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冬绿肥覆盖对土壤团聚体及有机碳和AMF多样性的影响

鲁泽让, 陈佳钰, 李智贤, 李永梅, 罗志章, 杨锐, 田明洋, 赵吉霞*, 范茂攀*

(云南农业大学资源与环境学院, 昆明 650201)

摘要: 为探究冬绿肥覆盖对土壤AMF(丛枝菌根真菌)群落和团聚体及其有机碳含量的影响. 以坡耕地红壤为研究对象, 采用Illumina MiSeq高通量测序、湿筛法和重铬酸钾外加热法分别测定AMF群落组成、团聚体和有机碳含量. 研究了苕子覆盖(VC)、豌豆覆盖(PC)和冬季休耕(WF)这3个处理下AMF群落组成及多样性和有机碳含量与团聚体稳定性的关系. 结果表明, VC和PC处理的>2 mm团聚体含量和团聚体稳定性显著高于WF, 0.25~1 mm和<0.25 mm团聚体含量则相反; VC处理的0.25~1 mm团聚体和全土有机碳含量较PC、WF分别显著提高了33.21%、27.10%和25.68%、58.45%, PC处理的<0.25 mm团聚体有机碳含量则显著低于VC和WF; VC、PC的ACE和Chao1指数分别较WF处理分别显著提高了252.03%、158.55%和243.75%、158.33%; *Glomus*(球囊霉属)为各处理的优势属, PC和VC处理下*Claroideoglossum*(近明球囊霉属)的相对丰度较WF显著降低了76.29%和71.21%, PC处理下*Acaulospora*(无梗囊霉属)的相对丰度显著高于VC和WF处理; PCoA分析发现, PCoA1和PCoA2轴分别解释了57.76%和30.07%的AMF群落组成差异; Spearman相关性分析表明, 0.25~1 mm团聚体和全土有机碳含量与 $R_{0.25}$ 、MWD和GMD呈显著正相关; RDA分析表明, >2 mm团聚体含量、 $R_{0.25}$ 、MWD和GMD与多样性(Chao1、ACE、Shannon)指数、*Glomus*、*Gigaspora*(巨孢囊霉属)及*Scutellospora*(盾巨孢囊霉属)相对丰度呈正相关关系, AMF群落丰富度(ACE和Chao1指数)和*Gigaspora*是冬绿肥覆盖下促进土壤团聚体稳定的主要影响因子($P<0.05$); SEM分析发现, AMF群落丰富度通过改变SOC含量来影响土壤团聚体的形成与稳定. 结果表明, 在休耕期进行冬绿肥覆盖, 可通过提高土壤AMF群落丰富度和团聚体有机碳含量, 从而进一步提高团聚体稳定性. 研究结果可为我国南方红壤坡耕地休耕期推行冬绿肥覆盖模式和农田土壤侵蚀的防治提供理论依据.

关键词: 冬绿肥覆盖; AMF群落多样性; 团聚体有机碳; 团聚体稳定性; 结构方程模型; 丛枝菌根真菌(AMF)

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Effects of Winter Green Manure Mulching on Soil Aggregates, Organic Carbon, and AMF Diversity

LU Ze-rang, CHEN Jia-yu, LI Zhi-xian, LI Yong-mei, LUO Zhi-zhang, YANG Rui, TIAN Ming-yang, ZHAO Ji-xia*, FAN Mao-pan*

(College of Resources and Environment, Yunnan Agricultural University, Kunming 650201, China)

Abstract: To investigate the effects of winter green manure mulching on a soil arbuscular mycorrhizal fungi (AMF) community and aggregates and their organic carbon content, Illumina MiSeq high-throughput sequencing, the wet sieve method, and potassium dichromate external heating method were used to determine AMF community composition, aggregates, and organic carbon content in red soil of sloping farmland. The relationship between AMF community composition and diversity, organic carbon content, and aggregate stability under the three treatments of vetch mulching (VC), pea mulching (PC), and winter fallow (WF) was studied. The results showed that the content of >2 mm aggregates and the stability of aggregates treated with VC and PC were significantly higher than those of WF, whereas the content of 0.25-1 mm and <0.25 mm aggregates showed the opposite. The organic carbon content of 0.25-1 mm aggregates and whole soil in the VC treatment was significantly increased by 33.21% and 27.10% and 25.68% and 58.45%, respectively, compared with those in PC and WF. The organic carbon content of <0.25 mm aggregates in the PC treatment was significantly lower than that in VC and WF. The ACE and Chao1 indexes of VC and PC were significantly increased by 252.03% and 158.55% and 243.75% and 158.33%, respectively, compared with those in the WF treatment. *Glomus* was the dominant genus in each treatment. The relative abundance of *Claroideoglossum* under the PC and VC treatments was significantly lower than that of WF by 76.29% and 71.21%, respectively. The relative abundance of *Acaulospora* under the PC treatment was significantly higher than that of the VC and WF treatments. PCoA analysis showed that the PCoA1 and PCoA2 axes explained 57.76% and 30.07% of the differences in the AMF community composition, respectively. Spearman correlation analysis showed that 0.25-1 mm aggregates and total soil organic carbon content were significantly positively correlated with $R_{0.25}$, MWD, and GMD. RDA analysis showed that the content of >2 mm aggregates, $R_{0.25}$, MWD, and GMD were positively correlated with the diversity (Chao1, ACE, and Shannon) index and the relative abundance of *Glomus*, *Gigaspora*, and *Scutellospora*. AMF community richness (ACE and Chao1 index) and *Gigaspora* were the main factors affecting the stability of soil aggregates under winter green manure mulching ($P<0.05$). SEM analysis showed that AMF community richness affected the formation and stability of soil aggregates by changing SOC content. The results showed that winter green manure mulching during the fallow period could further improve the stability of aggregates by increasing the richness of the soil AMF community and the content of organic carbon in aggregates, which could provide a theoretical basis for the implementation of winter green manure mulching mode and the prevention and control of soil erosion in red soil sloping farmland in southern

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作者简介: 鲁泽让(1998~), 男, 硕士研究生, 主要研究方向为土壤微生物与耕地持续利用, E-mail: 1781796294@qq.com

* 通信作者, E-mail: zhaojixia@163.com; mpfan@126.com

China.

Key words: winter green manure coverage; AMF community diversity; aggregate organic carbon; aggregate stability; structural equation model; arbuscular mycorrhizal fungi(AMF)

近年来,农田土壤侵蚀一直备受关注,是目前全球农业面临的最严重的环境问题之一^[1].在云南滇中红壤区,由于雨水冲刷和风蚀作用及长期不合理的耕作方式造成的坡耕地水土流失和土壤质量下降问题愈加严重,该问题严重危及农业可持续发展^[2].而休耕期种植覆盖作物是一种能够降低地表裸露、减少土壤侵蚀和改善土壤健康的有效措施^[3].因此,对云南滇中红壤区坡耕地冬绿肥覆盖下土壤抗蚀机制的研究有助于改善这一现状.

土壤团聚体是土壤结构的基本单元,其组成和稳定性是评价土壤质量和水土保持效应的关键指标^[4],在土壤渗透性、保水性和抗水土流失方面起着重要作用^[5].而农田土壤有机碳(SOC)是陆地生态系统最为重要的碳库之一,对维持土壤肥力、保障农田生产力具有重要作用.土壤团聚体的形成和有机碳含量的提高是两个互相促进的过程,土壤团聚体一方面能包裹SOC,从而对SOC起到物理保护,另一方面土壤有机碳又可促进团聚体的形成^[6].此外,丛枝菌根真菌(AMF)作为一种能够与地球上约80%的植物根系建立共生关系的真菌,是土壤微生物群落的关键组成部分和参与农业可持续发展的重要微生物群之一,对于改善土壤生物环境、减少土壤侵蚀和提高土壤质量至关重要^[7,8].有研究表明,覆盖作物通过增加有机质和土壤团聚体来改善土壤质量和促进养分循环,并控制杂草生长和刺激AMF等土壤微生物的活动,从而维持土壤健康,促进农业生态系统的可持续性^[9,10].Zhang等^[11]研究发现AMF的产生菌丝体产物,如球囊霉素(GRSP)和菌丝等通过增强土壤团聚体进一步促进土壤有机碳的

固存.Qin等^[12]研究也表明竹林扩张显著改变了土壤AMF群落,增加了AMF生物量,从而提高了土壤团聚体和碳储量.Thapa等^[13]研究发现覆盖作物是改变土壤团聚体特性的重要措施,苜蓿作为绿肥施用可改善土壤有机碳和团聚体稳定性.Hudek等^[14]也得到了相似的结果,即覆盖作物的根系通过包裹土壤颗粒从而稳定土壤颗粒,有利于土壤团聚.尽管最新研究表明覆盖作物能够改善AMF群落结构、提高土壤团聚体稳定性和促进土壤有机碳的固存,但在云南滇中红壤地区,关于冬季覆盖作物下AMF群落结构和多样性、土壤团聚体及其有机碳三者关系的研究鲜见报道.

因此,本试验以坡耕地红壤为研究对象,设置苕子覆盖(VC)、豌豆覆盖(PC)和冬季休耕(WF)这3个处理,分析土壤AMF群落多样性、土壤团聚体及其有机碳含量在不同处理下的变化特征,采用冗余分析和结构方程模型进一步分析土壤AMF群落多样性和团聚体及其有机碳含量之间的相互关系,旨在为当地推行合理的冬绿肥覆盖模式及耕地持续利用提供一定的理论依据.

1 材料与方法

1.1 试验地概况

本试验在云南省昆明市松华坝水源保护区大摆村(25°02'29" N, 102°58'39" E)进行.试验地坡度为10°,海拔为2 234 m,年降水量在900~1 000 mm之间,年平均气温约为16℃,属亚热带高原季风气候.定位试验于2018年开始,本试验于2022年10月开始.土壤基本理化性质如表1所示.

表1 土壤基本理化性质

Table 1 Soil basic physical and chemical properties

项目	pH	ω [有机质(SOM)] /g·kg ⁻¹	ω [碱解氮(AN)] /mg·kg ⁻¹	ω [速效磷(AP)] /mg·kg ⁻¹	ω [速效钾(AK)] /mg·kg ⁻¹
参数	4.87	24.49	72.20	6.32	89.10

1.2 试验材料与设计

本试验小区面积为4 m×5 m,设置苕子覆盖(VC)、豌豆覆盖(PC)和冬季休耕(WF)3个处理,每个处理3次重复,共9个小区,区组内小区随机排列.供试作物:光叶紫花苕和白花矮茎豌豆.VC和PC于2022年10月玉米收获并翻耕后分别种植苕子和豌豆,WF于2022年10月玉米收获并翻耕后作为冬闲裸地(对照处理),所有处理的玉米秸秆均不还田,且对覆盖绿肥作物不进行施肥,于每年4月中

旬以翻耕的形式将覆盖作物翻压还田,5月中旬种植玉米.

1.3 样品采集

于2023年4月绿肥盛花期,用五点取样法采集0~20 cm土层的土样,将每个小区内5个样点的土样放于事先准备好的牛皮纸上(每个小区1张牛皮纸),并将土样按其自然裂缝掰开,剔除石块和植物根系等杂物后充分混匀,用药匙挑取10 g左右的土样装入15 mL无菌离心管中并装在冰盒内,迅速运回实

验室并转移到-80℃超低温冰箱中保存,用于提取土壤 DNA;为避免运输过程中土样受到外力的影响,将剩余的土样装入塑料盒内,以保持土壤原状结构,在试验条件下风干后用于土壤团聚体及有机碳的测定。

1.4 样品测定

1.4.1 土壤团聚体及有机碳含量的测定及指标计算

团聚体有机碳的测定使用重铬酸钾-浓硫酸外加热法^[15];采用 Elliott 团聚体湿筛法测定团聚体粒径组成,按干筛法获得的各粒径团聚体按比例配制 50 g 土样用于湿筛,>2 mm、1~2 mm、0.25~1 mm 和 <0.25 mm 这 4 个粒径的水稳性团聚体,团聚体稳定性指标 [>0.25 mm 水稳性团聚体含量($R_{0.25}$)、平均重量直径(MWD)、几何平均直径(GMD)和分形维数(D)]的计算公式如下^[16]。

$$R_{0.25} = \frac{M_{r>0.25}}{M_T} \quad (1)$$

$$\text{MWD} = \sum_{i=1}^n \bar{x}_i \omega_i \quad (2)$$

$$\text{GMD} = \exp \left[\frac{\sum_{i=1}^n \omega_i \ln \bar{x}_i}{\sum_{i=1}^n \omega_i} \right] \quad (3)$$

$$\frac{M_{r<\bar{R}_i}}{M_T} = \left(\frac{\bar{R}_i}{R_{\max}} \right)^{3-D} \quad (4)$$

式中, $M_{r>0.25}$ 为粒径>0.25 mm 水稳性团聚体质量(g); M_T 为水稳性团聚体总质量(g); $\bar{x}_i$ 为第*i*级水稳性团聚体平均直径(mm); ω_i 为各粒级水稳性团聚体质量分数(%); $\bar{R}_i$ 为某级团聚体平均直径(mm); $M_{r<\bar{R}_i}$ 为粒径小于 $\bar{R}_i$ 的团聚体的质量; $R_{\max}$ 为团聚体最大粒径。

1.4.2 土壤 DNA 提取、PCR 扩增及生物信息学分析

按照 E. Z. N. A. soil 试剂盒操作规范抽提土壤 DNA,用 1% 的琼脂糖凝胶电泳检测 DNA 的提取质量。PCR 采用 TransGen AP221-02: TransStart Fastpfu DNA Polymerase, 20 μ L 反应体系;全部样本按照正规试验条件进行,每个样本 3 个重复,将同一样本的 PCR 产物混合后用 2% 琼脂糖凝胶电泳检测,使用 AxyPrepDNA 凝胶回收试剂盒(AXYGEN 公司)切胶回收 PCR 产物,用 Tris_HCl 缓冲液进行洗脱,并用 2% 琼脂糖电泳检测;使用 NanoDrop 2000 测定 DNA 浓度和纯度。所有样品的 AMF DNA 采用巢式 PCR 扩增,第一对引物为 AML1F(ATCAACTTTTCG ATGCTAGGATAGA)和 AML2R(GAACCCAAACAC TTTGGTTTCC),第二对引物为 AMV4-5NF(AAGCT CGTAGTTGAATTTTCG)和 AMDGR(CCCAACATATC

CCTATTAATCAT)。参照电泳初步定量结果,将 PCR 产物用 QuantiFluor™-ST 蓝色荧光定量系统(Promega 公司)进行检测定量,然后按照每个样本的测序量要求,进行相应比例的混合,测序在 MiSeq PE 300 平台进行(上海美吉生物医药科技有限公司)^[17]。

物种分类数据库为 maarjam20220506/AM,并利用 Flash 1.2.11 进行 pair-end 双端序列拼接,用 Uparse 11 进行 OTU 聚类,将所有样品基于序列数 49 982 进行抽平,以抽平后的 OTU 丰度表进行后续所有分析计算。使用 Uparse 11 在相似度为 97% 的水平上进行 OTU 聚类,为了得到每个 OTU 对应的物种分类信息,采用 RDP classifier 贝叶斯算法对 97% 相似水平的 OTU 代表序列进行分类学分析,置信度阈值为 0.7,共获得 69 个 OTU,从门到种依次进行分类为 1 门、4 纲、5 目、9 科、11 属和 29 种。使用 Mothur(version v.1.30.2)进行 alpha 多样性分析。

1.5 数据处理

利用 Microsoft Excel 2016 和 SPSS 23.0 软件进行数据的整理与分析,利用单因素方差分析(one-way ANOVA)评价不同处理间各指标的差异显著性;用 Origin 2021 软件进行绘图,采用 Canoco 5.0 软件进行冗余分析,用 Amos Graphics 进行结构方程模型分析。

2 结果与分析

2.1 冬绿肥覆盖下土壤团聚体组成及稳定性变化特征

不同处理对团聚体组成及稳定性的影响各异(表 2)。 >2 mm 团聚体含量、 $R_{0.25}$ 、MWD 和 GMD 的大小顺序均为: VC>PC>WF,且各处理间差异显著,其中 VC 处理的 >2 mm 团聚体含量、 $R_{0.25}$ 、MWD 和 GMD 分别较 WF 处理显著提高了 152.80%、18.25%、46.84% 和 55.10%,PC 处理较 WF 分别显著提高了 38.89%、8.69%、18.99% 和 20.41%,VC 处理较 PC 显著提高了 82.01%、8.80%、23.40% 和 28.81%;而 VC、PC 处理的 0.25~1 mm 和 <0.25 mm 团聚体含量分别较 WF 处理显著降低了 26.17%、11.22% 和 34.46%、16.41%,VC 较 PC 处理显著降低了 16.84% 及 21.60%; D 在各处理间无显著差异性。

2.2 冬绿肥覆盖下土壤团聚体有机碳含量变化特征

不同处理对各粒径团聚体有机碳的影响各异(图 1)。VC 处理下的 0.25~1 mm 团聚体有机碳含量较 PC 和 WF 分别显著提高了 33.21% 和 27.10%,而 PC 处理的<0.25 mm 团聚体有机碳含量较 VC 和 WF 处理

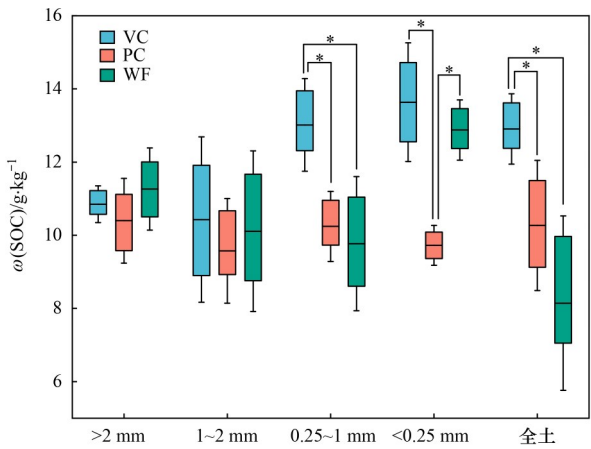
表 2 冬绿肥覆盖下土壤团聚体组成及稳定性¹⁾

Table 2 Composition and stability of soil aggregates under winter green manure mulching

处理	团聚体组成/%				团聚体稳定性			
	>2 mm	1~2 mm	0.25~1 mm	<0.25 mm	$R_{0.25}$	MWD	GMD	D
VC	40.17±0.61a	10.96±3.16a	26.18±0.16c	22.69±2.39c	77.31±2.39a	1.16±0.03a	0.76±0.05a	2.37±0.07a
PC	22.07±3.34b	17.51±6.42a	31.48±0.17b	28.94±3.16b	71.06±3.16b	0.94±0.03b	0.59±0.04b	2.34±0.08a
WF	15.89±1.73c	14.03±1.79a	35.46±1.78a	34.62±1.74a	65.38±1.74c	0.79±0.05c	0.49±0.03c	2.36±0.02a

1) VC、PC 和 WF 分别表示苕子覆盖、豌豆覆盖和冬季休耕;数据为平均值±标准差,同列不同小写字母表示相同团聚体在不同处理间差异显著 ($P<0.05$)

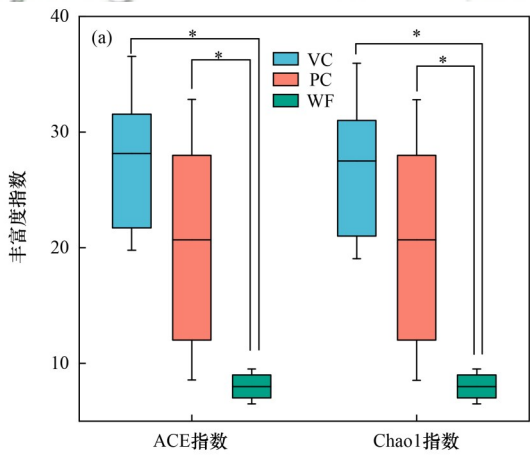
分别显著降低了 28.69% 和 24.49%, VC 处理下的全土有机碳含量较 PC 和 WF 分别显著提高了 25.68% 和 58.45%, >2 mm 和 1~2 mm 团聚体有机碳在各处理间无显著差异.



*表示相同粒径团聚体有机碳含量在不同处理间差异显著 ($P<0.05$)

图 1 土壤团聚体有机碳含量变化特征

Fig. 1 Change characteristics of organic carbon content in soil aggregates



*表示同一指标在不同处理间差异显著 ($P<0.05$)

图 2 冬绿肥覆盖下 AMF 群落丰富度和多样性变化特征

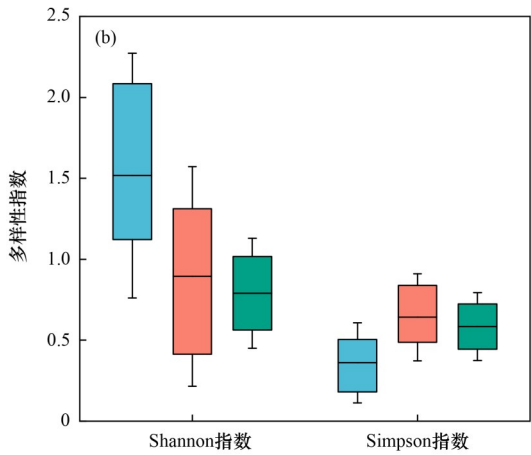
Fig. 2 Variation characteristics of AMF community richness and diversity under winter green manure mulching

基于 Bray-Curtis 距离算法的主坐标分析(PCoA)表明(图 4), PCoA1 和 PCoA2 轴分别解释了 57.76% 和 30.07% 的 AMF 群落组成差异, 差异贡献值为 87.83%. ANOSIM 检验结果表明, VC 和 PC 处理的 AMF 群落与 WF 完全分开, 说明覆盖处理与冬季休

2.3 冬绿肥覆盖下 AMF 多样性及群落的变化特征

不同处理对 AMF 多样性的影响各不相同(图 2). VC、PC 的 ACE 和 Chao1 指数较 WF 处理分别显著提高了 252.03%、158.55% 和 243.75%、158.33%[图 2(a)], Shannon 和 Simpson 指数在各处理间无显著差异[图 2(b)]. 结果表明, VC 和 PC 处理下的 AMF 群落丰富度显著高于 WF ($P<0.05$).

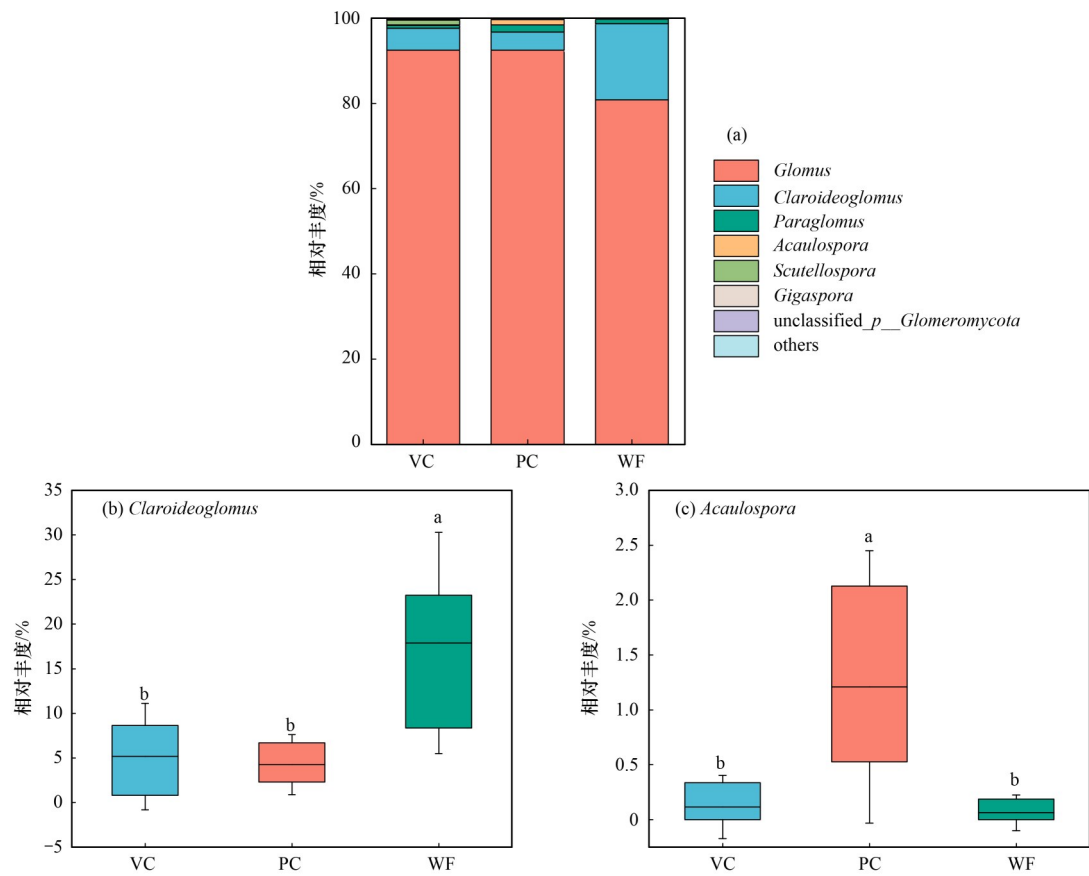
在属水平上对不同处理下的 AMF 群落进行分析得出[图 3(a)], AMF 群落各属相对丰度的大小顺序为 *Glomus* (球囊霉属)、*Claroideoglomus* (近明球囊霉属)、*Paraglomus* (类球囊霉属)、*Acaulospora* (无梗囊霉属)、*Scutellospora* (盾巨孢囊霉属)、*Gigaspora* (巨孢囊霉属) 和 *unclassified_p_Glomeromycota* (球囊菌门未分类属); 其中 *Glomus* 为优势属, 在各处理中的相对丰度顺序为: VC > PC > WF; PC 和 VC 处理下 *Claroideoglomus* 的相对丰度较 WF 处理显著降低了 76.29% 和 71.21%[图 3(b)], PC 处理下 *Acaulospora* 的相对丰度显著高于 VC 和 WF 处理[图 3(c)].



耕之间差异显著 ($R^2=0.583$, $P=0.027$).

2.4 冬绿肥覆盖下土壤团聚体有机碳含量与土壤团聚体稳定性的关系

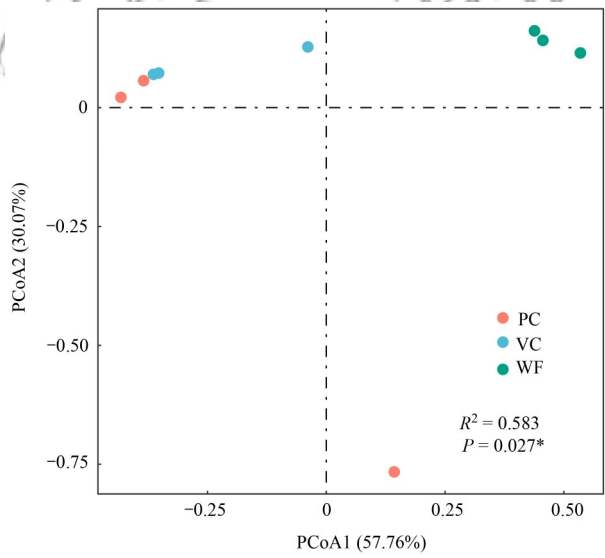
Spearman 相关性分析表明(图 5), >2 mm 团聚体有机碳含量与团聚体稳定性存在较弱的负相关性,



不同小写字母表示同一个AMF属水平相对丰度在不同处理间差异显著($P<0.05$)

图3 冬绿肥覆盖下AMF群落结构(属水平)分布特征

Fig. 3 Distribution characteristics of AMF community structure (genus level) under winter green manure mulching



*表示 $P\leq0.05$

图4 冬绿肥覆盖下基于Bray-Curtis距离AMF群落PCoA图

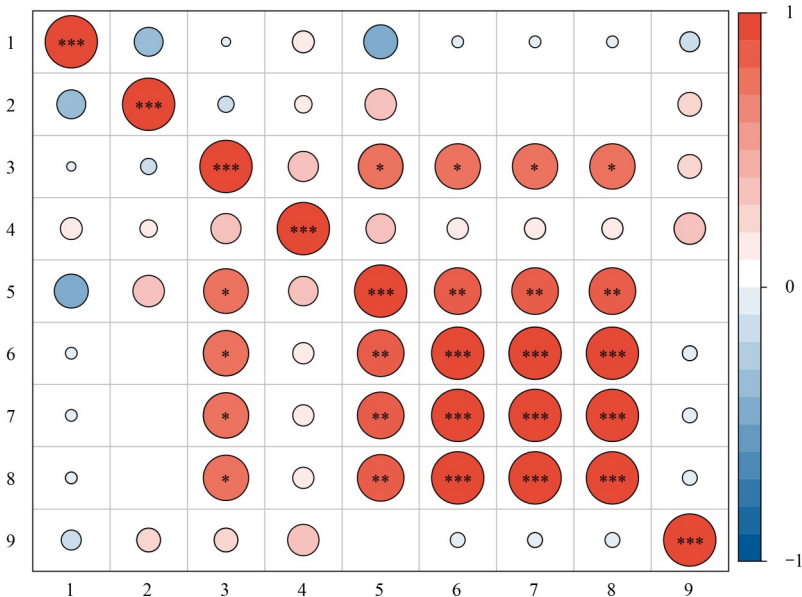
Fig. 4 PCoA plot based on Bray-Curtis similarities of AMF community under winter green manure mulching

0.25~1 mm SOC 含量与团聚体稳定性指标 ($R_{0.25}$ 、MWD 和 GMD) 呈显著正相关 ($P<0.05$), 全土 SOC 含量与 $R_{0.25}$ 、MWD 和 GMD 均呈显著正相关关系 ($P<0.01$).

2.5 冬绿肥覆盖下 AMF 多样性及群落组成与土壤团聚体的关系

冗余分析表明(图 6), >2 mm 团聚体含量、 $R_{0.25}$ 、MWD 和 GMD 与 Chao1、ACE 和 Shannon(指数)之间均呈显著正相关关系 ($P<0.05$), 1~2 mm、0.25~1 mm 和 <0.25 mm 团聚体含量与 Simpson 呈正相关关系[图 6(a)]. >2 mm 团聚体含量、 $R_{0.25}$ 、MWD 和 GMD 与 *Glomus*、*Gigaspora* 和 *Scutellospora* 呈正相关关系, 与 *Claroideoglomus* 和 *unclassified_p_Glomeromycota* 呈负相关[图 6(b)]. 综上, AMF 群落丰富度(ACE 和 Chao1 指数)和 *Gigaspora* 是冬绿肥覆盖下促进土壤团聚体稳定的主要影响因素。

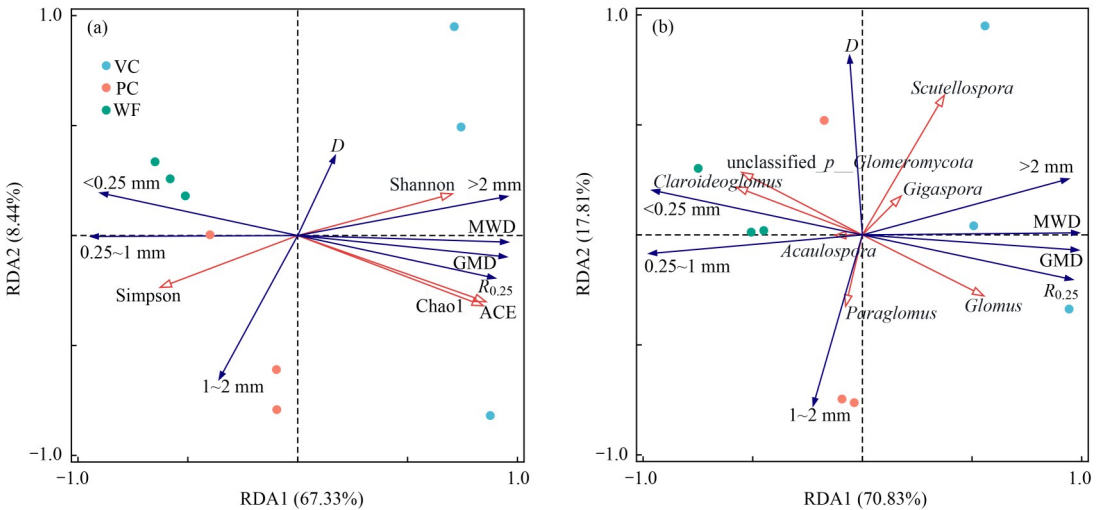
为明确 AMF 群落丰富度、SOC 和 MWD 之间的关系, 通过建立结构方程模型(图 7)进行分析, 结果显示: CMIN / DF 的值为 0.01、 P 值为 0.921、GFI 为 0.999、CFI 为 1、TLI 为 1.165 和 RMSEA 为 0, 该模型适配良好, 能代表自变量和因变量间的关系. AMF 丰富度(Chao1 指数)对 SOC 和 $R_{0.25}$ 均有正向的直接影响, 路径系数分别为 0.673 ($P<0.01$) 和 0.578 ($P<0.05$); SOC 和 $R_{0.25}$ 对 MWD 均有正向的直接影响, 路径系数分别为 0.227 ($P<0.05$) 和 0.794 ($P<0.001$), 而



1~9 分别表示: >2 mm SOC、1~2 mm SOC、0.25~1 mm SOC、<0.25 mm SOC、全土 SOC、 $R_{0.25}$ 、MWD、GMD 和 D ; *表示 $P<0.05$, **表示 $P<0.01$, ***表示 $P<0.001$; 圆的直径越大说明相关性越强, 直径越小则相关性越弱, 红色表示正相关, 蓝色则表示负相关

图 5 土壤团聚体有机碳含量与土壤团聚体稳定性的关系

Fig. 5 Relationship between soil aggregate organic carbon content and soil aggregate stability



红色箭头表示 AMF 多样性指数和前 7 个属, 蓝色箭头表示团聚体粒径及稳定性

图 6 冬绿肥覆盖下 AMF 多样性及群落与土壤团聚体的关系

Fig. 6 AMF diversity and the relationship between community and soil aggregates under winter green manure mulching

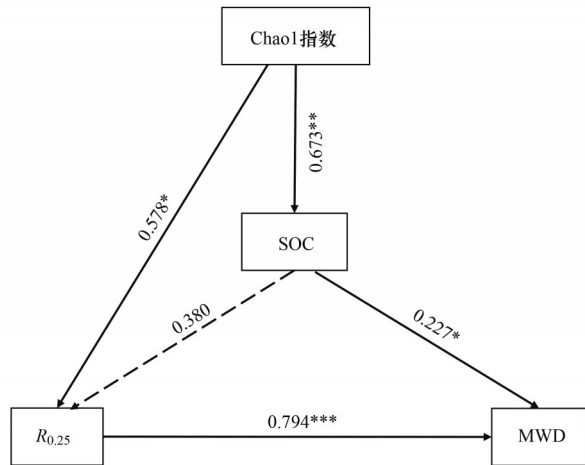
SOC 对 $R_{0.25}$ 的影响不显著. 从各影响因子对 MWD 的直接效应和间接效应可以看出 (表 3), 各因子对 MWD 的标准总效应大小顺序为: Chao1 指数 > $R_{0.25}$ > SOC.

3 讨论

3.1 冬绿肥覆盖对土壤团聚体组成及稳定性的影响

土壤团聚体是土壤颗粒与胶体、黏土颗粒相互作用形成的土壤结构的基本单位^[18]. 土壤团聚体对土壤性质影响较大, 其含量反映了土壤的持水能力、养分储存能力和渗透性^[19]. 本研究发现, 与冬

季休耕相比, 苕子和豌豆覆盖处理均能显著提高 >2 mm 团聚体含量、 $R_{0.25}$ 、MWD 和 GMD. 这与马佳玉等^[3]研究得到的结果相似, 即种植覆盖作物增加了土壤大团聚体含量和团聚体稳定性. Thapa 等^[13]研究也表明, 覆盖作物是改变土壤团聚体特性的重要实践, 苜蓿作为绿肥施用可改善土壤有机碳和团聚体稳定性. Nouri 等^[20]研究也发现, 与无覆盖处理的土壤相比, 在粉壤土中连续施用 34 a 覆盖作物 (毛野豌豆) 显著改善了 MWD. 究其原因, 覆盖作物一方面减少土壤在休耕时的地面裸露, 降低风蚀和水蚀, 从而促进土壤团聚体的稳定; 另一方面, 覆盖作物根系通过缠绕和包裹土壤颗粒从而有利于土壤团聚和



CMIN/DF=0.01, $P=0.921$, GFI=0.999, CFI=1, TLI=1.165, RMSEA=0; 实线箭头表示显著的路径, 虚线箭头表示不显著的路径, 箭头旁边的数字表示路径系数, *表示 $P<0.05$, **表示 $P<0.01$, ***表示 $P<0.001$

图7 AMF 丰富度、SOC 和团聚体的结构方程模型 (SEM)

Fig. 7 Structural equation model (SEM) of AMF richness, SOC, and aggregates

表3 基于结构方程模型各因子对 MWD 的标准总效应

Table 3 Total effect of each factor on MWD based on structural equation model

因子	直接效应	间接效应	总效应
Chao1 指数	0	0.814	0.814
SOC	0.227	0.301	0.528
$R_{0.25}$	0.794	0	0.794

稳定, 而冬季休耕处理中无覆盖作物的生长、地表裸露度高, 从而缺少作物根系对土壤颗粒的缠绕和包裹作用, 因此不利于土壤大团聚体的恢复和稳定^[14]. 本研究还发现, 苕子覆盖的>2 mm 团聚体含量和团聚体稳定性显著高于豌豆覆盖, 其原因可能是苕子和豌豆的根长生物量和根长密度不同所致, 不同覆盖作物根系导致不同程度的土壤黏结, 根长密度和根生物量高的植物通常更有利于将微团聚体包裹在一起形成大团聚体^[21,22].

3.2 冬绿肥覆盖对土壤团聚体有机碳含量的影响

农田土壤有机碳(SOC)是陆地生态系统最为重要的碳库之一, 对维持土壤肥力、保障农田生产力有重要作用. 土壤团聚体一方面能包裹 SOC, 从而对 SOC 起到物理保护, 另一方面土壤有机碳又可促进团聚体自身的形成^[6]. 而覆盖种植对有机碳固存的影响取决于有机碳分解和植物残留物的碳输入^[23]. 在本研究中, 与豌豆覆盖和冬闲休耕处理相比, 苕子覆盖处理显著提高了全土和 0.25~1 mm 团聚体有机碳含量. Ali 等^[24]研究也得出了相似的结果, 即与休耕地相比, 覆盖作物显著提高了土壤及团聚体有机碳含量. 其原因可能是覆盖处理中苕子和豌豆生

物量衍生凋落物和根系渗出物增加导致矿质土壤碳输入量增加^[25]. Peng 等^[26]研究也表明, 与没有覆盖作物相比, 覆盖作物的使用始终导致地表有机碳储量增加, 这与本研究得到的结果一致. 本研究还发现, 豌豆覆盖处理的<0.25 mm 团聚体有机碳含量较苕子覆盖和冬闲休耕显著降低了 28.69% 和 24.49%. 其原因可能是不同的覆盖作物类型对固碳途径和固碳量有不同的影响, 具有细枝根的覆盖作物在减少侵蚀造成的碳损失方面更有效^[27]. 而本研究中, 苕子较豌豆具有更细的根系, 因此苕子覆盖处理的固碳效果优于豌豆, 这与前人研究的结果相似.

3.3 冬绿肥覆盖对 AMF 多样性和群落组成的影响

丛枝菌根真菌(AMF)是自然和农业生态系统的重要组成部分, 在维持生态系统可持续性和稳定性方面发挥着重要作用, 其多样性及群落结构受耕作方式、覆盖、种植制度和施肥等农业管理措施的影响^[28,29]. 在本研究中, 与冬季休耕相比, 覆盖作物处理显著提高了 AMF 群落丰富度(ACE 和 Chao1 指数), 且 AMF 群落组成在覆盖作物与冬季休耕处理间差异显著(图4), 这与大多数研究结果相似. 覆盖作物是 AMF 等有益土壤生物群的宿主^[30], Higo 等^[31]研究发现, 连续栽培 AMF 寄主作物或使用 AMF 寄主覆盖作物代替冬季休耕有利于增加土壤 AMF 丰度和多样性. 文献^[32]研究也表明覆盖作物代替冬季休耕, 通过为专性共生体提供寄主植物和有机碳供应, 改善了 AMF 发展的条件. 究其原因, 作物覆盖减少季节性休耕期, 通过刺激生物地球化学循环提高土壤肥力并抑制杂草. 此外, 覆盖作物的引入可以通过维持土壤 AMF 孢子丰度和增加 AMF 根定植^[33]. Higo 等^[34]研究也表明大麦作为冬季覆盖作物, 其较大的根生物量和较高的根定植量可能促进了繁殖体的产生.

在本研究中, *Glomus* 为各处理中土壤 AMF 的优势属. 已有学者对农田、森林、草地、湿地及免耕和生物有机肥施用条件下的 AMF 多样性及群落结构进行研究, 发现 *Glomus* 为优势属^[28], 这与本研究得到的结果一致. 其原因可能是 *Glomus* 具有较高的产孢率和特定的繁殖方式, 对农业管理活动扰动的忍耐能力较强, 且能够适应不同的环境^[35,36]. Lehman 等^[37]在一项为期 1 a 的研究中发现, 越冬覆盖作物(毛豌豆)增加了春季土壤样品中 *Glomus* 孢子的数量, 这与本研究结果相似. 另外, 本研究发现, 覆盖处理下的 *Claroideoglomus* 的相对丰度显著低于冬季休耕处理. 汪志琴等^[38]研究发现免耕覆盖下施肥降低了 *Claroideoglomus* 的相对丰度, 这与本研究结果相似. 究其原因, *Claroideoglomus* 似乎能更好地适

应受干扰且裸露的环境,覆盖措施对 *Claroideoglossum* 造成了较大程度的破坏和抑制,而在冬季休耕处理中,能够更快地恢复或重建^[39].本研究还发现,豌豆覆盖下 *Acaulospora* 的相对丰度显著高于苕子覆盖和冬季休耕处理.其原因可能是苕子和豌豆根系分泌物及根际微生态不同所致^[40].

3.4 冬绿肥覆盖下 AMF 多样性及群落组成、有机碳与土壤团聚体的关系

土壤有机碳是团聚体的胶结物质,对团粒结构的形成和稳定有重要作用,土壤有机碳含量越高,越有利于土壤团聚体的形成和稳定性的提升,而土壤团聚体为有机碳提供了保护场所,缓解微生物的分解^[41].本研究得出,全土 SOC 含量和 0.25~1 mm 团聚体有机碳含量均与团聚体稳定性指标($R_{0.25}$ 、MWD 和 GMD)呈显著正相关,这与大多数研究者得出的结果一致^[42].王心怡等^[43]研究也发现土壤团聚体平均重量直径(MWD)与土壤有机碳及团聚体有机碳均呈显著正相关.在土壤有机碳形成过程中,微团聚体通过有机物质胶结形成大团聚体,随着大团聚体的形成,平均重量直径增大,土壤结构逐渐趋于稳定^[43].

AMF 对于土壤生态系统功能至关重要,在土壤团聚体形成、稳定以及植物和土壤系统之间的联系中发挥着关键作用^[44].以往的研究表明,AMF 一方面通过分泌多糖、酚酸及 GRSP 等有机物质与土壤颗粒和微团聚体结合^[45];另一方面,AMF 较强的真菌菌丝通过缠绕和包裹初级颗粒或微团聚体形成大团聚体^[46].Wilson 等^[44]研究表明土壤团聚体形成与 AMF 的群落和丰度密切相关.本研究发现,>2 mm 团聚体含量、 $R_{0.25}$ 、MWD 和 GMD 与 Chao1、ACE 和 Shannon 之间均呈显著正相关关系.这与 Qin 等^[12]研究得出的大团聚体百分比(0.25~2 mm)与土壤 AM 真菌生物量呈正相关的结果相似.鲁泽让等^[17]通过研究周年轮作休耕模式下土壤团聚体与 AMF 群落多样性的相互关系发现,AMF 多样性和丰富度指数与团聚体稳定性正相关,也与本研究结果相似.>2 mm 团聚体含量、 $R_{0.25}$ 、MWD 和 GMD 与 *Glomus*、*Gigaspora* 和 *Scutellospora* 呈正相关关系,与 *Claroideoglossum* 和 *unclassified_p_Glomeromycota* 呈负相关,这与 Lu 等^[47]通过研究不同耕作方式下土壤 AMF 群落特征与团聚体关系得出的结果相似. Lehmann 等^[48]研究发现腐养真菌通过降解植物叶片和根,为土壤团聚体的形成提供必要的原料.同样, Cao 等^[49]研究也表明,AMF 通过与腐养真菌建立共生关系,间接促进有机物的分解和总体胞外酶丰富度的提高.在本研究中,冬季覆盖处理的绿肥生物量凋落物繁多,这可能促进

了腐生真菌的生长和繁殖,而腐生真菌又与 AMF 形成共生关系共同促进了土壤团聚体的形成与稳定^[27].

本研究通过结构方程模型分析发现,AMF 群落丰富度对 SOC 和 $R_{0.25}$ 有正向的直接影响,而 SOC 和 $R_{0.25}$ 对 MWD 有正向的直接影响. Zhang 等^[46]研究表明,AMF 可以通过增强菌丝体对养分和土壤水分的吸收来刺激作物的生长和繁殖.以上过程可以促进 AMF 分泌各种有机化合物(如球囊素相关土壤蛋白),从而提高土壤碳含量. Horsch 等^[50]研究表明苏丹草种植条件下 AMF 群落降低了 SOC 含量,但增加了矿物相关碳,这与本研究得到的结果相悖,其原因可能是植物类型不同所致. Qin 等^[12]研究表明竹林扩张显著改变了土壤 AMF 群落,增加了 AMF 生物量,从而提高了土壤团聚体和碳储量,这与本研究得到结果相似.其原因可能是 AMF 孢子、菌丝渗出物和根外死亡菌丝可能直接促进了有机碳积累和团聚体的形成^[51].

4 结论

(1)冬绿肥覆盖降低了 0.25~1 mm 和 <0.25 mm 团聚体含量,但显著提高了 >2 mm 团聚体含量和团聚体稳定性,且苕子覆盖处理的效果最佳.

(2)与冬季休耕和豌豆覆盖相比,苕子覆盖显著提高了 0.25~1 mm 团聚体和全土有机碳含量,豌豆覆盖的 <0.25 mm 团聚体有机碳含量显著低于苕子覆盖和冬季休耕;0.25~1 mm 团聚体和全土有机碳含量与 $R_{0.25}$ 、MWD 和 GMD 呈显著正相关.

(3)AMF 群落组成在覆盖处理与冬季休耕之间差异显著,且冬绿肥覆盖处理的 AMF 群落丰富度指数显著高于冬季休耕;*Glomus* 为各处理的优势属,覆盖处理下 *Claroideoglossum* 的相对丰度均显著低于冬季休耕,豌豆覆盖下 *Acaulospora* 的相对丰度则显著高于苕子覆盖和冬季休耕处理.

(4)>2 mm 团聚体含量、 $R_{0.25}$ 、MWD 和 GMD 与多样性指数(Chao1、ACE、Shannon)、*Glomus*、*Gigaspora* 及 *Scutellospora* 相对丰度呈正相关关系.其中,AMF 群落丰富度(ACE 和 Chao1 指数)和 *Gigaspora* 是冬绿肥覆盖下促进土壤团聚体稳定的主要影响因子.

(5)SEM 分析表明,AMF 群落丰富度通过改变 SOC 含量来影响土壤团聚体的形成与稳定.

参考文献:

- [1] Wooliver R, Jagadamma S. Response of soil organic carbon fractions to cover cropping: a meta-analysis of agroecosystems[J]. Agriculture, Ecosystems & Environment, 2023, 351, doi: 10.1016/j.agee.2023.108497.
- [2] 隋鑫,霍海南,鲍雪莲,等.覆盖作物的种植现状及其对下茬

- 作物生长和土壤环境影响的研究进展[J]. 应用生态学报, 2021, **32**(8): 2666-2674.
- Sui X, Huo H N, Bao X L, *et al.* Research advances on cover crop plantation and its effects on subsequent crop and soil environment [J]. Chinese Journal of Applied Ecology, 2021, **32**(8): 2666-2674.
- [3] 马佳玉, 王涛, 刘小利, 等. 覆盖作物对我国粮食作物的产量效应及影响因素的 Meta 分析[J]. 中国农业科学, 2023, **56**(10): 1871-1880.
- Ma J Y, Wang T, Liu X L, *et al.* Meta-analysis of yield effects and influencing factors of cover crops on main grain crops in China [J]. Scientia Agricultura Sinica, 2023, **56**(10): 1871-1880.
- [4] Deng L, Liu G B, Shangguan Z P. Land-use conversion and changing soil carbon stocks in China's 'grain-for-green' program: a synthesis [J]. Global Change Biology, 2014, **20**(11): 3544-3556.
- [5] Zhao J S, Chen S, Hu R G, *et al.* Aggregate stability and size distribution of red soils under different land uses integrally regulated by soil organic matter, and iron and aluminum oxides [J]. Soil & Tillage Research, 2017, **167**: 73-79.
- [6] 林洪羽, 周明华, 张博文, 等. 生物炭及秸秆长期施用对紫色土坡耕地土壤团聚体有机碳的影响[J]. 中国生态农业学报(中英文), 2020, **28**(1): 96-103.
- Lin H Y, Zhou M H, Zhang B W, *et al.* Effect of long-term application of biochar and straw on soil organic carbon in purple soil aggregates of sloping uplands [J]. Chinese Journal of Eco-Agriculture, 2020, **28**(1): 96-103.
- [7] Marinho F, Oehl F, Da Silva I R, *et al.* High diversity of arbuscular mycorrhizal fungi in natural and anthropized sites of a Brazilian tropical dry forest (Caatinga) [J]. Fungal Ecology, 2019, **40**: 82-91.
- [8] Bender S F, Wagg C, van der Heijden M G A. An underground revolution: biodiversity and soil ecological engineering for agricultural sustainability [J]. Trends in Ecology & Evolution, 2016, **31**(6): 440-452.
- [9] Hontoria C, García-González I, Quemada M, *et al.* The cover crop determines the AMF community composition in soil and in roots of maize after a ten-year continuous crop rotation [J]. Science of the Total Environment, 2019, **660**: 913-922.
- [10] García-González I, Quemada M, Gabriel J L, *et al.* Legacy of eight-year cover cropping on mycorrhizae, soil, and plants [J]. Journal of Plant Nutrition and Soil Science, 2018, **181**(6): 818-826.
- [11] Zhang J, Ekblad A, Sigurdsson B D, *et al.* The influence of soil warming on organic carbon sequestration of arbuscular mycorrhizal fungi in a sub-arctic grassland [J]. Soil Biology and Biochemistry, 2020, **147**, doi: 10.1016/j.soilbio.2020.107826.
- [12] Qin H, Niu L M, Wu Q F, *et al.* Bamboo forest expansion increases soil organic carbon through its effect on soil arbuscular mycorrhizal fungal community and abundance [J]. Plant and Soil, 2017, **420**(1-2): 407-421.
- [13] Thapa V R, Ghimire R, Vanleeuwen D, *et al.* Response of soil organic matter to cover cropping in water-limited environments [J]. Geoderma, 2022, **406**, doi: 10.1016/j.geoderma.2021.115497.
- [14] Hudek C, Putinica C, Otten W, *et al.* Functional root trait-based classification of cover crops to improve soil physical properties [J]. European Journal of Soil Science, 2022, **73**(1), doi: 10.1111/ejss.13147.
- [15] 王兴, 钟泽坤, 张欣怡, 等. 长期撂荒恢复土壤团聚体组成与有机碳分布关系[J]. 环境科学, 2020, **41**(5): 2416-2424.
- Wang X, Zhong Z K, Zhang X Y, *et al.* Relationship between the composition of soil aggregates and the distribution of organic carbon under long-term abandoned restoration [J]. Environmental Science, 2020, **41**(5): 2416-2424.
- [16] 邓华, 高明, 龙翼, 等. 生物炭和秸秆还田对紫色土旱坡地土壤团聚体与有机碳的影响[J]. 环境科学, 2021, **42**(11): 5481-5490.
- Deng H, Gao M, Long Y, *et al.* Effects of biochar and straw return on soil aggregate and organic carbon on purple soil dry slope land [J]. Environmental Science, 2021, **42**(11): 5481-5490.
- [17] 鲁泽让, 夏梓泰, 芦美, 等. 周年轮作休耕对土壤 AMF 群落和团聚体稳定性的影响[J]. 环境科学, 2023, **44**(9): 5154-5163.
- Lu Z R, Xia Z T, Lu M, *et al.* Effects of annual crop rotation and fallow on soil AMF community and aggregate stability [J]. Environmental Science, 2023, **44**(9): 5154-5163.
- [18] Wang F L, Liu Y, Liang B, *et al.* Variations in soil aggregate distribution and associated organic carbon and nitrogen fractions in long-term continuous vegetable rotation soil by nitrogen fertilization and plastic film mulching [J]. Science of the Total Environment, 2022, **835**, doi: 10.1016/j.scitotenv.2022.155420.
- [19] Hu R W, Liu Y J, Chen T, *et al.* Responses of soil aggregates, organic carbon, and crop yield to short-term intermittent deep tillage in southern China [J]. Journal of Cleaner Production, 2021, **298**, doi: 10.1016/j.jclepro.2021.126767.
- [20] Nouri A, Lee J, Yin X H, *et al.* Thirty-four years of no-tillage and cover crops improve soil quality and increase cotton yield in Alfisols, Southeastern USA [J]. Geoderma, 2019, **337**: 998-1008.
- [21] Xiao L, Yao K H, Li P, *et al.* Increased soil aggregate stability is strongly correlated with root and soil properties along a gradient of secondary succession on the Loess Plateau [J]. Ecological Engineering, 2020, **143**, doi: 10.1016/j.ecoleng.2019.105671.
- [22] Vannoppen W, De Baets S, Keeble J, *et al.* How do root and soil characteristics affect the erosion-reducing potential of plant species? [J]. Ecological Engineering, 2017, **109**: 186-195.
- [23] Zhang X, Shen S W, Xue S Q, *et al.* Long-term tillage and cropping systems affect soil organic carbon components and mineralization in aggregates in semiarid regions [J]. Soil and Tillage Research, 2023, **231**, doi: 10.1016/j.still.2023.105742.
- [24] Ali W, Hussain S, Chen J Z, *et al.* Cover crop root-derived organic carbon influences aggregate stability through soil internal forces in a clayey red soil [J]. Geoderma, 2023, **429**, doi: 10.1016/j.geoderma.2022.116271.
- [25] Anuo C O, Cooper J A, Koehler-Cole K, *et al.* Effect of cover cropping on soil organic matter characteristics: Insights from a five-year field experiment in Nebraska [J]. Agriculture, Ecosystems & Environment, 2023, **347**, doi: 10.1016/j.agee.2023.108393.
- [26] Peng Y J, Rieke E L, Chahal I, *et al.* Maximizing soil organic carbon stocks under cover cropping: insights from long-term agricultural experiments in North America [J]. Agriculture, Ecosystems & Environment, 2023, **356**, doi: 10.1016/j.agee.2023.108599.
- [27] Zhang Z L, Kaye J P, Bradley B A, *et al.* Cover crop functional types differentially alter the content and composition of soil organic carbon in particulate and mineral-associated fractions [J]. Global Change Biology, 2022, **28**(19): 5831-5848.
- [28] Liu W J, Ma K, Wang X L, *et al.* Effects of no-tillage and biologically-based organic fertilizer on soil arbuscular mycorrhizal fungal communities in winter wheat field [J]. Applied Soil Ecology, 2022, **178**, doi: 10.1016/j.apsoil.2022.104564.
- [29] Fall A F, Nakabonge G, Ssekandi J, *et al.* Roles of arbuscular mycorrhizal fungi on soil fertility: contribution in the improvement

- of physical, chemical, and biological properties of the soil [J]. *Frontiers in Fungal Biology*, 2022, **3**, doi: 10.3389/FFUNB.2022.723892.
- [30] Njeru E M, Avio L, Bocci G, *et al.* Contrasting effects of cover crops on 'hot spot' arbuscular mycorrhizal fungal communities in organic tomato [J]. *Biology and Fertility of Soils*, 2015, **51**(2): 151-166.
- [31] Higo M, Isobe K, Kondo T, *et al.* Temporal variation of the molecular diversity of arbuscular mycorrhizal communities in three different winter cover crop rotational systems [J]. *Biology and Fertility of Soils*, 2015, **51**(1): 21-32.
- [32] García-González I, Quemada M, Gabriel J L, *et al.* Arbuscular mycorrhizal fungal activity responses to winter cover crops in a sunflower and maize cropping system [J]. *Applied Soil Ecology*, 2016, **102**: 10-18.
- [33] Higo M, Isobe K, Miyazawa Y, *et al.* Molecular diversity and distribution of indigenous arbuscular mycorrhizal communities colonizing roots of two different winter cover crops in response to their root proliferation [J]. *Journal of Microbiology*, 2016, **54**(2): 86-97.
- [34] Higo M, Isobe K, Yamaguchi M, *et al.* Diversity and vertical distribution of indigenous arbuscular mycorrhizal fungi under two soybean rotational systems [J]. *Biology and Fertility of Soils*, 2013, **49**(8): 1085-1096.
- [35] 马琨, 宋丽丽, 王明国, 等. 玉米秸秆还田对土壤丛枝菌根真菌群落的影响 [J]. *应用生态学报*, 2019, **30**(8): 2746-2756.
Ma K, Song L L, Wang M G, *et al.* Effects of maize straw returning on arbuscular mycorrhizal fungal community structure in soil [J]. *Chinese Journal of Applied Ecology*, 2019, **30**(8): 2746-2756.
- [36] Xue J F, Pu C, Liu S L, *et al.* Effects of tillage systems on soil organic carbon and total nitrogen in a double paddy cropping system in southern China [J]. *Soil and Tillage Research*, 2015, **153**: 161-168.
- [37] Lehman R M, Taheri W I, Osborne S L, *et al.* Fall cover cropping can increase arbuscular mycorrhizae in soils supporting intensive agricultural production [J]. *Applied Soil Ecology*, 2012, **61**: 300-304.
- [38] 汪志琴, 马琨, 王小玲, 等. 冬麦免耕覆盖栽培对土壤丛枝菌根真菌多样性的影响 [J]. *核农学报*, 2019, **33**(5): 969-977.
Wang Z Q, Ma K, Wang X L, *et al.* Effect of no-tillage and mulching management on soil arbuscular mycorrhizal fungal diversity [J]. *Journal of Nuclear Agricultural Sciences*, 2019, **33**(5): 969-977.
- [39] Oehl F, Sieverding E, Ineichen K, *et al.* Impact of land use intensity on the species diversity of arbuscular mycorrhizal fungi in agroecosystems of central Europe [J]. *Applied and Environmental Microbiology*, 2003, **69**(5): 2816-2824.
- [40] 阮仕琴, 陶刚, 姜璇, 等. 丛枝菌根真菌生态功能及其与共生植物互作机理 [J]. *中国土壤与肥料*, 2022, (5): 237-244.
Ruan S Q, Tao G, Lou X, *et al.* The ecological functions of arbuscular mycorrhizal fungi and their interaction mechanisms with the symbiotic plants [J]. *Soil and Fertilizer Sciences in China*, 2022, (5): 237-244.
- [41] 王富华, 吕盛, 黄容, 等. 缙云山 4 种森林植被土壤团聚体有机碳分布特征 [J]. *环境科学*, 2019, **40**(3): 1504-1511.
Wang F H, Lü S, Huang R, *et al.* Distribution of organic carbon in soil aggregates from four kinds of forest vegetation on Jinyun Mountain [J]. *Environmental Science*, 2019, **40**(3): 1504-1511.
- [42] 任荣秀, 杜章留, 孙义亨, 等. 华北低丘山地不同土地利用方式下土壤团聚体及其有机碳分布特征 [J]. *生态学报*, 2020, **40**(19): 6991-6999.
Ren R X, Du Z L, Sun Y H, *et al.* Soil aggregate and its organic carbon distribution characteristics at different land use patterns in hilly areas of North China [J]. *Acta Ecologica Sinica*, 2020, **40**(19): 6991-6999.
- [43] 王心怡, 周聪, 冯文瀚, 等. 不同林龄杉木人工林土壤团聚体及其有机碳变化特征 [J]. *水土保持学报*, 2019, **33**(5): 126-131.
Wang X Y, Zhou C, Feng W H, *et al.* Changes of soil aggregates and its organic carbon in Chinese fir plantations with different forest ages [J]. *Journal of Soil and Water Conservation*, 2019, **33**(5): 126-131.
- [44] Wilson G W T, Rice C W, Rillig M C, *et al.* Soil aggregation and carbon sequestration are tightly correlated with the abundance of arbuscular mycorrhizal fungi: results from long-term field experiments [J]. *Ecology Letters*, 2009, **12**(5): 452-461.
- [45] Gao Y Z, Zong J, Que H, *et al.* Inoculation with arbuscular mycorrhizal fungi increases glomalin-related soil protein content and PAH removal in soils planted with *Medicago sativa* L. [J]. *Soil Biology and Biochemistry*, 2017, **115**: 148-151.
- [46] Zhang S, Meng L B, Hou J, *et al.* Maize/soybean intercropping improves stability of soil aggregates driven by arbuscular mycorrhizal fungi in a black soil of Northeast China [J]. *Plant and Soil*, 2022, **481**(1-2): 63-82.
- [47] Lu X L, Lu X N, Liao Y C. Effect of tillage treatment on the diversity of soil arbuscular mycorrhizal fungal and soil aggregate-associated carbon content [J]. *Frontiers in Microbiology*, 2018, **9**, doi: 10.3389/fmicb.2018.02986.
- [48] Lehmann A, Rillig M C. Understanding mechanisms of soil biota involvement in soil aggregation: A way forward with saprobic fungi? [J]. *Soil Biology and Biochemistry*, 2015, **88**: 298-302.
- [49] Cao T T, Fang Y, Chen Y R, *et al.* Synergy of saprotrophs with mycorrhiza for litter decomposition and hotspot formation depends on nutrient availability in the rhizosphere [J]. *Geoderma*, 2022, **410**, doi: 10.1016/j.geoderma.2021.115662.
- [50] Horsch C C A, Antunes P M, Fahey C, *et al.* Trait-based assembly of arbuscular mycorrhizal fungal communities determines soil carbon formation and retention [J]. *New Phytologist*, 2023, **239**(1): 311-324.
- [51] Frey S D. Mycorrhizal fungi as mediators of soil organic matter dynamics [J]. *Annual Review of Ecology, Evolution, and Systematics*, 2019, **50**: 237-259.

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