果 树 学 报 2019，36（1）：86-93
Journal of Fruit Science

DOI:10.13925/j.cnki.gsxb.20180273

江苏省不同区域草莓连作土壤养分及微生物区系分析

王廷峰[1,2]，赵密珍[1*]，关 玲[1]，赵 帆[1]，于红梅[1]，庞夫花[1]

（[1]江苏省农业科学院果树研究所·江苏省高效园艺作物遗传改良重点实验室，南京 210014；
[2]南京农业大学园艺学院，南京 210095）

摘 要：【目的】探究不同区域草莓连作障碍的发生原因。【方法】用典型调查法调查并统计江苏省邳州港上镇、东海石榴镇和溧水白马镇草莓连作土壤的养分含量及微生物区系，并采集当地连作土与非连作土盆栽草莓，观察植株茎粗、鲜质量、株高、根长和根质量的生长状况。【结果】港上镇和石榴镇的草莓连作土壤有机质和碱解氮含量缺乏；港上镇0~10 cm土层的土壤有机质，有效钙、镁、铁和硼含量比10~20 cm土层低10.50%~54.65%，根际土壤养分流失严重；港上镇土壤有效锰含量缺乏，白马镇的土壤硼含量很缺乏；港上镇和白马镇的草莓连作土壤已发生轻度盐渍化，石榴镇土壤已发生中度盐渍化；各地连作土壤微生物均以细菌为主，真菌的数量最低；连作会给植株茎粗、鲜质量、株高、根质量和根长带来显著的负影响。【结论】草莓连作会使土壤理化性质改变、养分失衡以及微生物群落结构失衡，影响植株生长。生产上应尽可能采取措施避免连作，并及时对连作土壤进行修复改良。

关键词：草莓；连作；土壤微生物；土壤养分；江苏省

中图分类号：S668.4 **文献标志码：**A **文章编号：**1009-9980（2019）01-0086-08

Analysis of nutrient contents and microbial flora in the continuous cropping soil of strawberry in different regions of Jiangsu province

WANG Tingfeng[1, 2], ZHAO Mizhen[1*], GUAN Ling[1], ZHAO Fan[1], YU Hongmei[1], PANG Fuhua[1]

（[1]*Institute of Pomology, Jiangsu Academy of Agricultural Sciences · Jiangsu Key Laboratory of Horticultural Crops Genetic Improvement, Nanjing 210014, Jiangsu, China;* [2]*College of Horticulture, Nanjing Agricultural University, Nanjing 210095, Jiangsu, China*）

Abstract:【Objective】In recent years, different levels of continuous cropping obstacles have occurred in strawberry production in China. Continuous cropping reduces the content of soil organic matter and leads to increasing shortage of trace elements. It may also cause imbalance of microbial structure in the soil. As a result, strawberry plants become susceptible to pests and diseases that cause huge losses for strawberry producers. In our study, soils of continuous cropping of strawberry were collected from Gangshang town, Shiliu town, and Baima town, which are the main strawberry producing areas in Jiangsu province. By investigating the nutrient contents and microflora status of the continuous cropping soils at different depths in these areas, we planned to analyze the effect of continuous cropping on strawberry plants, understand the mechanisms of continuous cropping obstacles, find countermeasures, as well as provide a theoretical basis for overcoming continuous cropping obstacles in strawberry.【Methods】Soil samples were collected from strawberry greenhouses in Gangshang town, Shiliu town, and Baima town in Jiangsu province at the end of May 2016, and these areas have been continuously cropping strawberries for more than seven years. The greenhouses at different locations in each region were used and the soils of 0 to 10 cm, 10 to 20 cm, and 20 to 30 cm in depths were collected using a five-

---

收稿日期：2018-07-17 接受日期：2018-10-10

基金项目：江苏省现代农业研究开发示范类项目（BE2016369）；江苏省三新工程（编号：SXGC[2017]261）

作者简介：王廷峰，男，在读硕士研究生，研究方向：果树生理栽培。E-mail：2017804173@njau.edu.cn

*通信作者 Author for correspondence. E-mail：njzhaomz@163.com

point sampling method. The soil samples were divided into two equal parts, one of which was used to detect soil microorganisms, and the other was used to determine soil physical and chemical properties. On September 5th of the same year, 20 strawberry plants were planted in continuous cropping soils collected from each area in a potted manner, and the non-continuous cropping soils in the same area were used as the experimental control. Three replicates were conducted in this experiment. On the 57th day after planting (November 1st), the status of plant growth was investigated. 【Results】The organic matter content ($g \cdot kg^{-1}$) of the surface soils (0 to 20 cm) in Gangshang town, Shiliu town, and Baima town was 18.40±5.42, 18.26±1.28, and 28.63±8.04, respectively, and the organic matter in Gangshang town and Shiliu town is in shortage. As the depth of the soil increased, the organic matter content in Shiliu town and Baima town showed a decreasing trend, while it increased first and then decreased in Gangshang town. The content of available nitrogen ($mg \cdot kg^{-1}$) in the surface of Gangshang town, Shiliu town, and Baima town was 75.37±1.24, 81.25±3.09, and 113.75±14.21, respectively, and the available nitrogen in Gangshang town and Shiliu town is relatively in shortage, and the content of available nitrogen in Baima town is moderate. The available soil nitrogen in the three regions was mainly concentrated in the 0 to 20 cm soil layer, and the available nitrogen content in the deeper soil layer decreased by 33%-45%. The available manganese content ($mg \cdot kg^{-1}$) in the surface of Gangshang town, Shiliu town, and Baima town was 3.76±0.56, 44.15±3.20, and 13.06±0.85, respectively, corresponding to lacking, abundant, and moderate, respectively. The boron concentration ($mg \cdot kg^{-1}$) in continuous cropping soil in Gangshang town, Shiliu town, and Baima town was 0.63±0.27, 0.51±0.03 and 0.25±0.03, respectively. The soil boron was moderate in Gangshang town and Shiliu town, but lacking in Baima town. The contents of available potassium, phosphorus, magnesium, iron and zinc were very high in the three regions. The result of soil electrical conductivity (EC) showed that the continuous cropping soils in Gangshang town and Baima town had mild salinization, and the soils in Shiliu town had moderate salinization. Soils in Gangshang town and Shiliu town were neutral in pH, while soils in Baima town belonged to the slightly alkaline soil. As the depth of soil increased, the abundance of soil actinomycetes in Gangshang town, Shiliu town and Baima town showed a decreasing trend; the abundance of soil bacteria in Gangshang town and Shiliu town tended to decrease; while that in Baima town increased. Interestingly, with the deepening of the soils, the abundance of fungi in Gangshang town first decreased and then increased; that in the Shiliu town showed a decreasing trend, while soils in Baima town showed an increasing trend.【Conclusion】Continuous cropping results in the loss of soil nutrients and the imbalance of microbial community structure, which will have a significant impact on strawberry production. As long as possible, continuous cropping should be avoided in the production, and soil improvement should be conducted in time.

Key words: Strawberry; Continuous cropping; Soil microorganism; Soil nutrients; Jiangsu province

草莓（*Fragaria × ananassa* Duch.）属蔷薇科（Rosaceae）多年生草本植物，其果实酸甜可口、营养丰富，深受人们喜爱。江苏省是我国草莓的主产区之一，其栽培面积和产量均居国内前列。近年来，由于可利用土地紧缺、园艺设施搬动成本高，江苏各地的草莓生产均发生了不同程度的连作障碍[1]。研究表明，随着连作年限的增加，土壤有机质含量逐渐下降，微量元素丰缺差距逐渐扩大，土壤中的细菌、真菌和放线菌比例逐渐失衡[2-3]。土壤养分的缺失和根际微生物群落结构的破坏使草莓植株易受病虫害侵染，植株长势和抗病力逐年变弱，甚至出现整株死亡的现象，使草莓生产损失巨大[4-5]。连作障碍已成为阻滞农业可持续发展的主要因素之一[6]。

土壤有机质主要来源于土壤中的动物、植物和

微生物残体，是植物摄取养分的主要来源之一，有机质含量可以决定土壤的理化性质，在一定范围内与土壤肥力呈正相关关系[7]。土壤微生物也是植株正常生长不可或缺的环境组分，在土壤养分循环中起到关键作用，微生物群落结构中有益菌和有害菌的比例影响着植株根系吸收养分和抵御疾病的能力[8-9]。笔者采集江苏草莓主产区邳州港上镇、东海石榴镇和溧水白马镇的草莓连作土壤，分析各地区不同深度连作土的养分含量和微生物区系状况，并结合土壤理化性质分析连作土对草莓植株的影响，以明确草莓连作障碍的形成机制和改善措施，为克服江苏乃至华东地区草莓连作障碍提供理论依据。

1 材料和方法

1.1 土壤材料

土壤样品于2016年5月底采于江苏省邳州港上镇、东海石榴镇和溧水白马镇的草莓连作大棚，其中港上镇连作7 a(年)，前茬品种为'甜查理'，栽前土壤进行太阳能闷棚；石榴镇连作9 a，前茬品种为'红颊'，栽前土壤进行太阳能闷棚；白马镇连作8 a，前茬品种为'宁玉'，栽前土壤进行有机质+石灰氮结合太阳能闷棚。设置各地区3个不同位置的草莓连作大棚为试验重复，每个连作棚按照"S"形均匀布置5个点采集土样，每个取样点按照土层深度0~10 cm、10~20 cm和20~30 cm采集土壤。将各地区不同土层土分别混合用于当年9月初的盆栽试验，剩余土壤分成2份，其中一份用以分析土壤微生物区系(4 ℃保存)，另一份自然风干后研磨，过0.8 mm尼龙筛，取100 g筛后样品再次研磨后过0.16 mm尼龙筛，收集筛后样品用以测定土壤理化性质。取各点相邻的露地小麦田土壤为盆栽试验的对照(CK)。

1.2 盆栽试验

同年9月5日，各处理定植草莓品种'宁玉'20株(1株•盆$^{-1}$)，在定植后的第57天(11月1日)，调查植株茎粗、鲜质量、株高、根长和根质量等生长指标。

1.3 测定方法

采用常规方法测定土壤养分含量[10]、pH值和EC值[11]；使用常规方法培养并计数土壤微生物数量[12]。

1.4 土壤pH值、EC值及养分分级标准

土壤pH值分级标准参考美国土壤调查手册[13]，土壤EC值的分级标准参考张鹤航等[14]的研究结果，土壤有机质、大量和微量元素的养分分级指标参考中国第二次土壤普查推荐的养分分级标准[15]，其中有效钙和有效镁含量分级指标参考章永松等[16]的研究结果，各养分分级标准见表1。

表1 土壤养分含量分级标准

Table 1 Classification standard of soil nutrient contents

丰缺程度 Abundance	w(有机质) Organic matter content/(g·kg^{-1})	w(碱解氮) Available N content/(mg·kg^{-1})	w(速效钾) Available K content/(mg·kg^{-1})	w(速效磷) Available P content/(mg·kg^{-1})	w(有效铁) Available Fe content/(mg·kg^{-1})	w(有效锰) Available Mn content/(mg·kg^{-1})	w(有效锌) Available Zn content/(mg·kg^{-1})	w(硼) Boron content/(mg·kg^{-1})	w(有效钙) Available Ca content/(g·kg^{-1})	w(有效镁) Available Mg content/(mg·kg^{-1})
极缺乏 Extremely lacking	<6	<30	<30	<3						
很缺乏 Very lacking	6~10	30~60	30~50	3~5	<2.5	<1	<0.3	<0.3	<0.4	<60
缺乏 Lacking	10~20	60~90	50~100	5~10	2.5~4.5	1~5	0.3~0.5	0.3~0.5	0.4~0.8	60~120
适中 Moderate	20~30	90~120	100~150	10~20	4.5~10	5~15	0.5~1.0	0.5~1.0	0.8~1.2	120~180
丰富 Rich	30~40	120~150	150~200	20~40	10~20	15~30	1.0~3.0	1.0~2.0	>1.2	>180
很丰富 Very rich	>40	>150	>200	>40	>20	>30	>3.0	>2.0		

1.5 数据处理

使用SPSS 17.0软件对相关数据进行多重比较(LSD法)、相关性分析(Pearson法)和差异显著性检验。

2 结果与分析

2.1 连作土壤的理化性质

港上镇、石榴镇和白马镇的表层土壤(0~20 cm)有机质含量(*w*，后同)(表2)分别为(18.40±5.42) g·kg^{-1}(丰缺程度属缺乏)、(18.26±1.28) g·kg^{-1}(缺乏)和(28.63±8.04) g·kg^{-1}(适中)。随着土层深度的增加，石榴镇和白马镇的土壤有机质含量呈减少趋势，而港上镇的土壤有机质含量则呈先增后减趋势(图1)；港上镇、石榴镇和白马镇的表层土壤碱解氮含量分别为(75.37±1.24) mg·kg^{-1}(缺乏)、(81.25±3.09) mg·kg^{-1}(缺乏)和(113.75±14.21) mg·kg^{-1}(适中)，3个地

表 2　3 个地区 0~20 cm 土层土壤的平均养分含量

Table 2 The average nutrient contents in soils of 0-20 cm of depth in three regions

地区 Area	w(有效钙) Available Ca content/ (g·kg^{-1})	w(有效镁) Available Mg content/ (mg·kg^{-1})	w(有效铁) Available Fe content/ (mg·kg^{-1})	w(有效锰) Available Mn content/ (mg·kg^{-1})	w(有效锌) Available Zn content/ (mg·kg^{-1})	w(硼) Boron content/ (mg·kg^{-1})	w(有机质) Organic matter content/ (g·kg^{-1})	w(碱解氮) Available N content/ (mg·kg^{-1})	w(速效钾) Available K content/ (mg·kg^{-1})	w(速效磷) Available P content/ (mg·kg^{-1})	pH	EC/ (mS·cm^{-1})
邳州港上镇 Gangshang, Pizhou	1.88±0.21 b	345.97±22.45 b	35.18±4.51 b	3.76±0.56 c	3.79±0.50 c	0.63±0.27 a	18.40±5.42 b	75.37±1.24 b	272.92±13.12 b	88.22±6.37 c	6.97±0.11 c	0.87±0.18 b
东海石榴镇 Shiliu, Donghai	0.97±0.03 c	240.61±4.06 c	51.70±3.51 a	44.15±3.20 a	12.19±0.44 a	0.51±0.03 a	18.26±1.28 b	81.25±3.09 b	404.82±42.61 a	258.34±14.21 a	7.28±0.05 b	1.24±0.11 a
溧水白马镇 Baima, Lishui	2.15±0.11 a	529.21±19.36 a	32.64±5.09 b	13.06±0.85 b	4.96±0.56 b	0.25±0.03 b	28.63±8.04 a	113.75±14.21 a	424.35±133.34 a	124.55±20.23 b	7.50±0.04 a	0.68±0.26 b

注：表中数据为平均值±标准差，不同小写字母表示同列数据在 $p < 0.05$ 显著差异。下同。

Note: The data in the table is the mean ± standard deviation. Different small letters indicate significant difference in the same column at $p < 0.05$. The same below.

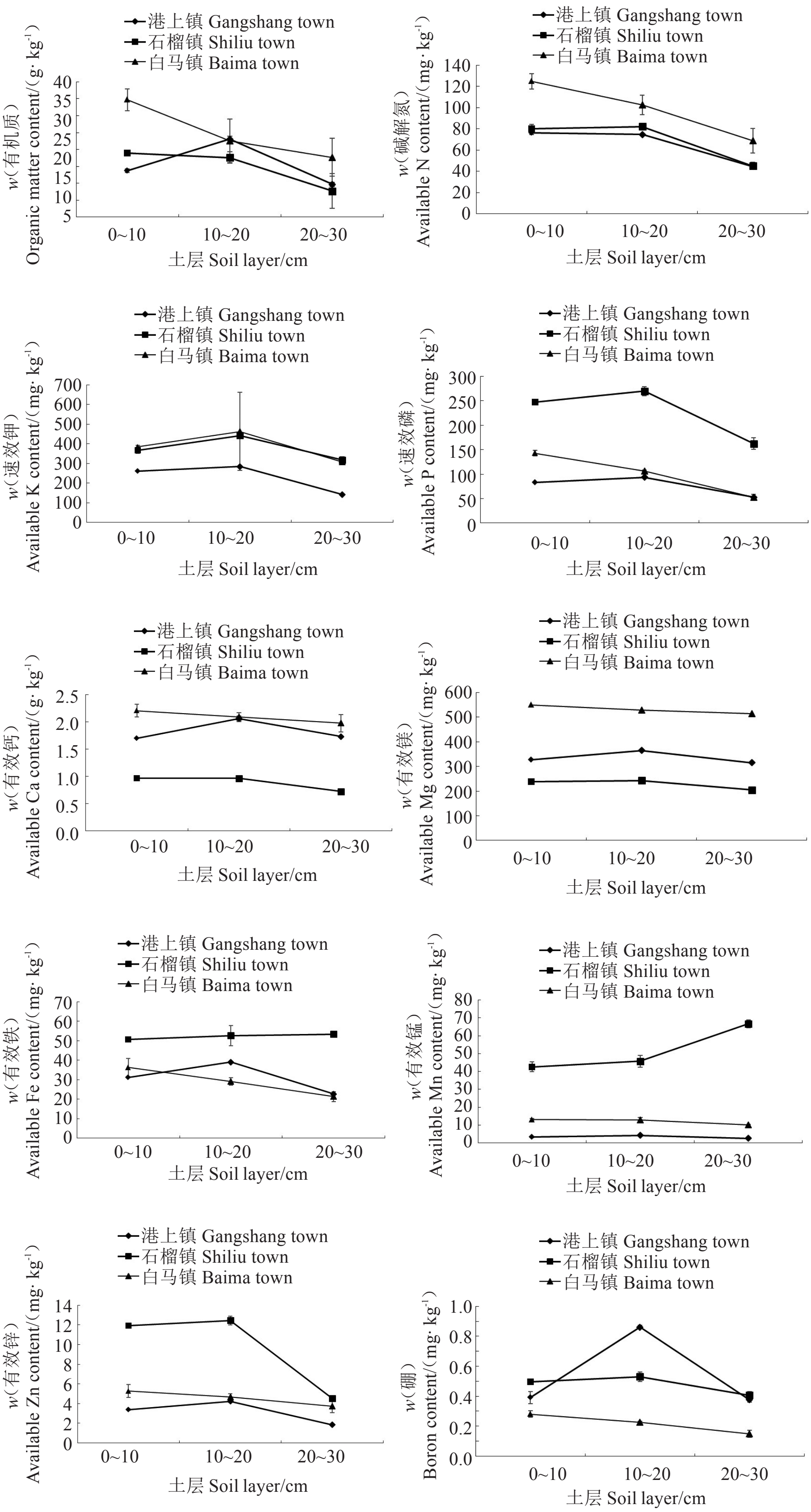

图 1　各地区不同深度草莓连作土层的养分含量变化

Fig. 1 Changes in nutrient contents of continuous cropping soils at different depths in different strawberry production areas

区的土壤碱解氮都主要集中在0~20 cm土层，深土层的碱解氮含量减少了33%~45%。港上镇、石榴镇和白马镇的表层土壤有效锰含量分别为(3.76±0.56)mg·kg-1(缺乏)、(44.15±3.20)mg·kg-1(很丰富)和(13.06±0.85)mg·kg-1(适中)；港上镇、石榴镇和白马镇的表层连作土壤硼含量分别为(0.63±0.27)mg·kg-1(适中)、(0.51±0.03)mg·kg-1(适中)、(0.25±0.03)mg·kg-1(很缺乏)；港上镇、石榴镇和白马镇的表层连作土壤有效钙含量分别为(1.88±0.21)g·kg-1(丰富)、(0.97±0.03)g·kg-1(丰富)、(2.15±0.11)g·kg-1(适中)；三个地区连作土的表层土壤有效镁含量都较丰富，有效铁、速效磷、速效钾和有效锌含量都很丰富；根据所测土壤EC值，港上镇和白马镇的连作土壤有轻度盐渍化[(0.55~0.90 mS·cm-1)]，石榴镇土壤有中度盐渍化[(0.90~1.80 mS·cm-1)]；根据所测土壤pH值，港上镇和石榴镇的土壤属于中性土壤(pH 6.6~7.3)，而白马镇土壤属于微碱性土壤(pH 7.3~7.8)。

2.2 各地区连作土壤微生物群落结构

由表3可知，各地区连作土的微生物都以细菌为主，真菌的数量最低。随着土层深度的增加，港上镇、石榴镇和白马镇的土壤放线菌数量都呈减少趋势；港上镇和石榴镇的土壤细菌数量呈减少趋势，白马镇则呈增加趋势；港上镇的真菌数量呈先降后增趋势，石榴镇呈降低趋势，而白马镇呈增高趋势。

表3 3个地区草莓连作土壤的微生物群落结构

Table 3 Microbial community structure of continuous cropping soils in three areas

地区 Area	土层 Soil layer/cm	真菌数量 Fungi/ (10^3CFU·g-1)	放线菌数量 Actinomycetes/ (10^5CFU·g-1)	细菌数量 Bacteria/ (10^6CFU·g-1)
邳州港上镇 Gangshang, Pizhou	0~10	4.65±0.84 c	6.07±0.17 de	2.56±0.59 bc
	10~20	3.97±0.51 d	6.63±0.17 de	3.43±0.42 ab
	20~30	5.25±0.18 c	2.56±0.17 f	1.90±0.17 c
东海石榴镇 Shiliu, Donghai	0~10	10.12±0.84 ab	26.19±3.37 a	2.74±0.17 bc
	10~20	12.17±1.87 a	13.26±1.70 c	2.39±0.30 bc
	20~30	9.17±0.50 b	8.81±1.68 d	1.67±0.33 d
溧水白马镇 Baima, Lishui	0~10	6.75±0.68 c	22.17±0.34 b	3.25±0.51 abc
	10~20	6.05±1.57 c	7.90±1.40 de	2.60±0.87 bc
	20~30	10.38±0.53 ab	4.88±0.53 e	4.13±1.24 a

2.3 土壤微生物群落结构与土壤理化性质的相关性分析

3个地区的连作土壤中，细菌数量与土壤有效钙和有效镁含量呈显著正相关(表4)；真菌数量与土壤有效铁、有效锰含量和土壤EC值呈显著正相关，与土壤有效锌、速效钾和速效磷含量呈极显著正相关；放线菌数量与土壤有效钙含量呈极显著负相关，与土壤有效铁和有效锰含量呈极显著正相关，与土壤有效锌、速效磷含量和土壤EC值呈显著正相关，与土壤有效镁含量呈显著负相关。

表4 土壤微生物数量与土壤理化性质的相关性分析

Table 4 Correlation between soil microorganisms and soil physical and chemical properties

	有效钙 Available Ca	有效镁 Available Mg	有效铁 Available Fe	有效锰 Available Mn	有效锌 Available Zn	硼 Boron	有机质 Organic matter	碱解氮 Available N	速效钾 Available K	速效磷 Available P	pH	EC
细菌 Bacteria	0.475*	0.586*	−0.043	−0.178	−0.249	−0.064	0.432	0.464	0.087	−0.224	0.467	−0.195
真菌 Fungi	−0.392	−0.125	0.508*	0.488*	0.759**	−0.230	0.180	0.317	0.699**	0.794**	0.444	0.545*
放线菌 Actinomycetes	−0.702**	−0.561*	0.708**	0.713**	0.491*	0.039	−0.310	−0.231	0.340	0.568*	0.395	0.549*

注：表中数据为相关性系数，正负符号分别代表正相关与负相关，* 表示显著相关，** 表示极显著相关。

Note: The data in the table are correlation coefficients，positive and adverse represent positive correlation and adverse correlation, respectively. * represents significant correlation，and ** represents extremely significant correlation.

2.4 各地区连作土对植株的影响

3个地区连作土植株的死亡率均高于对照，石榴镇的相对死亡率最高，为30%，白马镇的相对死亡率较低，仅为1%(表5)；三个地区的连作土对植株生长都有抑制作用，经显著性差异分析，石榴镇连作土植株的茎粗、植株鲜质量、株高、根质量和根长都与对照植株在$p < 0.05$水平上显著减少了21.55%~58.38%；港上镇的连作土植株除根长与对照差异显著外，其余指标均显示差异不显著；白马镇的所有指标都显示差异不显著。

表 5　3 个地区草莓植株在连作土与对照中的生长状况

Table 5 Growth status of strawberry plants cultivated in continuous cropping soils and in the control soils in three regions

地区 Area	连作植株的相对死亡率 Relative mortality of continuous cropping/%	茎粗 Stem diameter/mm		植株鲜质量 Plant fresh mass/g		株高 Plant height/cm		根质量 Root mass/g		根长 Root length/cm	
		连作 Continuous cropping	对照 Control	连作 Continuous cropping	对照 Control	连作 Continuous cropping	对照 Control	连作 Continuous cropping	对照 Control	连作 Continuous cropping	对照 Control
邳州港上镇 Gangshang, Pizhou	20	8.04±2.03	9.79±1.70	8.50±2.75	12.77±2.87	9.17±2.36	10.33±2.08	3.33±0.91	5.17±1.60	9.17±1.04*	12.33±0.58
东海石榴镇 Shiliu, Donghai	30	6.05±1.18*	9.30±1.44	7.77±2.05*	18.67±1.00	8.63±1.31*	11.00±1.00	3.80±1.18*	8.50±2.89	9.47±0.50*	15.83±1.26
溧水白马镇 Baima, Lishui	1	7.78±0.62	8.45±1.38	9.57±0.85	10.47±4.19	9.33±1.53	11.00±1.00	3.50±0.56	3.77±1.15	10.67±2.08	9.33±1.76

注：* 表示同一地区的连作土植株与对照植株在 $p < 0.05$ 差异显著。为方便比较，定义连作土处理与对照处理的植株死亡率之差为连作植株的相对死亡率。

Note: * indicates that the continuous cropping soil and control plants in the same region showed significant differences at $p < 0.05$. For convenience, the difference between the mortality rates of the continuous cropping and the control treatments was defined as the relative mortality of continuous cropping.

3 讨　论

3.1　草莓连作土壤理化性质

土壤的理化性质或营养状况直接影响着果树的生长发育、产量和品质[17-18]，国内外关于土壤理化性质的调查研究已有不少报道[19-20]。由于不同地域的气候条件、成土母质和适栽物种，其相对应的施肥手段和栽培管理措施不尽相同，导致不同地区的土壤理化性质差异很大。通过调查分析江苏省草莓连作土的理化性质状况，可以全面分析江苏地区草莓连作障碍的发生原因，并为该地区的草莓栽培措施改良提供科学依据。

通过分析，苏北地区港上镇和石榴镇的连作土壤有机质含量缺乏，这可能是因为该地区土壤质地偏沙性，土壤有机质容易流失，也有可能是因为该地草莓种植户常年使用单质肥料造成土壤板结[21]，没有合适的补充有机肥。土壤养分含量主要集中在表层土壤，这可能是因为草莓根系较浅，植株的断根会首先在表层土壤中被酶和微生物分解。正常情况下，随着浇水对土壤的淋溶作用，土壤有机质会部分下渗，所以石榴镇和白马镇的土壤有机质随土层的加深呈递减趋势。然而，港上镇的土壤有机质含量随土层加深呈先增后减趋势，不仅如此，港上镇土壤中的有效钙、镁、铁和硼含量都随土层加深呈先增后减趋势，且 0~10 cm 土层的土壤有机质、有效钙、有效镁、有效铁和硼含量比 10~20 cm 土层低 10.50%~54.65%，这可能是因为港上镇表层土壤偏砂质，孔隙较大，难以保肥。碱解氮的含量可以间接反映一个地区有机质的含量和质量，同时也是影响植株氮素营养水平的关键因素[22]，港上镇和石榴镇的土壤碱解氮含量缺乏，白马镇的土壤碱解氮含量适中，因而前者的草莓生产可以施用速效氮肥以缓解。土壤中的有效锰指的是可供植株直接利用的氧化态锰、水溶态锰和交换态锰，锰参与植株的光合作用，缺锰会导致果树生长受滞，产量降低[23]，蒲玉琳等[24]发现，土壤有效锰含量与土壤有机质含量呈显著正相关关系。港上镇的土壤有效锰含量缺乏，可通过施用鸡粪、牛粪和猪粪等畜禽有机肥料得到有效改善[25]。硼是植株必需的重要微量元素之一，它参与植株糖类运输和受精结实并在植株细胞壁和蛋白质的合成过程中起到关键作用[26]，通过分析发现白马镇的土壤硼含量很缺乏，可以通过施用硼肥以调节。根据

所测土壤EC值,港上镇和白马镇的连作土壤有轻度盐渍化,石榴镇土壤有中度盐渍化,这可能是因为草莓生产中长期施用化肥或浇灌高矿物质水致使土壤可溶性离子增加。而土壤中的可溶性盐含量过高会使植株遭受损伤,高盐度土壤甚至会产生反渗透压,造成植株脱水萎蔫乃至死亡。

3.2 草莓连作土壤微生物区系与其理化性质相关联

研究表明,连作会破坏土壤微生物群落结构,致使土壤优势菌落发生交替,土壤养分失衡[27-28]。调查显示,三个地区的连作土壤微生物都以细菌为主,真菌的数量最低,但不同地区各土层的菌种群落结构都不一样,其受植株根系长度[29]、土壤质地和土壤养分等众多因素影响。在三个地区连作土壤中,细菌数量与土壤有效钙和有效镁含量呈正相关关系;真菌数量与土壤有效铁、有效锰、有效锌、速效钾、速效磷含量和土壤EC值呈正相关关系;放线菌数量与土壤有效钙含量呈负相关关系,与土壤有效铁、有效锰、有效锌、速效磷含量和土壤EC值呈正相关关系,与土壤有效镁含量呈负相关关系。这说明草莓连作可能导致土壤理化性质改变,进而影响土壤微生物优势菌种的交替。

3.3 连作土对植株的影响

本试验中石榴镇的草莓连作土会对草莓植株的茎粗、植株鲜质量、株高、根质量和根长产生显著的负影响,但白马镇和港上镇这一差异并不显著,尤其是白马镇,连作植株的相对死亡率仅为1%,这与白马镇连作后对土壤消毒灭菌处理的方式有关,说明草莓连作障碍可以通过一定措施得以克服或缓解。数据显示,港上镇、石榴镇和白马镇连作土壤中的速效钾、速效磷、有效镁、有效铁、有效锌含量均属于丰富水平,这说明连作过程中有除土壤养分以外的因素影响着草莓植株的生长。已有研究发现,草莓在连作的过程中,根系会分泌一些酚酸类化感物质,对连作草莓造成自毒影响[30],具体的影响途经和发生机制有待今后的进一步研究。

4 结 论

草莓连作会使土壤理化性质改变、养分失衡以及微生物群落结构失衡,给植株生长带来影响。草莓生产上应尽可能避免连作,并及时对连作土壤进行修复改良。

参考文献 References:

[1] 高福新,钱亚明,赵密珍,关玲 . 江苏草莓主要产区生产状况调查分析[J]. 农业开发与装备,2016(11): 9-10.
GAO Fuxin,QIAN Yaming,ZHAO Mizhen,GUAN Ling. Investigation and analysis of production status of main production areas in strawberry in Jiangsu province[J]. Agriculture Development & Equipments,2016(11): 9-10.

[2] 杨焕青,王开运,范昆,林才华,段海明,原晓玲 . 草莓枯萎病菌的生物学特性及 7 种杀菌剂对其抑制作用[J]. 植物保护学报,2008,35(2): 169-174.
YANG Huanqing,WANG Kaiyun,FAN Kun,LIN Caihua,DUAN Haiming,YUAN Xiaoling. Biological characteristics of strawberry *Fusarium* wilt and inhibitory effects of seven fungicides[J]. Journal of Plant Protection,2008,35(2): 169-174.

[3] 张端喜,范学臻 . 草莓连作障碍发生原因及克服技术[J]. 现代农业科技,2012(23): 126-126.
ZHANG Duanxi,FAN Xuezhen. Causes of continuous cropping obstacles in strawberry and its overcoming techniques[J]. Modern Agricultural Science and Technology,2012(23): 126-126.

[4] 代丽,赵红梅,甄文超 . 草莓再植病害中的化感作用研究[J]. 科技导报,2006,24(6): 52-54.
DAI Li,ZHAO Hongmei,ZHEN Wenchao. Study of allelopathy in strawberry replanting disease[J]. Science & Technology Review,2006,24(6): 52-54.

[5] 刘小林,徐胜光,刘紫英,李润根,沈春修,邓正青,黄涛 . 草莓连作自毒障碍研究综述[J]. 宜春学院学报,2017(12): 1-5.
LIU Xiaolin,XU Shengguang,LIU Ziying,LI Rungen,SHEN Chunxiu,DENG Zhengqing,HUANG Tao. Review on continuous cropping self-poisonous disorder of strawberry[J]. Journal of Yichun College,2017(12): 1-5.

[6] NARWAL S S,ZENG R S. Allelopathy in ecological sustainable organic agriculture[J]. Allelopathy Journal,2010,25(1): 537-564.

[7] BREMER E,JANZEN H H,JOHNSTON A M. Sensitivity of total,light fraction and mineralizable organic matter to management practices in a lethbridge soil[J]. Canadian Journal of Soil Science,1994,74(2): 131-138.

[8] BOSSIO D A,SCOW K M. Impacts of carbon and flooding on soil microbial communities: Phospholipid fatty acid profiles and substrate utilization patterns[J]. Microbial Ecology,1998,35(3/4): 265-278.

[9] ZABINSKI C A,GANNON J E. Effects of recreational impacts on soil microbial communities[J]. Environmental Management,1997,21(2): 233.

[10] 鲁如坤 . 土壤农业化学分析方法[M]. 北京: 中国农业科技出版社,2000: 108-109.
LU Rukun. Soil agricultural chemical analysis method[M]. Beijing: China Agricultural Science and Technology Press,2000: 108-109.

[11] 鲍士旦 . 土壤农化分析[M]. 北京: 中国农业出版社,1990.
BAO Shidan. Analysis of soil agrochemical[M]. Beijing: China Agriculture Press,1990.

[12] 李阜棣. 农业微生物学实验技术[M]. 北京: 中国农业出版社,

1996.
LI Fudi. Agricultural microbiology experiment technology[M]. Beijing: China Agriculture Press，1996.

[13] Soil Survey Staff. Soli survey manual[M].Washington，U.S：Department of Agriculture Handbook No. 18 U.S. Government Printing Office，1993: 437-1036.

[14] 张鹤航，石军 . 电导法在土壤盐渍化程度评估中的应用[J]. 天津农业科学，1995(3): 27-28.
ZHANG Hehang，SHI Jun. Application of conductance method in evaluation of soil salinization degree[J]. Tianjin Agricultural Sciences，1995(3): 27-28.

[15] 全国土壤普查办公室 . 中国土壤[M]. 北京: 中国农业出版社，1998: 860-934.
National Soil Survey Office. Soil of China[M]. Beijing: China Agriculture Press，1998: 860-934.

[16] 章永松，倪吾钟，林咸永 . 杭州市郊菜园土壤的有效养分状况与施肥对策[M]//谢建昌，陈际型 . 菜园土壤肥力与蔬菜合理施肥 . 南京: 河海大学出版社，1997: 43-46.
ZHANG Yongsong，NI Wuzhong，LIN Xianyong. Effective nutrient status and fertilization countermeasures of vegetable soil in Hangzhou suburbs[M]//XIE Jianchang，CHEN Jixing. Soil fertility in vegetable garden and rational fertilization of vegetables. Nanjing: Hohai University Press，1997: 43-46.

[17] 范伟国，贾霞，杨超 . 土壤理化性质与果树生长发育的关系[J]. 河北果树，2003(1): 9-10.
FAN Weiguo，JIA Xia，YANG Chao. Relationship between soil physical and chemical properties and growth and development of fruit trees[J]. Hebei Fruits，2003(1): 9-10.

[18] 李建刚，侯宗海，张旭美，董元华 . 江苏丰县苹果主产区果园土壤养分状况的调查[J]. 西北林学院学报，2015，30(2): 65-69.
LI Jiangang，HOU Zonghai，ZHANG Xumei，DONG Yuanhua. State of soil nutrients of apple orchards in the major production area of Feng county in Jiangsu province[J]. Journal of Northwest Forestry University，2015，30(2): 65-69.

[19] ALIASGHARZAD N，RASTIN N S，TOWFIGHI H，ALIZADEH A. Erratum to: Occurrence of arbuscular mycorrhizal fungi in saline soils of the tabriz plain of iran in relation to some physical and chemical properties of soil[J]. Mycorrhiza，2001，11(3): 119-122.

[20] KORTE N E，SKOPP J，FULLER W H，NIEBLA E E，ALESII B A. Trace element movement in soils: Influence of soil physical and chemical properties[J]. Soil Science，2011，122(6): 350-359.

[21] 汪红霞，廖文华，孙伊辰，张伟，刘建玲 . 长期施用有机肥和磷肥对潮褐土土壤有机质及腐殖质组成的影响[J]. 中国土壤与肥料，2014(6): 39-43.
WANG Hongxia，LIAO Wenhua，SUN Yichen，ZHANG Wei，LIU Jianling. Effect of long-term application of organic manure and phosphate fertilizer on soil organic matter and humus composition in cinnamon soil[J]. Soil and Fertilizer Sciences，2014 (6): 39-43.

[22] 刘秀英，王力，常庆瑞，王晓星，尚艳. 基于相关分析和偏最小二乘回归的黄绵土土壤全氮和碱解氮含量的高光谱预测[J]. 应用生态学报，2015，26(7): 2107-2114.
LIU Xiuying，WANG Li，CHANG Qingrui，WANG Xiaoxing，SHANG Yan. Prediction of total nitrogen and alkali hydrolysable nitrogen content in loess using hyperspectral data based on correlation analysis and partial least squares regression[J]. Chinese Journal of Applied Ecology，2015，26(7): 2107-2114.

[23] 刘铮 . 土壤与植物中锰的研究进展[J]. 土壤学进展，1991(6): 1-10.
LIU Zheng. Research progress of manganese in soil and plants [J]. Advances in Soil Science，1991(6): 1-10.

[24] 蒲玉琳，龙高飞，苟文平，刘世全 . 西藏土壤有效锰含量及其影响因子分析[J]. 西南师范大学学报(自然科学版)，2010，35(6): 163-168.
PU Yulin，LONG Gaofei，GOU Wenping，LIU Shiquan. Status of available soil manganese in Tibet and its affecting factors[J]. Journal of Southwest China Normal University (Natural Science Edition)，2010，35(6): 163-168.

[25] 赵明，陈雪辉，赵征宇，蔡葵，王正国 . 鸡粪等有机肥料的养分释放及对土壤有效铜、锌、铁、锰含量的影响[J]. 中国生态农业学报，2007，15(2): 47-50.
ZHAO Ming，CHEN Xuehui，ZHAO Zhengyu，CAI Kui，WANG Zhengguo. Releasing of N，P and K of organic fertilizers and their effects on the contents of available Cu，Zn，Fe and Mn in soil[J]. Chinese Journal of Eco-Agriculture，2007，15(2): 47-50.

[26] 刘鹏，吴建之，杨玉爱 . 土壤中的硼及其植物效应的研究进展[J]. 农业环境科学学报，2000，19(2): 119-122.
LIU Peng，WU Jianzhi，YANG Yu'ai. Research progress of boron and its plant effects in soil[J]. Journal of Agro-Environment Science，2000，19(2): 119-122.

[27] 陈宏宇，李晓鸣，王敬国 . 抗病性不同大豆品种根面及根际微生物区系的变化Ⅱ. 连作大豆(重茬)根面及根际微生物区系的变化[J]. 植物营养与肥料学报，2006，12(1): 104-108.
CHEN Hongyu，LI Xiaoming，WANG Jingguo. Change of microflora in the rhizoplane and rhizosphere of different disease resistance soybean cultivars Ⅱ.Change of microflora in the rhizoplane and rhizosphere of soybean under continuous cropping condition[J]. Plant Nutrition and Fertilizer Science，2006，12(1): 104-108.

[28] 赵帆，赵密珍，王钰，关玲，史芳芳 . 草莓不同连作年限土壤养分及微生物区系分析[J]. 江苏农业科学，2017，45(16): 110-113.
ZHAO Fan，ZHAO Mizhen，WANG Yu，GUAN Ling，SHI Fangfang. Effect of different continuous cropping years on strawberry-growing soil's nutrients and microflora[J]. Jiangsu Agricultural Sciences，2017，45(16): 110-113.

[29] 马宁宁 . 设施番茄根围土壤的微生物特性研究[D]. 沈阳：沈阳农业大学，2013.
MA Ningning. Study on soil microbial of properties in protected tomato root circumference[D]. Shenyang：Shenyang Agricultural University，2013.

[30] 田给林 . 连作草莓土壤酚酸类物质的化感作用及其生物调控研究[D]. 北京：中国农业大学，2015.
TIAN Geilin. Allelopathic effect and biological regulation of phenolic acids in the continuous cropping strawberry soil[D]. Beijing：China Agricultural University，2015.