significantly decreased trend. Furthermore, the plant height, leaf area index, root volume, and fresh weight reductions had amplitudes of 5.60–27.36%, 9.53–67.86%, 17.71–57.35%, and 17.54–45.03%, respectively. The distinctions between C1 and C2 were essentially not statistically significant, and the same was evident for C3 and C4. The root yield and sugar yield exhibit noteworthy relationships with each growth indices. Compared with CKN (CKY), C1N, C2N, C3N, and C4N significantly reduced their root yield and sugar yield by 19.20% and 25.08% (19.63% and 25.67%), 24.13% and 31.02% (24.74% and 32.32%), 44.03% and 55.15% (48.47% and 58.09%), and 47.89% and 61.85% (52.35% and 64.43%). Bio-organic fertilizers applied during the same planting year all had effects on the growth and yield of sugar beet; however, these effects were only significant under the planting year treatments of CK, C1, and C2. The amplitude of the increase in plant height, leaf area index, root volume, fresh weight, and root yield reached 2.76–7.95%, 10.21–24.67%, 10.66–14.88%, 7.03–14.83%, and 18.74–19.69%, respectively. Above all, sugar beet were hindered by continuous cropping, and bio-organic fertilizer can greatly increase sugar beet yield and growth for continuous cropping lasting one or two years; for continuous cropping lasting three or more years, additional measures should be considered.

Keywords Sugar beet · Continuous cropping · Bio-organic fertilizer · Growth · Yield · Sugar content

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Introduction

In addition to being a vital global feed source, sugar beet (*Beta vulgarias L.*) serves as a raw ingredient for the sugar industry (Chhikara et al. 2019; Li et al. 2020). The cultivated area supplies 16% of the world's sugar production and makes up around one-third of the global sugar crop cultivation area (Geng and Yang. 2015; De Oliveira et al. 2020). Only sugarcane has a higher planting area and output than sugar beet (Mall et al. 2021). Since beet is a taproot crop, it should not be grown continuously. A healthy soil environment is a prerequisite for high yield of sugar beet (Geng et al. 2020; Huang et al. 2021). However, due to improper land use and cultivation methods, beet often adopts continuous cropping, resulting in poor plant growth, frequent diseases and pests, reduced sugar content and yield (Huang et al. 2020). Due to the shortage of cultivated land resources, imperfect farming management systems, production environment constraints and other factors (Deihimfard et al. 2019; Holmquist et al. 2021), the problem of continuous cropping obstacles in sugar beet is becoming increasingly severe and and needs to be solved urgently.

Numerous studies (Qin et al. 2017; Wu et al. 2018; Huang et al. 2020) have sought to investigate the mechanism of continuous cropping barriers from the aspects of changes in soil physicochemical parameters, allelochemical accumulation, and soil microbial changes. Continuous cropping obstacle is a comprehensive effect of plant-soil-microbial interaction (Standing et al. 2007; Inselsbacher et al. 2011). Bio-organic fertilizer has the characteristics of both biological and organic fertilizer. Bio-organic fertilizer mainly composed of active microorganism and biodegradable organic material, such as livestock excrement and crop straw (Wu et al. 2009), providing a comprehensive nutritional balance with rapid and long-lasting fertility. It is widely used in crop fertilization, contaminated soil remediation and soil improvement. Numerous studies have demonstrated that adding bio-organic fertilizer can enhance the microbial community structure, soil fertility, and physical and chemical characteristics of the soil (Wu et al. 2014; Ansari et al. 2017). Furthermore, Mohanty discovered that bio-organic fertilizer can inhibit pathogenic microorganisms, lower plant disease incidence, and boost soil microbial diversity (Mohanty et al. 2000). Numerous studies have demonstrated the significance of bio-organic fertilizer in enhancing the chemical and physical characteristics of soil and yielding superior agricultural products (Zhao et al. 2016). Due to its widespread use in recent years, bio-organic fertilizer has become increasingly popular as a means of managing and preventing crop continuous cropping issues. Studies have shown that it is possible to effectively lower soil-borne illnesses caused by continuous cropping including cotton (Luo et al. 2015), cucumbers (Xu et al. 2008), and Pingyi sweet tea (Wang et al. 2019a, b) repeatedly, which would boost agricultural growth and productivity.

However, most of the previous studies only involved the short-term effects of bio-organic fertilizer on soil physical and chemical properties, biological characteristics, and crop quality (Ansari et al. 2017; Yilmaz et al. 2017). The application effect of bio-organic fertilizer under continuous cropping conditions is still unclear. The majority of current studies on using bio-organic fertilizer to prevent and manage ongoing cropping problems are predicated on applying chemical fertilizers equally (Qu et al. 2019; Liu et al. 2015). However, the reaction of bio-organic fertilizer to continuous cropping difficulties under reduced fertilizer application has received comparatively little research, particularly in the study of continuous cropping cultivation of sugar beet, which has not yet been published. Therefore, the purpose of this research was to study the effects of bio-organic fertilizer application on plant height, leaf area index, root volume, yield and sugar content of sugar beet under high intensity continuous cropping conditions, so as to provide scientific basis for improving yield and quality of sugar beet.

Materials and Methods

Site Description

The field experiment was conducted during the 2019, 2020 and 2021 sugar beet growing seasons at Agriculture and Forestry Sciences of Ulanqab in Inner Mongolia (40.9232°N, 113.1196°E). This region was a typical temperate continental monsoon climate with large variation in rainfall quantity and distribution. It has the elevation of about 1962 m, with annual rainfall of 376 mm and mean annual temperature of 4.5 °C, respectively. The rainfall mainly was unevenly distributed and concentrated in July and August. The soil texture is chestnut soil, the organic matter is 12.09 g/kg, total nitrogen is 1.34 g/kg, the total phosphorus is 0.74 g/kg, the total potassium is 13.56 g/kg, the alkali hydrolyzed nitrogen content is 108.78 mg/kg, the available potassium content is 145.35 mg/kg, the available phosphorus content is 15.02 mg/kg, the pH value is 8.18.

Experimental Design

The continuous cropping experiment for sugar beet was carried out over an extended period from 2015 to 2021. Moreover, the planting area is 2,000 m^2 (25 m × 80 m) each year. The land plot planted in 2015 was grown continuously from 2015 to 2019, the land plot planted in 2016 was grown continuously from 2016 to 2020, the land plot planted in 2017 was grown continuously from 2017 to 2021, the land plot planted in 2018 was grown continuously from 2018 to 2021, the land plot planted in 2019 was grown continuously from 2019 to 2021, and the land plot planted in 2020 was only grown in 2021. The experiment was carried out in a split-plot design with three replicates during the three growing seasons from 2019 to 2021. The main plot was chosen to be sugar beet continuous cropping for 1, 2, 3, and 4 years (designated as C1, C2, C3, and C4, respectively), with the new cropping of each growing season serving as the control (CK). The sub-plot consisted of two fertilization treatments: 0 kg hm^{-2} bio-organic fertilization (N) and 6000 kg hm^{-2} bio-organic fertilizer (Y). And the amount of bio-organic fertilizer is based on the results of our previous studies (Tian et al. 2024). Additionally, Fig. 1 displays the field text layout.

Sowing and Fertilizing

Sugar beet (IM1162), which is widely grown in Inner Mongolia, was planted in all plots from 2019 to 2021. Sugar beet was all sown on 1st of May and harvested on 8th of October of 2019, 2020, and 2021. For the plots that do not use bio-organic fertilizer, compound granular fertilizer (12-18-15) was applied each year at 900 kg ha^{-1} resulting in 108 kg ha^{-1} nitrogen, 162 kg ha^{-1} phosphorous, and 135 kg ha^{-1} potassium. While for the plots that use bio-organic fertilizer, compound granular fertilizer (12-18-15) was applied each year at 600 kg ha^{-1} consisting of in 72 kg ha^{-1} nitrogen, 108 kg ha^{-1} phosphorous and 90 kg ha^{-1} potassium. And compound granular fertilizer and bio-organic fertilizer were applied once before planting and were buried at a depth of 15 cm in the middle of the ridges of each plot. At a depth of 1.5 cm, seeds were sown at a density of 100,050 plants ha^{-1}, with a plant spacing of 18 cm and row spacing of 50 cm. Field management was carried out using normal farming methods.

Sampling and Measurement Methods

Destructive sampling was performed in a 1 m^2 area, which included 10 plants in each plot at the seeding stage (SS), rapid growth stage of foliage (RS), root and sugar growth stage (RSS), sugar accumulation stage (SAS), and harvest stage (HS) of sugar beet. And these plant samples were determined for plant height, leaf area index, fresh weight and root volume.

Plant Height

Plant height was measured by a graduated ruler at the growth stages of SS, RS, RSS, SAS, and HS. And the plant height is the height of the longest leaf of sugar beet.

Leaf Area Index

Leaf area index was measured by the weighing method at the growth stages of RS, RSS, SAS, and HS. Using the first lateral vein at the base of the leaf as the boundary between the leaf and the petiole, select 10 representative large, medium, and small leaves from each sample, and use a 4 cm-diameter ring knife to drill holes at 1/3 of the midvein at the tip of the leaf for sampling. Weigh the fresh weight of the small leaves, and calculate the leaf area index using the below formula.

$$\mathit{Leaf\ area\ index} = \frac{12.56 \times 30}{\mathit{Fresh\ weight\ of\ small\ leaves} \times \mathit{whole\ fresh\ weight\ of\ leaves}} / 10000 / 667$$

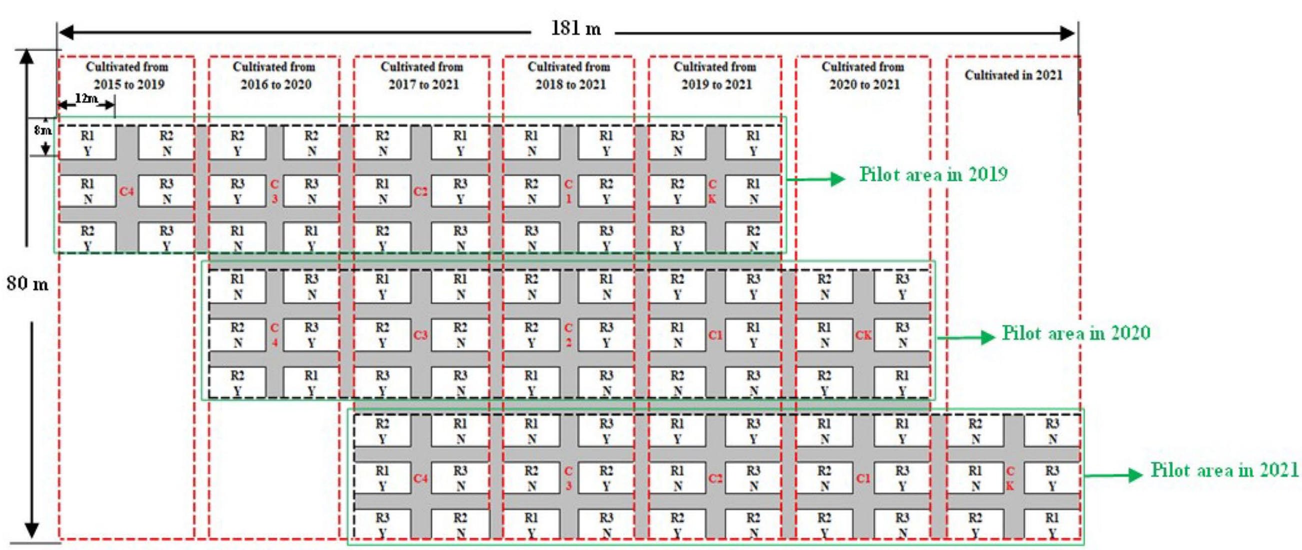

Fig. 1 The layout of the experimental field during 2015–2019 (R = replicate; Y = bio-organic fertilization added; N = no bio organic fertilization added)

Plant Fresh Weight

Plant fresh weight was measured by the weighing method at the growth stages of SS, RS, RSS, SAS, and HS. Divide the beet plant into three parts: the leaf, petiole, and root. And then weigh the three parts with a balance.

Root Volume

Block root volume measurement with a graduated cylinder drainage method.

Root Yield and Sugar Content

At the harvesting stage, 10 m^2 root tubers were chosen for weighing in each plot in order to calculate the root yield. 15 sugar beet root tubers were randomly selected from each plot. A computerized portable refractometer called the Atago Refractometer PAL-1, manufactured in Japan, was used to test the root brix and convert its sugar content. The sugar content and sugar yield were calculated by the below formula.

$$\textit{Sugar Content} = \textit{The root brix} \times 80\%$$

$$\textit{Sugar Yield} = \textit{Root yield} \times \textit{Sugar content}$$

Statistical Analyses

All data are shown as the mean values of the three plot replicates. Statistical analyses were carried out in R (version 4.1.1) (R Core Team, 2022). The analysis of variance (ANOVA) was performed using the R packages "lme4 ″ and "lmer Test" (Kuznetsova et al. 2015). Differences between the treatments (i.e., the ten treatments obtained by the interaction of five cropping year treatments combined with two fertilizer treatments) were compared using the Fisher's least significant difference (LSD) approach (Williams and Abdi. 2010) at the $P \leq 0.05$ significance level. Root yield, sugar content and sugar yield were analyzed using a three-way ANOVA approach, with cropping year, fertilizer, and year as the fixed factors. Pearson's correlation was performed to elucidate and visualize the relationships among yield index and plant characteristics. Pearson's correlations were determined using the R packages Hmisc (version 4.6) and corrplot (version 0.9). R packages corrplot (version 0.9), Lattice (version 0.2-45) (Sarkar. 2008), ggplot2 (version 3.3.5) (Wickham. 2011), and Factoextra (version 1.07) (Kassambara and Mundt. 2017) were used to visualize the results. Figures were produced using the Origin 2021 software.

Results

Root yield and Sugar Yield

The cropping year (C), fertilizer (F), and the interaction of C×F and F×Y significantly ($P \leq 0.001$ or $P \leq 0.01$) affected the root yield (Table 1). In general, from 2019 to 2021, the root yield decreased significantly due to continuous cropping. Compared with CKN (CKY), the root yield of C1N (C1Y), C2N (C2Y), C3N (C3Y), and C4N (C4Y) decreased by an average of 19.20% (19.63%), 24.13% (24.74%), 44.03% (48.47%) and 47.89% (52.35%), respectively. The application of bio-organic fertilizer was higher than that treated without fertilizer, and especially the Y treatment of CK, C1, and C2 showed significant effects. Compared with CKN, C1N, and C2N, the root yield of CKY, C1Y, and C2Y increased by 19.69%, 19.07%, and 18.74% on average, respectively.

The cropping year (C), fertilizer (F), and year (Y) and the interaction of C×F and C×Y significantly ($P \leq 0.001$ or $P \leq 0.01$) affected the sugar content (Table 1). In general, from 2019 to 2021, the sugar content decreased significantly due to continuous cropping. Compared with CKN (CKY), the sugar content of C1N (C1Y), C2N (C2Y), C3N (C3Y), and C4N (C4Y) decreased by an average of 1.27 (1.20), 1.74 (1.63), 3.31 (3.00), and 4.48 (4.08), respectively. But the results showed bio-organic fertilizer had effects on decreasing sugar content, and especially the Y treatment of CK, C1, and C2 showed significantly effects. Compared with CKN, C1N, and C2N, the sugar content decreased by 0.70, 0.61, and 0.56 on average, respectively.

The cropping year (C), fertilizer (F), and year (Y) and the interaction of C×F, C×Y, and F×Y significantly ($P \leq 0.001$or $P \leq 0.01$) affected the sugar yield (Table 1). Sugar yield was determined by root yield and sugar content. In general, from 2019 to 2021, the sugar yield decreased significantly due to continuous cropping. Compared with CKN (CKY), the yield of C1N (C1Y), C2N (C2Y), C3N (C3Y), and C4N (C4Y) decreased by an average of 25.08% (25.67%), 31.02% (32.32%), 55.15% (58.09%), and 61.85% (64.43%), respectively. The application of bio-organic fertilizer can increase the sugar yield, and especially the Y treatment of CK, C1, and C2 showed significant effects. Compared with CKN, C1N and C2N, the yield increased by 14.80%, 14.36%, and 14.28% on average, respectively.

Plant Height

The plant height of sugar beet was substantially different during the whole growing stage (Fig. 2). And the maximum plant height was shown in the root and sugar growth stage (RSS) of each year. The effects of cropping years (C),

Table 1 Effects of continuous cropping and fertilizer on root yield and sugar yield of sugar beet

Year	Treatment	Root yield (kg/667 m^2)	Sugar content (%)	Sugar yield (kg/667 m^2)
2019	CKN	4123.72b	17.04a	702.72b
	CKY	4926.03a	16.42b	808.86a
	C1N	3281.93d	16.13bc	529.49d
	C1Y	3946.84bc	15.58de	614.85c
	C2N	3182.96d	15.77 cd	501.77d
	C2Y	3820.60c	15.25e	582.46c
	C3N	2301.62ef	14.33f	329.62ef
	C3Y	2559.8e	13.94f	356.36e
	C4N	2119.64f	13.00 g	275.78 g
	C4Y	2311.51ef	12.75 g	294.87 fg
2020	CKN	3921.63b	16.84a	660.73b
	CKY	4760.23a	16.14b	768.15a
	C1N	3223.61d	15.43c	497.44d
	C1Y	3850.86bc	14.84de	571.54c
	C2N	3053.14d	14.97 cd	457.1e
	C2Y	3609.84c	14.44e	521.39d
	C3N	2205.89ef	12.71f	279.9 fg
	C3Y	2402.51e	12.40f	298.23f
	C4N	2001.10f	11.62 g	232.23 h
	C4Y	2219.1ef	11.36 g	251.76gh
2021	CKN	4096.49b	16.37a	670.91b
	CKY	4843.38a	15.66b	758.44a
	C1N	3302.12c	14.87c	491.21d
	C1Y	3879.66b	14.19de	550.45c
	C2N	2972.52d	14.3de	425.07e
	C2Y	3506.17c	13.66ef	479.02d
	C3N	2287.99ef	13.28 fg	303.73 fg
	C3Y	2526.52e	12.86 g	324.86f
	C4N	2207.77f	12.19 h	268.8 g
	C4Y	2392.64ef	11.87 h	284.26 fg
Cropping year	CK	4445.25a	16.41a	728.30a
	C1	3580.84b	15.17b	542.50b
	C2	3357.54c	14.73b	494.47c
	C3	2380.72d	13.25c	315.45d
	C4	2208.63d	12.13d	267.95e
Fertilizer	Y	3437.05a	14.09a	497.70a
	N	2952.14b	15.59a	441.77a
Year	2019	3257.47a	15.02a	499.68a
	2020	3124.79a	14.08b	453.85a
	2021	3201.53a	13.92b	455.68a
Significance of factor	Cropping year (C)	***	***	***
	Fertilizer (F)	***	***	***
	Year (Y)	**	***	***
	C×F	***	NS	***
	C×Y	NS	***	**
	F×Y	NS	NS	NS
	C×F×Y	NS	NS	NS

Numbers followed by different letters in each column indicate significantly differences at $\alpha = 0.05$ based on ANOVA test

The statistical significance is denoted by *, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.001$, and NS, not significant

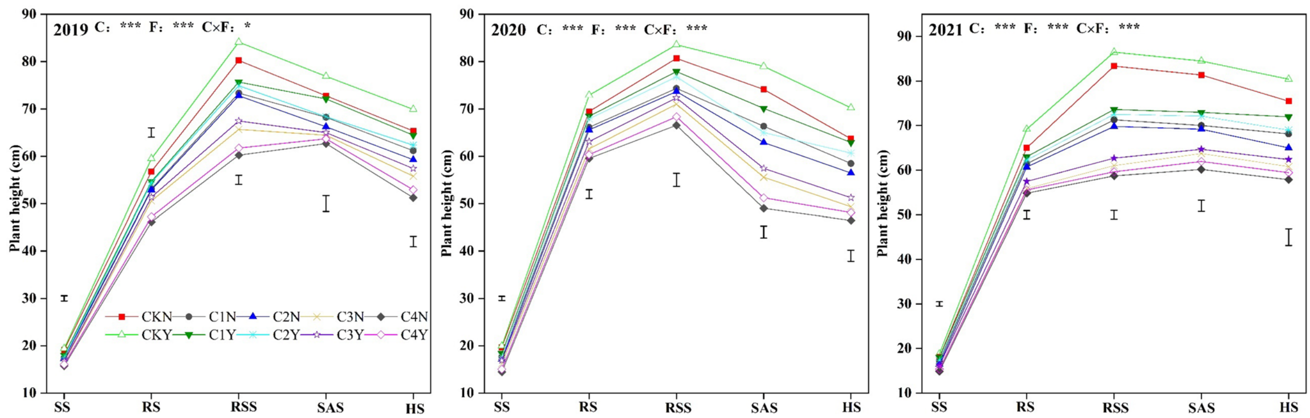

Fig. 2 Effects of continuous cropping and fertilizer on plant height of sugar beet. SS: Seedling stage, RS: Rapid growth stage of foliage, RSS: Root and sugar growth stage, SAS: Sugar accumulation stage, and HS: Harvest stage. The statistical significance is denoted by *, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.001$, and NS, not significant.

fertilizer (F), and their interactions were all very significant ($P \leq 0.001$) or significant ($P \leq 0.05$) during the whole growth stage.

No matter the bio-organic fertilizer applied or not, with the extension of continuous cropping years, the plant height of sugar beet showed a decreasing trend, and the application of bio-organic fertilizer significantly affected the plant height (Fig. 2). From 2019 to 2021, compared with CKN (CKY), the plant height of C1N (C1Y), C2N (C2Y), C3N (C3Y), and C4N (C4Y) decreased significantly over the growing stage, with an average decrease of 5.60–10.34% (6.59–10.60%), 6.38–13.07% (8.47–14.53%), 12.18–19.44% (14.23–22.51%), and 16.29–24.67% (19.24–27.36%), respectively. From 2019 to 2021, from the rapid growth stage of foliage (RS) to the harvest stage (HS), this difference of CKY was all significant. Compared with CKN, the plant height of CKY increased by 4.08–7.95% on average, respectively. From the root and sugar growth stage (RSS) to the harvest stage (HS), this differences between C1 and C2 showed significant difference, compared with C1N and C2N, the plant height of C1Y and C2Y increased by 2.76–6.21% and 3.69–6.29% on average, respectively.

Leaf Area Index

The leaf area index of sugar beet was substantially different during the whole growth stage (Fig. 3). And the maximum leaf area index was shown in root and sugar growth stage (RSS) of each year. The effects of cropping years (C) were all very significant ($P \leq 0.001$) during the whole growth stage. The effects of fertilizer (F) were all very significant ($P \leq 0.01$) or significant ($P \leq 0.05$) except at the rapid growth stage of foliage in 2020. And the effects of their interactions were only very significant ($P \leq 0.01$) at the sugar accumulation stage in 2019 and 2021.

In different continuous cropping years, the leaf area index of sugar beet at different growth stage is shown in Fig. 3. In general, the leaf area index decreased significantly in all growth stages due to continuous cropping from 2019 to 2021, and at different growth stage, the significant differences among different cropping years showed differently. And in general, the leaf area index of CK was significantly higher than that of four continuous cropping year treatments; that of C1 and C2 was significantly higher than that of C3 and C4, and there was a significantly difference between C1 and C2, C3 and C4. Compared with CKN (CKY), the average leaf area index of C1N (C1Y), C2N (C2Y), C3N (C3Y), and C4N (C4Y) decreased by 9.53–33.36% (10.34–34.19%), 11.42–40.34% (11.61–38.91%), 19.23–53.36% (22.13–57.72%) and 29.49–52.63% (31.82–67.86%). And the leaf area index of sugar beet treated with bio-organic fertilizer was significantly higher than that treated without fertilizer in some growth stages. From 2019 to 2021, from the root and sugar growth stage (RSS) to the harvest stage (HS), these differences under CK, C1, and C2 was all significant. Compared with CKN, C1N, and C2N, the leaf area index of CKY, C1Y, and C2Y increased by 10.64–23.80%, 10.21–23.83%, and 11.68–24.67% on average, respectively.

Root volume

The root volume of sugar beet was substantially different during the whole growth stage (Fig. 4). And with the growth stages going on, the root volume showed an increased trend. The effects of cropping year (C) were all very significantly ($P \leq 0.001$) during the whole growth stage. The effects of fertilizer (F) were all very significant ($P \leq 0.001$, $P \leq 0.01$) or significant ($P \leq 0.05$) except at the rapid growth stage of foliage in 2019. And the effects of their interactions were

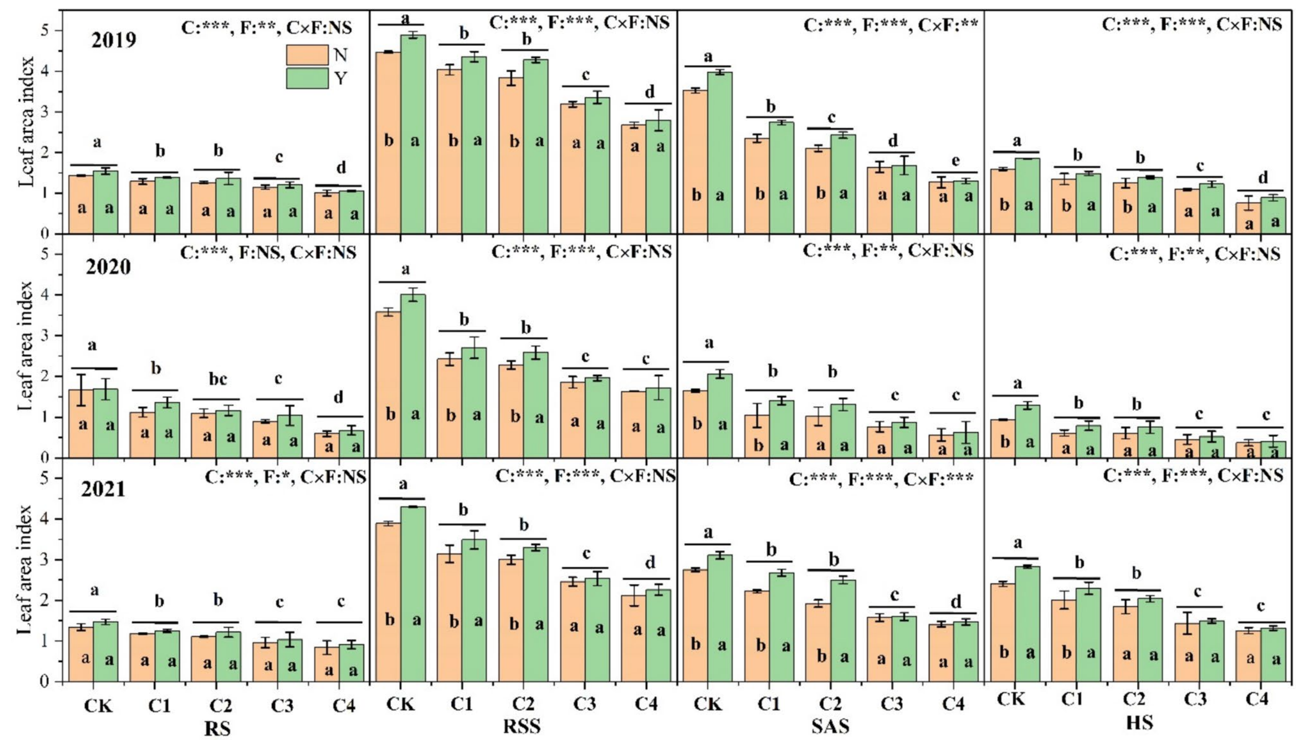

Fig. 3 Effects of continuous cropping and fertilizer on leaf area index of sugar beet. SS: Seedling stage, RS: Rapid growth stage of foliage, RSS: Root and sugar growth stage, SAS: Sugar accumulation stage, and HS: Harvest stage. Numbers followed by different letters in each treatment indicate significantly differences at $\alpha = 0.05$ based on ANOVA test. The statistical significance is denoted by *, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.001$, and NS, not significant

only very significant ($P \leq 0.001$) at the sugar accumulation stage and the harvest stage in 2021.

In different continuous cropping years, the root volume of sugar beet at different growth stage is shown in Fig. 4. In general, the root volume decreased significantly in all growth stages due to continuous cropping from 2019 to 2021, and at different growth stage, the significant differences among different cropping years showed differently. And in general, the root volume of CK was significantly higher than that of four continuous cropping year treatments; that of C1 and C2 was significantly higher than that of C3 and C4, and there was a significantly different between C1 and C2, and the same was evident for C3 and C4. Compared with CKN (CKY), the average root volume of C1N (C1Y), C2N (C2Y), C3N (C3Y), and C4N (C4Y) decreased by 17.71–34.95% (18.17–30.59%), 20.98–39.09% (20.62–36.93%), 29.68–52.10% (34.29–52.10%), and 35.76–56.74% (39.61–57.35%). And the root volume of sugar beet treated with bio-organic fertilizer was higher than that treated without fertilizer in some growth stage. From 2019 to 2021, from the root and sugar growth stage (RSS) to the harvest stage (HS), this differences of CK, C1, and C2 were all significantly, compared with CKN, C1N, and C2N, the root volume of CKY, C1Y, and C2Y increased by 11.58–13.84%, 10.66–14.85% and 10.68–14.88% on average, respectively.

Fresh Weight

The fresh weight of sugar beet was substantially different during the whole growth stages (Fig. 5). And with the growth stages going on, the fresh weight of leaves and petioles showed a decreased trend, and the fresh weight of roots showed an increased trend. From Table 2, the cropping year (C), fertilizer (F), and year (Y) all significantly ($P \leq 0.001$) affected the fresh weight. The interaction of C×Y significantly ($P \leq 0.001$) affected the fresh weight of leaf, petiole, and the whole plant. The interaction of C×F and F×Y had different significant effects on fresh weight among different plant organs and growth stages. The interaction of C×F×Y showed no significant difference during the whole growth stages.

In different continuous cropping years, the fresh weight at different growth stage is shown in Fig. 5. In general, the fresh weight decreased significantly in all growth stages due to continuous cropping from 2019 to 2021, and at different growth stage, the significant differences among different cropping years showed differently. And in general, the

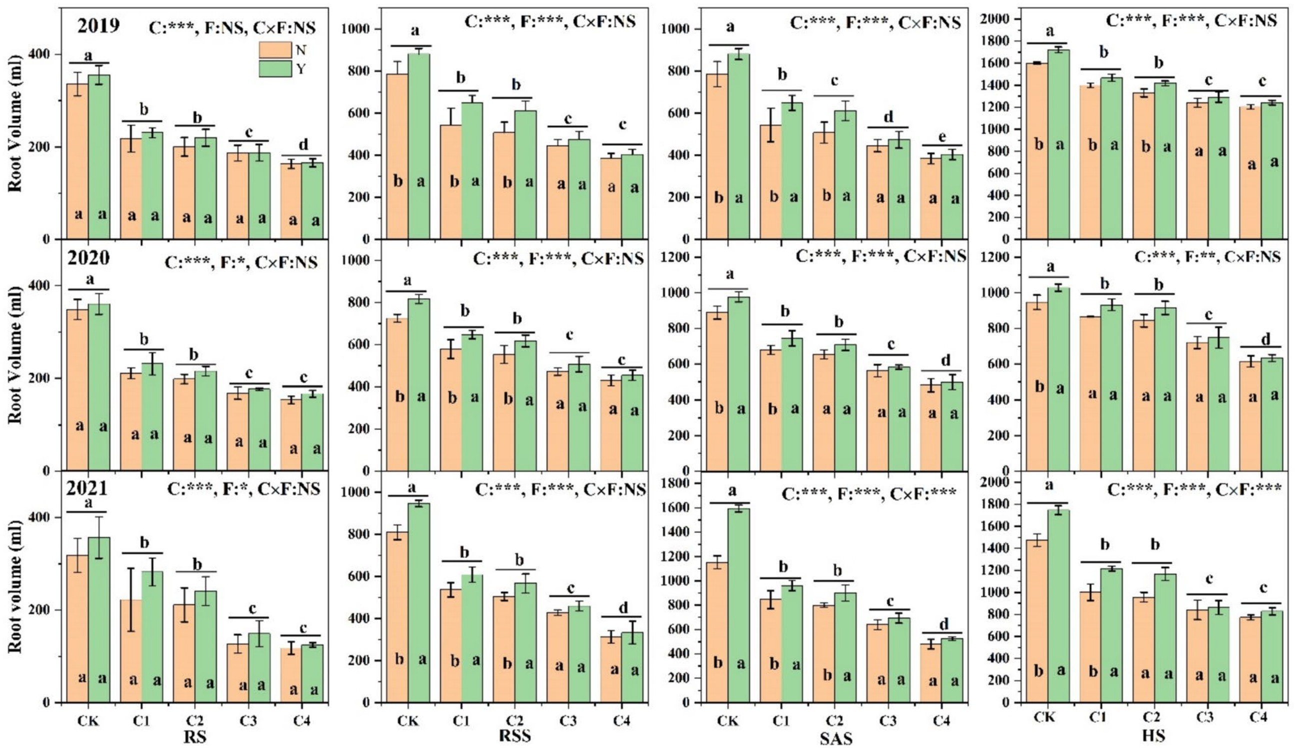

Fig. 4 Effects of continuous cropping and fertilizer on root volume of sugar beet. SS: Seedling stage, RS: Rapid growth stage of foliage, RSS: Root and sugar growth stage, SAS: Sugar accumulation stage, and HS: Harvest stage. Numbers followed by different letters in each treatment indicate significantly differences at α = 0.05 based on ANOVA test. The statistical significance is denoted by *, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.001$, and NS, not significant

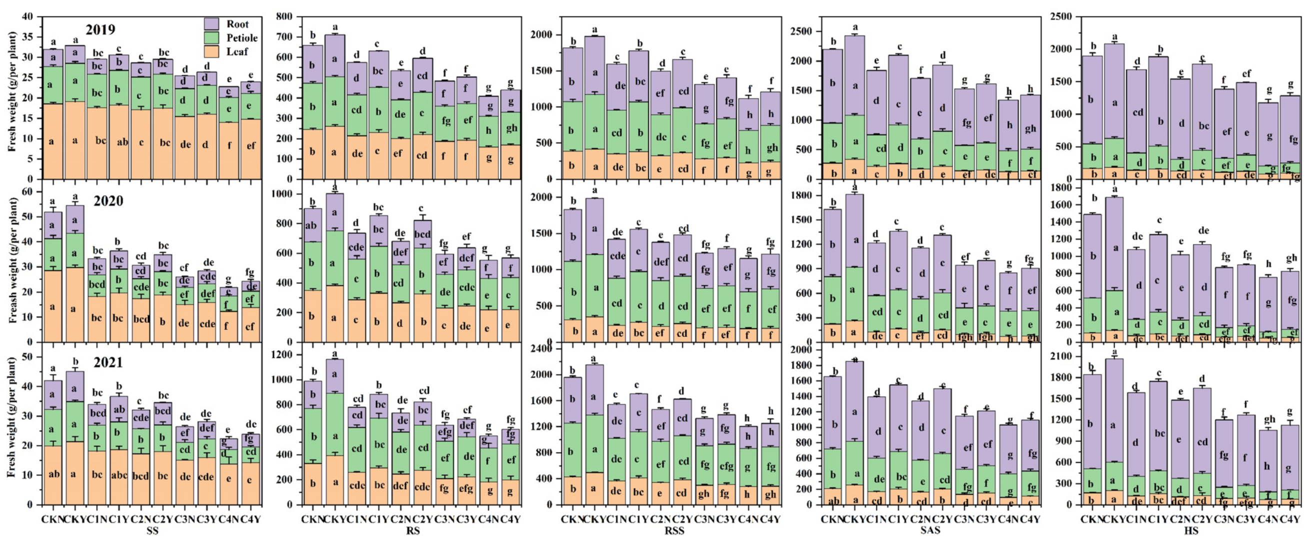

Fig. 5 Effects of continuous cropping and fertilizer on fresh weight of sugar beet. SS: Seedling stage, RS: Rapid growth stage of foliage, RSS: Root and sugar growth stage, SAS: Sugar accumulation stage, and HS: Harvest stage. Numbers followed by different letters in each column of the same color indicate significantly differences at α = 0.05 based on ANOVA test

fresh weight of CK was significantly higher than that of four continuous cropping year treatments. The fresh weight in different organs of C1 and C2 were significantly higher than those of C3 and C4, and there was a significant difference between C1 and C2, and the same was evident for C3 and C4 (Table 2). Compared with CKN (CKY), the average leaf fresh weight of four continuous cropping year treatment decreased by 16.24–58.70% (15.34–62.41%), the petiole fresh weight decreased by 15.36–72.72% (14.80–70.79%), the root fresh weight decreased by 10.93–55.40% (11.85–52.62%), and the whole plant fresh weight decreased by 17.54–44.44% (16.71–45.03%), respectively.

And the fresh weight treated with bio-organic fertilizer was higher than that treated without fertilizer in some stages. From 2019 to 2021, from the rapid growth stage of foliage (RS) to the harvest stage (HS), this differences of CK showed significant difference. Compared with CKN, the fresh weight of leaf, petiole, root, and the whole plant of CKY increased by 11.64–21.35%, 8.13–15.89%, 8.67–15.24%, and 9.02–12.22% on average, respectively. For the treatments C1 and C2, the application of bio-organic fertilizer significantly increased the fresh weight of the whole plant from the rapid growth stage of foliage (RS) to the harvest stage (HS), but there were significant differences among the fresh weight of leaf, petiole, and root. Compared with C1N and C2N, the fresh weight of the whole plant of C1Y and C2Y increased by 7.03–12.64% and 8.04–14.83% on average, respectively. For the treatments C3 and C4, the application of bio organic fertilizer had no significant effects on the fresh weight during the whole growth stage.

Relationship Between Growth Indices and Yield of Sugar Beet

The relationship between growth indices and yield is shown in Fig. 6. Obviously, growth indices all had very significant correlations ($P < 0.001$) with the root yield, sugar content, and sugar yield. And the correlation results showed that through the adjustment of plant growth, the root yield and sugar yield of sugar beet can be improved cooperatively in the present study.

Discussion

Effects of Cropping Year and Bio-Organic Fertilizer on Crop Growth

Crop growth indices are more sensitive to the response of continuous cropping. Studies have shown that the growth of soybean (Cui et al. 2018), corn (Utomo et al. 2013), potato (Liu et al. 2014), cucumber (Zhao et al. 2020) were inhibited, and disease index increased after long term continuous cropping, while with the increasing number of continuous cropping years, the inhibitory effects intensified. As Y. Li et al. (2012) determined continuous cropping evidently decreased the plant height, number, and weight per 100 of peanuts. Moreover, the decrease was considerably evident with an increase in continuous cropping years. This study showed that with the increasing of cropping years, the plant height, leaf area index, fresh weight, and root volume all showed a decreased trend. And we found that continuous cropping affected the growth from the early growth stages. From seedling stage to harvest stage, plant height, leaf area index, fresh weight, and root volume of continuous cropping treatments were all significantly lower than those of CK, but those differences showed differently among four continuous cropping treatments during different growth stages, and mainly showed that the differences between continuous cropping for 1 year (C1) and 2 years (C2) were basically not significant. These results were basically the same as in the early studies (Cui et al. 2018; Utomo et al. 2013; Liu et al. 2014; Zhao et al. 2020). In recent years, with the widespread application of bio-organic fertilizer, it has been increasingly applied in the prevention and control of continuous cropping obstacles. Previous studies showed bio-organic fertilizer can effectively alleviate soil-borne diseases caused by continuous cropping of crops such as cucumber (Xu et al. 2008), cotton (Luo et al. 2015), and Pingyi sweet tea (Wang et al. 2019a, b), thereby promoting crop growth and improving crop productivity under continuous cropping (Qu et al. 2019) In this study, bio-organic fertilizer can promote the growth of sugar beet under the same planting year, which was the same as in previous studies (Xu et al. 2008; Luo et al. 2015; Wang et al. 2019a, b). At the same time, we also found that under the planting year treatments of CK, C1, and C2, bio-organic fertilizer had significant effect on promoting the growth of sugar beet, but these effects did not show significant under the planting year treatments of C3 and C4. These findings differ from those related to cucumbers (Wang et al. 2019a, b), which showed that the longer the soil was continuously cropped after the application of bio-organic fertilizer, the greater the impact of the fertilizer on soil remediation for the cucumbers in the facility. This could be brought about by variations in crop traits and kinds of bioorganic fertilizer.

Effects of Cropping Year and Bio-Organic Fertilizer on Root Yield and Quality

The formation of crop yield and quality is the cumulative results of crop growth and development at different growth stages, influenced by various internal and external factors of crop cultivation during the growth period, among which cropping year and fertilizer are two key factors affecting crop yield and quality. Even with normal management measures, crop yield will be reduced when the same or similar crops are continuously planted in the same plot while the physical and chemical properties of the soil also deteriorate (Aparicio and Costa. 2007; Li and Huang 2007). Continuous cropping

Table 2 Effects of cropping year, fertilizer on fresh weight of sugar beet

Plant organ	Growth stage	Cropping year					Fertilizer		Year			Significance of factor						
		CK	C1	C2	C3	C4	Y	N	2019	2020	2021	Cropping Year (C)	Fertilizer (F)	Year (Y)	C×F	C×Y	F×Y	C×F×Y
Whole plant	SS	43.05a	33.39b	31.72b	26.80c	23.18d	32.67a	30.58a	28.17b	34.20a	32.52a	***	***	***	NS	***	NS	NS
	RS	904.05a	742.87b	698.06b	588.94c	520.26c	727.69a	653.97b	553.68b	734.34a	784.46a	***	***	***	***	***	**	NS
	RSS	1953.05a	1599.24b	1517.70c	1323.81d	1191.60e	1578.04a	1456.12 b	1536.30a	1453.17a	1561.77a	***	***	***	***	***	NS	NS
	SAS	1928.76a	1575.65b	1490.18b	1240.54c	1107.21c	1539.14a	1397.79a	1810.53a	1217.87c	1377.00b	***	***	***	***	***	*	NS
	HS	1843.04a	1538.57b	1432.27b	1185.32c	1035.49c	1476.86a	1337.01a	1618.50a	1101.02b	1501.29a	***	***	***	***	***	NS	NS
Leaf	SS	22.84a	18.40b	17.66b	15.56c	13.82d	18.10a	17.21a	16.82b	18.93a	17.22ab	***	**	***	NS	***	NS	NS
	RS	326.87a	269.49b	255.30b	214.42c	191.32c	264.07a	238.89a	207.57b	285.87a	261.01a	***	***	***	*	***	NS	NS
	RSS	397.86a	336.85b	314.80b	265.04c	234.83c	324.40a	295.35a	360.13a	242.62c	326.87b	***	***	***	**	***	NS	NS
	SAS	259.46a	189.76b	170.56b	129.69c	102.54d	185.55a	155.26b	204.19a	137.73c	169.28b	***	***	***	***	***	NS	NS
	HS	160.19a	124.15b	110.77b	90.06c	70.72d	119.66a	102.69b	130.57a	80.22b	122.73a	***	***	***	NS	**	NS	NS
Petiole	SS	11.82a	8.84b	8.51b	6.77c	5.89d	8.65a	8.08a	7.83a	8.86a	8.41a	***	***	***	NS	***	NS	NS
	RS	350.70a	294.22b	276.76bc	239.53 cd	215.88d	288.42a	262.42a	195.91c	273.57b	356.78a	***	***	***	NS	***	NS	NS
	RSS	802.35a	666.85b	630.69c	562.54d	533.37d	662.40a	615.92b	591.23b	646.36a	679.89a	***	***	***	NS	***	NS	NS
	SAS	621.68a	505.96b	473.62b	372.90c	329.66c	483.70a	437.82a	532.41a	433.04b	416.83b	***	***	***	**	***	*	NS
	HS	406.74a	277.33b	245.16b	171.83c	113.83d	267.47a	218.49b	266.90a	213.15a	248.89a	***	***	***	***	***	**	NS
Root	SS	8.39a	6.17b	5.55bc	4.47 cd	3.47d	5.92a	5.29a	3.51b	6.42a	6.89a	***	***	***	NS	***	NS	NS
	RS	226.48a	179.16b	166.00b	134.99c	113.00d	175.20a	152.65b	150.20b	174.91a	166.67ab	***	***	***	NS	NS	NS	NS
	RSS	752.84a	595.54b	572.22b	496.23c	423.40d	591.24a	544.86a	618.20a	564.20ab	521.74b	***	***	***	NS	***	NS	NS
	SAS	1047.62a	879.93b	846.00bc	737.95 cd	675.01d	869.89a	804.71a	1073.93a	647.09c	790.89b	***	***	***	*	NS	NS	NS
	HS	1276.11a	1137.08b	1076.34b	923.43c	850.94c	1089.73a	1015.83a	1221.03a	807.64c	1129.67b	***	***	***	*	***	NS	NS

Numbers followed by different letters in each line indicate significantly differences at α = 0.05 based on ANOVA test.

The statistical significance is denoted by $*P \leq 0.05$; $**P \leq 0.01$; $***P \leq 0.001$, and NS, not significant.

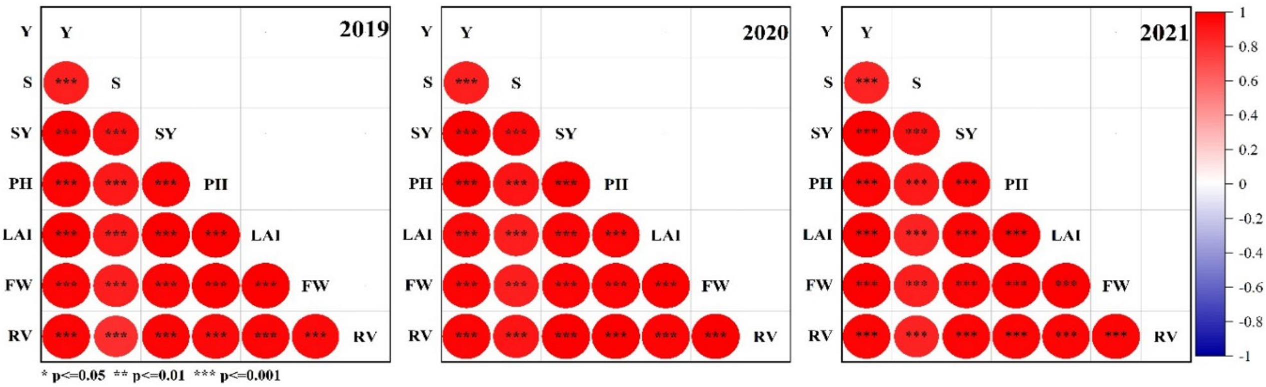

Fig. 6 Relationship between growth indices and yield of sugar beet. Y: Root yield, S: sugar content, SY: sugar yield, PH: plant height, LAI: leaf area index, FW: fresh weight, RV: root volume. The statistical significance is denoted by *, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.001$

usually leads to an imbalance of soil physical and chemical properties, autotoxicity, and the destruction of microbial diversity (Ling et al. 2014; Mondal et al. 2013). These may cause a decrease in crop yield and quality. It has been found that after planting cucumbers in the facility soil for 4, 5, 8, and 12 years of continuous cropping, the cucumber yield, soluble solid content, and VC content decreased with the extension of the continuous cropping period (He et al. 2008). This study showed a similar trend in root yield, sugar content, and sugar yield. Continuous cropping resulted in a significant decrease in root yield, sugar content, and sugar yield, and with the extension of continuous cropping years, the decline in sugar beet yield continued to increase. This is similar to the conclusions drawn from previous researches on other crops as described above. In this study, we also found that no matter whether bio-organic fertilizer was used or not, the root yield and sugar yield of four continuous cropping treatments were significantly lower than those of CK, but those differences between continuous cropping for 3 years (C3) and 4 years (C4) were basically not significant. According to Zhang et al. (2021), continuous cropping may drastically reduce the amount of nutrients in rhizosphere soil, particularly P and K. In addition, one of the reasons by which continuous cropping lowers sugar beetroot root output may be the lowered nutrients and imbalance in nutrient element proportions in the rhizosphere soil. Many researchers have confirmed that bio-organic fertilizer can play an important role in improving crop yield and quality in the continuous cropping system. Furthermore, prior research has essentially demonstrated that the use of bio-organic fertilizer can effectively replace the nutrients and organic matter that continuous cropping soil lacks by controlling the soil environment (Chen et al. 2011); additionally, beneficial microorganisms can reproduce in the soil to break down self-toxic substances created by continuous cropping (Sun et al. 2010), thereby lessening the negative effects of continuous cropping on crop growth and increasing crop yield. The majority of earlier research, however, primarily looked at the immediate impacts of bio-organic fertilizer on the biological traits, crop quality, and physical and chemical properties of the soil; little is known about the effects of bio-organic fertilizer under continuous cropping. The same findings were obtained in our study: although the impacts varied between cropping years, bio-organic fertilizer improved root and sugar yield in the same cropping year. For the treatments of CK, C1, and C2, the application of bio-organic fertilizer significantly increased root yield and sugar yield, but the effects of C3 and C4 were not significant. The amount that the bio-organic fertilizer improves the soil for continuous cropping depends on the number of years of continuous cropping. The longer continuous cropping is permitted to continue, the more or various types of bio-organic fertilizer are needed (Wang et al. 2019a, b). In this case, it is necessary to think about collaborating with other strategies, including rotation, soil disinfection, etc., in order to implement thorough prevention and control. In this study, the application of bio-organic fertilizer reduced the sugar content under the same planting year, and the effects of this reduction decreased with the increase in continuous cropping years. And under the planting year treatments of CK, C1, and C2, bio-organic fertilizer significantly decreased the sugar content, and these effects showed no significant decrease under treatments of C3 and C4. This may be due to the sensitivity of sugar content in sugar beets to water and fertilizer, and some previous studies also showed these results (Guo et al. 2016; Huang et al. 2018).

Conclusion

In addition to reducing root output and quality, continual cropping stunted the growth of sugar beet. As the number of cropping years increased, there were a considerable drop in the root yield, sugar content, sugar yield, root volume, plant height, and leaf area index. Under continuous cropping settings, the application of bio-organic fertilizer improved sugar beet growth, root yield, and quality; the effects of bio-organic fertilizer were particularly noticeable during the first to two years of continuous cropping. Furthermore, although bio-organic fertilizer did have some effects, they were not statistically significant for cropping that was carried out for a duration of three years or longer.

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Declarations

Conflict of interest The authors declare no conflicts of interest. We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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