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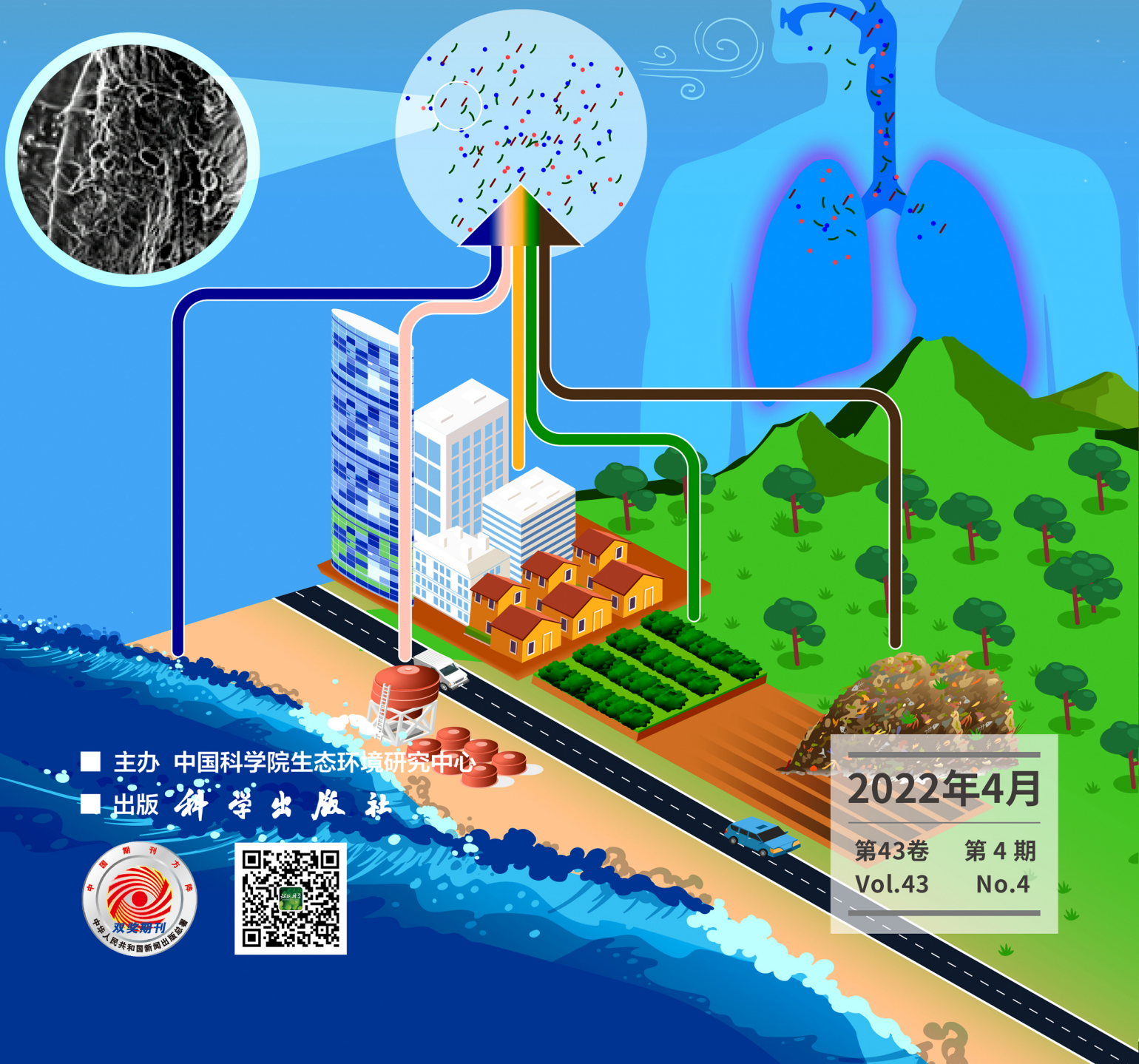
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HUANJING KEXUE

大连海岸带夏、秋季大气沉降(微)塑料的赋存特征及其表面生物膜特性

涂晨, 田媛, 刘颖, 张馨宁, 骆永明



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有机肥替代化肥对旱地黄壤有机碳矿化及活性有机碳的影响

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摘要: 目前有机肥替代化肥对旱地黄壤有机碳矿化及活性有机碳的影响特征及机制还不够明确。为探究有机肥替代化肥对旱地黄壤有机碳矿化及活性有机碳的影响, 采集施肥处理为: 不施肥 (CK)、单施化肥 (NP)、50% 有机肥替代化肥 [1/2 (NPM)] 和 100% 有机肥替代化肥 (M) 的土壤进行有机碳室内矿化培养研究, 探究有机肥替代化肥条件下土壤有机碳变化特征及活性有机碳变化。结果表明, 有机肥替代化肥显著提高土壤 pH、有机碳 (SOC)、全氮 (TN) 和 C/N。培养期间, 各处理土壤有机碳矿化速率均表现为初期 (第 2~4 d) 大幅下降, 中期 (第 4~20 d) 小幅度下降, 末期 (第 20~60 d) 趋近于平稳。施肥后土壤有机碳累积矿化量显著增加了 7.9%~27.7%, 与 NP 处理相比, 1/2 (NPM) 处理土壤有机碳累积矿化量降低了 5.2%, M 处理则增加了 12.2%。矿化培养前, 有机肥替代化肥对土壤易氧化有机碳 (ROC) 无显著影响, 显著增加了微生物量碳 (MBC) 含量, 1/2 (NPM) 处理显著增加可溶性有机碳 (DOC) 含量, M 处理则显著降低。培养 60 d 后, 各处理土壤活性有机碳含量较初始含量均有所减少, 其中 MBC 减少量最多, 为 30.6%~41.2%。有机碳累积矿化量与土壤 pH 和 SOC 呈显著正相关, 与 MBC 初始值及培养前后的变化值呈极显著正相关。综上, 100% 有机肥替代化肥显著促进土壤有机碳矿化, 降低土壤有机碳的稳定性; 50% 有机肥替代化肥抑制土壤有机碳矿化, 有利于土壤固碳培肥; 50% 有机肥替代化肥显著增加土壤活性有机碳含量, MBC 在土壤有机碳矿化过程中被作为主要碳源所利用。

关键词: 有机肥替代化肥; 旱地黄壤; 土壤基本性质; 有机碳矿化; 活性有机碳

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Effects of Organic Fertilizer Replacing Chemical Fertilizer on Organic Carbon Mineralization and Active Organic Carbon in Dryland Yellow Soil

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Abstract: At present, the effect characteristics and mechanism of organic fertilizer replacing chemical fertilizer on organic carbon mineralization and active organic carbon in dryland yellow soil remain unclear. In order to explore the effect of organic fertilizer replacing chemical fertilizer on organic carbon mineralization and active organic carbon in dryland yellow soil, we used soil with no fertilization (CK), only chemical fertilizer (NP), 50% organic fertilizer replacing chemical fertilizer (1/2 (NPM)), and 100% organic fertilizer replacing chemical fertilizer (M). We examined the indoor mineralization culture of organic carbon and explored the characteristics of soil organic carbon and the change in active organic carbon under the condition of organic fertilizer replacing chemical fertilizer. The results showed that organic fertilizer replacing chemical fertilizer increased soil pH, organic carbon (SOC), total nitrogen (TN), and C/N. During the culture period, the soil organic carbon mineralization rate of all treatments decreased sharply in the initial stage (2-4 days), decreased slightly in the middle stage (4-20 days), and tended to be stable in the last stage (20-60 days). After fertilization, the cumulative mineralization of soil organic carbon significantly increased by 7.9%-27.7%. Compared with that in the NP treatment, the cumulative mineralization of soil organic carbon decreased by 5.2% in the 1/2 (NPM) treatment and increased by 12.2% in the 1/2 (NPM) treatment. Before mineralization culture, the substitution of organic fertilizer for chemical fertilizer had no significant effect on soil recalcitrant organic carbon (ROC) but significantly increased the content of microbial biomass carbon (MBC). The content of dissolved organic carbon (DOC) was significantly increased in the 1/2 (NPM) treatment and decreased in the M treatment. After 60 days of culture, the content of soil active organic carbon in all treatments decreased compared with the initial content, of which MBC decreased the most (30.6%-41.2%). The accumulated mineralization of organic carbon was significantly positively correlated with soil pH and SOC and significantly positively correlated with the initial value of MBC and the change value before and after culture. To summarize, 100% organic fertilizer replacing chemical fertilizer significantly promoted soil organic carbon mineralization and reduced soil organic carbon stability; 50% organic fertilizer replacing chemical fertilizer inhibited soil organic carbon mineralization, which was beneficial to soil sequestration and fertilization; and 50% organic fertilizer replacing chemical fertilizer significantly increased soil active organic carbon content, and MBC was used as the main carbon source in the process of soil organic carbon mineralization.

Key words: organic fertilizer replacing chemical fertilizer; dryland yellow soil; basic properties of soil; organic carbon mineralization; active organic carbon

长期以来,我国施用化肥获得作物高产和推进农业发展的同时,化肥施用过多而造成的土壤板结和农业面源污染等土壤质量下降问题也日益突出,因此减少化肥施用具有重要的现实意义^[1]。有机肥中不仅含有作物生长所需的必要养分,还有大量有机养分及活性物质,是很好的化肥替代物。随着“两

减”行动的推行,传统的依赖化肥性农作方法将被

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改变^[2].在保证不减产和减少对土壤生态破坏的前提下,有机肥替代化肥的可行性研究成为热点^[3].土壤有机碳矿化是陆地生态系统有机碳库循环的重要过程,直接关系到土壤中养分元素的释放与供应、温室气体的形成和土壤质量的保持等.揭示土壤有机碳矿化规律对于养分的科学管理和全球气候变暖的有效控制意义重大^[4~7].土壤活性有机碳是指土壤中活性较强、周转速率较快且容易分解的那部分有机碳,包括可溶性有机碳(DOC)、易氧化有机碳(ROC)和微生物生物量碳(MBC)^[8,9].土壤中的活性有机碳是矿化过程中重要的碳源物质^[10],其含量及组分影响着有机碳的矿化特征^[11],因此,从活性有机碳的角度研究土壤有机碳的矿化也逐步受到了关注.

目前,关于施肥对土壤有机碳的影响已有不少报道.如 Veloso 等^[12]在巴西南部进行了 30 a 的试验研究发现,施肥通过改变土壤环境、土壤微生物的多样性和组成以及有机碳与土壤矿物质的关系进而影响土壤有机碳矿化. Ribeiro 等^[13]的研究发现,有机肥化肥配施促进养分快速释放,显著增加碳库的矿化. Chatterjee 等^[14]的研究发现长期施入有机肥显著提高了稻田土壤 MBC 和 ROC 含量. Xu 等^[15]通过对人为集约土的研究发现,不同肥料施入土壤中后,土壤 SOC、DOC 和 MBC 的排序为:不施肥 < 单施化肥 < 有机肥化肥配施 < 单施有机肥. 谭立敏等^[16]通过对水稻土的矿化研究发现,可溶性有机碳和微生物生物量碳随矿化培养的进行逐渐减小,与矿化速率变化趋势一致.然而,目前有机肥替代化肥对旱地黄壤有机碳矿化及活性有机碳的影响特征及机制还不够明确.

因此,本研究以等氮条件下有机肥替代化肥的旱地黄壤为对象,结合室内矿化培养,明确不同比例有机肥替代化肥处理后有机碳矿化特征,探讨有机肥替代化肥对旱地黄壤有机碳矿化及活性有机碳的影响,以期对贵州旱地黄壤的固碳培肥提供理论依据.

1 材料与方法

1.1 研究区概况

试验地位于贵州省安顺市西秀区鸡场乡(E 106°05'59", N 26°06'29"),海拔 1 271 m.该区域属亚热带季风性湿润气候,年均气温 13.2~15.0℃.年均降雨量 968~1 309 mm.土壤为黄壤,基本性质为:pH 4.54, ω [有机碳(SOC)] 17.06 g·kg⁻¹, ω (碱解氮) 126.73 mg·kg⁻¹, ω (有效磷) 20.92 mg·kg⁻¹, ω (速效钾) 159.50 mg·kg⁻¹.

1.2 试验设计及供试材料

试验采用随机区组设计,共设置 4 个处理,分别为不施肥(CK)、单施化肥(NP)、50% 有机肥替代化肥[1/2(NPM)]和 100% 有机肥替代化肥(M);施肥量见表 1.各小区间隔 1 m,小区面积为 13.2 m² (3.3 m×4 m),每个处理 3 次重复,随机排列,共 12 个小区.

种植制度为玉米/大豆间作.于 2020 年 4 月 20 日播种,大豆与玉米之间行距为 60 cm,玉米株距 30 cm,大豆株距 20 cm,5 月 10 日间苗,5 月 20 日至 6 月 20 日每周除草一次,6 月 21 日打药除病虫害,8 月 15 日收获大豆,8 月 31 日收获玉米并采集土样.供试玉米品种为“黔单 16 号”,大豆品种为安顺本地春大豆.供试有机肥为贵州万盛肥料厂所生产生物有机肥(含有机质≥45%,含 N 2.29%,含 P₂O₅ 2.7%),氮肥为尿素(含 N 46.2%),磷肥为过磷酸钙(含 P₂O₅≥16%),所有肥料均作为基肥一次性施入.

表 1 田间试验不同处理施肥量

处理	肥料施用量/kg·hm ⁻²		
	化肥 N	化肥 P	有机肥 N
不施肥(CK)	0	0	0
单施化肥(NP)	150	45	0
50% 有机肥替代化肥[1/2(NPM)]	75	22.5	75
100% 有机肥替代化肥(M)	0	0	150

1.3 样品采集

玉米和大豆收获后,采集各小区(0~20 cm)耕层土壤样品;每个小区分别均匀采集 5 点组成一个混合样,将采集的土壤样品除去动、植物残体并且混匀,部分直接过孔径 2 mm 筛,置于 4℃ 冰箱内用于土壤矿化培养试验;剩余土壤样品风干后研磨过 2、0.25 和 0.149 mm 筛,用于土壤总有机碳、易氧化有机碳和土壤基本性质的测定.

1.4 测定和分析方法

有机碳矿化培养试验:采用碱液吸收法,分别称取 30.0 g 过 2 mm 筛的鲜土置于 50 mL 烧杯中,将含水量调节至田间持水量的 45% 左右,放入 1 000 mL 培养瓶底部,在培养箱中以 25℃ 预培养 7 d.然后将盛有 10 mL 0.1 mol·L⁻¹ NaOH 溶液的 50 mL 吸收杯也放置于培养瓶底部,加盖密封,在 25℃ 恒温箱中暗培养.每个土样设 3 次重复,同时设 6 个空白对照,共 42 组矿化培养系统.在培养的第 2、4、6、9、12、16、20、25、30、35、40、45、50、55 和 60 d 时,更换新的碱液吸收杯并加水至含水量恒重,吸收杯中加入 1 mol·L⁻¹ BaCl₂ 溶液 2 mL,再滴加 2 滴酚酞指示剂,用 0.1 mol·L⁻¹ HCl(每次使用前进行标定)滴定至红色消失.根据 CO₂ 的释放量计算培

养期内土壤有机碳的矿化量。

采用 pH 计测定土壤 pH(水土比为 2.5:1),采用常规方法测定土壤有机碳(SOC)和土壤全氮^[17];采用 0.333 mol·L⁻¹ KMnO₄ 氧化法测定易氧化有机碳(ROC)^[18], 0.5 mol·L⁻¹ K₂SO₄ 浸提法测定可溶性有机碳(DOC)^[19], 氯仿熏蒸-0.5 mol·L⁻¹ K₂SO₄ 浸提法测定土壤微生物生物量碳(MBC)^[20]。

1.5 计算公式

土壤有机碳矿化量(mg·kg⁻¹,以 CO₂ 计) =
 $c(\text{HCl}) \times (V_0 - V_1) \times 22/0.03$

式中, $c(\text{HCl})$ 为盐酸浓度, mol·L⁻¹; V_0 为空白滴定的体积, mL; V_1 为消耗盐酸的体积, mL。土壤有机碳累积矿化量指从培养开始至某一时间点土壤 CO₂ 总释放量。

土壤有机碳矿化速率[$\text{mg} \cdot (\text{kg} \cdot \text{d})^{-1}$, 以 CO₂ 计] = 培养时间内有机碳矿化量($\text{mg} \cdot \text{kg}^{-1}$, 以 CO₂ 计)/培养天数(d)。

土壤微生物熵(q_{MB} , %) = 微生物量有机碳($\text{mg} \cdot \text{kg}^{-1}$)/总有机碳($\text{mg} \cdot \text{kg}^{-1}$)

1.6 数据分析

利用 Excel 2010 进行处理, 采用 SPSS 17.0 软件对不同处理之间的差异进行 ANOVA 分析, LSD 法进行差异显著性检验($P < 0.05$)。

2 结果与分析

2.1 不同施肥处理的土壤基本性质

由表 2 可知, M 处理提高土壤 pH、SOC、TN 和 C/N。与 CK 处理相比, 各施肥处理均显著提高土壤 TN 含量, 其增幅为 4.6%~8.0%; 1/2(NPM) 和 M 两个处理显著提高土壤 SOC 含量, 其增值依次为 8.5% 和 9.5%; 仅 M 处理显著提高土壤 pH 值, 其增值为 3.2%; M 处理显著提高了土壤 C/N, 其增值为 4.9%, NP 显著降低土壤 C/N, 其减值为 0.4%, 而 1/2(NPM) 处理则无显著差异。与 NP 处理相比, 1/2(NPM) 和 M 两个处理均显著提高土壤 SOC 含量和 C/N, 其增值分别为 6.2%~7.2% 和 4.7%~9.3%, 仅 M 处理显著提高 pH 值, 各有机肥替代化肥处理 TN 无显著差异。

表 2 不同处理的土壤基本性质¹⁾
Table 2 Basic properties of the soil in different treatments

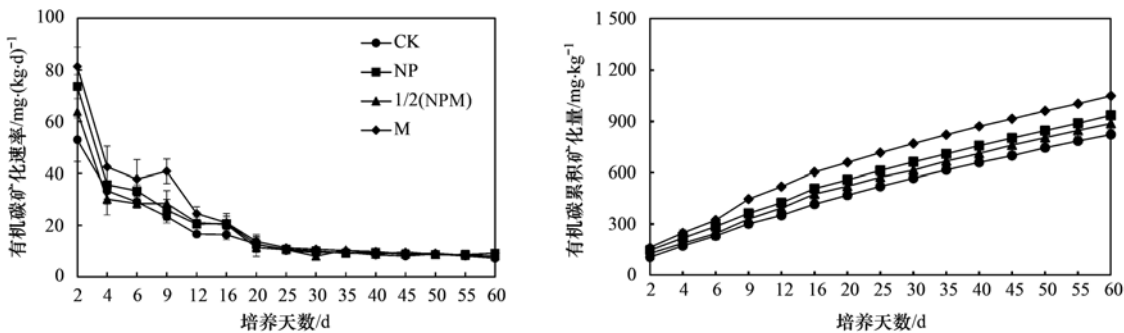
处理	pH	$\omega(\text{SOC})/\text{g} \cdot \text{kg}^{-1}$	$\omega[\text{全氮(TN)}]/\text{g} \cdot \text{kg}^{-1}$	C/N
CK	4.58 ± 0.17b	17.14 ± 0.20b	1.74 ± 0.01b	9.85 ± 0.13b
NP	4.60 ± 0.08b	17.51 ± 0.25b	1.85 ± 0.02a	9.45 ± 0.21c
1/2(NPM)	4.64 ± 0.12ab	18.60 ± 0.21a	1.88 ± 0.06a	9.89 ± 0.27ab
M	4.73 ± 0.04a	18.77 ± 0.25a	1.82 ± 0.03a	10.33 ± 0.30a

1) 不同小写字母表示处理间差异显著, $P < 0.05$, 下同

2.2 不同施肥处理土壤有机碳的矿化特征

由图 1 可知, 在培养期内所有处理土壤有机碳矿化速率总体上均呈下降趋势, 根据其降幅可分为 3 个阶段: 初期(第 2~4 d), 矿化速率从第 2 d 的最大值开始大幅下降, 第 4 d 的矿化速率为第 2 d 的 47.2%~62.9%, 中期(第 4~20 d)矿化速率小幅度下降, 第 20 d 的矿化速率为第 2 d 的 17.0%~24.3%, 末期(第 20~60 d), 矿化速率趋近于平稳,

第 60 d 的矿化速率为第 2 d 天的 11.4%~13.9%。与 CK 处理相比, NP、1/2(NPM) 和 M 这 3 个处理土壤有机碳累积矿化量依次增加 13.7%、7.9% 和 27.7%。土壤有机碳累积矿化量以 M 最高, 为 1049.3 $\text{mg} \cdot \text{kg}^{-1}$, 其次是 NP 处理和 1/2(NPM) 处理, 为 934.8 $\text{mg} \cdot \text{kg}^{-1}$ 和 886.5 $\text{mg} \cdot \text{kg}^{-1}$, CK 处理最低, 为 821.9 $\text{mg} \cdot \text{kg}^{-1}$, 各处理之间土壤有机碳累积矿化量均达到了显著差异水平($P < 0.05$)。



不同小写字母表示处理间差异显著, $P < 0.05$, 下同

图 1 不同处理下土壤有机碳矿化速率和累积矿化量

Fig. 1 Mineralization rate and cumulative mineralization of soil organic carbon in different treatments

土壤有机碳累积矿化量分配比是指在一定时间内土壤有机碳累积矿化量占土壤有机碳含量的比例,能在一定程度上反映土壤有机碳的固碳能力^[21].由图 2 可知,60 d 培养后,M 处理和 NP 处理土壤有机碳累积矿化量分配比均显著高于 CK,而 1/2(NPM)处理与 CK 无显著差异;与 NP 处理相比,1/2(NPM)处理土壤有机碳累积矿化量分配比达显著差异,这说明 NP 处理或 M 处理会降低土壤固碳能力,1/2(NPM)处理会提高土壤固碳能力.

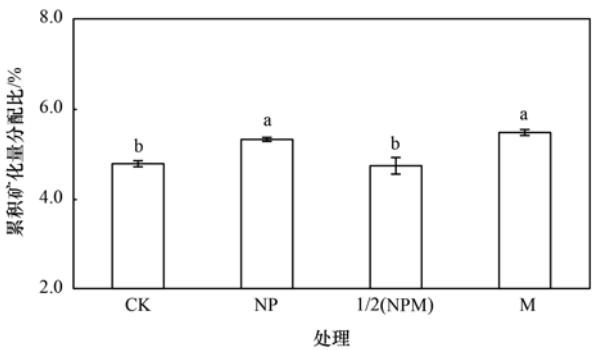


图 2 不同处理下土壤有机碳累积矿化量分配比

Fig. 2 Distribution ratios of cumulative mineralization amount to SOC contents in different treatments

2.3 不同施肥处理土壤活性有机碳含量及其矿化前后的变化

由表 3 可知,与 CK 处理相比,各施肥处理 ROC/SOC 和 DOC/SOC 显著增高,其增幅依次为 13.6%~16.8%和 21.3%~48.4%,各施肥处理 qMB 增加 13.6%~28.5%,1/2(NPM)处理和 M 处理达显著水平,而 NP 处理无显著差异.与 NP 处理相比,1/2(NPM)和 M 两个处理 ROC/SOC 和 qMB 均无显著差异,1/2(NPM)处理 DOC/SOC 无显著差异,M 处理显著降低了 DOC/SOC,其降低值为 18.2%.

由表 4 可知,与 CK 处理相比,各施肥处理 ROC、DOC 和 MBC 初始含量均显著增加,其增幅依次为 19.5%~29.3%、34.9%~59.0%和 16.3~43.6%.与 NP 处理相比,1/2(NPM)处理 ROC 含量无显著差异,DOC 和 MBC 含量依次显著增加了 5.1%和 13.5%,M 处理的土壤 ROC 含量无显著差异,DOC 含量降低 10.8%,MBC 增加了 23.5%.培

养 60 d 后,各处理 ROC、DOC 和 MBC 含量较初始含量分别减少了 9.1%~23.7%、5.7%~26.2%和 30.6%~41.2%.这说明 50% 有机肥替代化肥显著增加活性有机碳含量,活性有机碳在土壤有机碳矿化过程中被作为碳源所利用.

表 3 不同处理下 ROC/SOC、DOC/SOC 和 qMB 值

Table 3 ROC/SOC, DOC/SOC, and qMB in different treatments			
处理	ROC/SOC	DOC/SOC	qMB
CK	10.16 ± 0.43b	1.00 ± 0.02c	0.73 ± 0.07b
NP	11.87 ± 0.44a	1.48 ± 0.02a	0.83 ± 0.06ab
1/2(NPM)	11.54 ± 0.73a	1.46 ± 0.01a	0.88 ± 0.09a
M	11.76 ± 0.89a	1.21 ± 0.03b	0.94 ± 0.06a

表 4 不同处理土壤活性有机碳初始含量及其培养前后变化值

Table 4 Initial contents of labile soil organic carbon and changes before and after incubation in different treatments			
处理	ω [易氧化有机碳(ROC)]/g·kg ⁻¹		
	初始含量	培后含量	变化值
CK	1.74 ± 0.06b	1.58 ± 0.06b	0.16 ± 0.02b
NP	2.08 ± 0.05a	1.85 ± 0.11a	0.23 ± 0.13b
1/2(NPM)	2.15 ± 0.14a	1.75 ± 0.06a	0.41 ± 0.08ab
M	2.25 ± 0.15a	1.72 ± 0.11a	0.53 ± 0.22a
处理	ω [可溶性有机碳(DOC)]/mg·kg ⁻¹		
	初始含量	培后含量	变化值
CK	171.82 ± 4.50d	155.44 ± 8.42c	16.38 ± 5.46b
NP	259.94 ± 2.81b	193.41 ± 10.52b	66.53 ± 9.80a
1/2(NPM)	273.13 ± 3.62a	201.51 ± 7.14ab	71.62 ± 10.20a
M	231.81 ± 3.39c	218.70 ± 5.60a	13.10 ± 6.63b
处理	ω [微生物量碳(MBC)]/mg·kg ⁻¹		
	初始含量	培后含量	变化值
CK	124.77 ± 10.10d	86.65 ± 2.12b	38.12 ± 9.88b
NP	145.16 ± 8.26c	85.37 ± 9.74b	59.79 ± 13.40ab
1/2(NPM)	164.74 ± 16.13b	112.16 ± 2.38a	52.57 ± 14.82ab
M	179.21 ± 10.51a	114.50 ± 11.14a	64.71 ± 0.63a

2.4 土壤有机碳矿化与土壤基本性质和活性有机碳含量的关系

对土壤有机碳累积矿化量与土壤基本性质和活性有机碳含量进行相关性分析,结果表明(表 5),土壤有机碳累积矿化量与 pH 和 SOC 呈显著正相关($P < 0.05$),与 qMB 和 MBC 初始含量及其变化值之间呈极显著正相关($P < 0.01$),与 TN、C/N、ROC/SOC、DOC/SOC 和 ROC 初始含量及其变化值、DOC 初始含量及其变化值的相关性未达到显著

表 5 土壤有机碳累积矿化量与土壤基本性质和活性有机碳含量的相关性¹⁾

Table 5 Correlations of cumulative mineralization amount with soil physical and chemical properties and labile organic carbon							
项目	pH	SOC	TN	C/N	ROC/SOC	DOC/SOC	qMB
60-CO ₂ -C	0.704 *	0.651 *	0.299	0.428	0.446	0.211	0.761 **
项目	ROC		DOC		MBC		
	初始含量	变化值	初始含量	变化值	初始含量	变化值	
60-CO ₂ -C	0.358	0.289	0.322	-0.240	0.767 **	0.731 **	

1)60-CO₂-C 表示培养 60 d 累积矿化量; * 表示显著相关性($P < 0.05$), ** 表示极显著相关性($P < 0.01$)

水平. 这说明土壤有机碳累积矿化量与 pH、SOC、qMB 和 MBC 初始含量及变化值之间密切相关, 但与 TN、C/N、ROC/SOC、DOC/SOC、ROC 初始含量及其变化值和 DOC 初始含量及其变化值关系较弱.

3 讨论

3.1 不同施肥处理对土壤基本性质的影响

不同施肥处理土壤基本性质存在差异. 本研究表明, 单施化肥对土壤 pH 和 SOC 无显著影响, 显著提高土壤 TN, 显著降低土壤 C/N, 这与康国栋^[22]和吴建富等^[23]的研究结果不一致, 其原因可能是本研究供试土壤呈强酸性, 本身 SOC 含量较高, 短期内化肥对土壤基本性质的影响还未体现. 本研究中, 与单施化肥相比, 有机肥替代化肥对土壤 TN 无显著影响, 但显著影响了土壤 pH、SOC 含量和 C/N, 且随有机肥替代化肥比例增加而增加, 这与前人研究结果一致^[24~27]. 有机肥属于高碳聚合物具有较高的 C/N 且偏碱性, 其作为碳源施入土壤后, 使土壤 pH、SOC 含量和 C/N 均显著提高^[28].

3.2 不同施肥处理对土壤有机碳矿化的影响

土壤有机碳在微生物作用下矿化释放 CO₂ 是碳循环的重要组成部分. 在本研究中, SOC 矿化速率随培养时间呈现逐渐减缓, 最终趋于平稳的趋势, 这与王莲阁等^[29]和史登林等^[30]的研究结果一致, 其原因是在培养前期土壤中存在大量易分解的活性有机碳, 微生物活性强, 矿化速率快, 后期可供微生物矿化的碳源减少, 有机碳矿化被限制, 矿化速率逐渐降低并趋于稳定^[26, 31~33]. 土壤有机碳矿化一般受土壤固有性质和环境因素的调控. 本研究中 M 处理土壤有机碳累积矿化量显著高于 NP 处理, 1/2 (NPM) 处理土壤有机碳累积矿化量显著低于 NP 处理, 这可能是因为本研究供试土壤呈强酸性 (pH 值为 4.54), 有机肥的施入改善了土壤酸度, 使土壤环境更适宜微生物生长, 从而促进微生物对有机质的分解, 提高 CO₂ 的释放量. M 处理显著增加了 CO₂ 的释放量, 提高了土壤有机碳累积矿化量分配比, 这将不利于土壤有机碳的积累和气候变暖的控制, 可通过合理适当地降低有机肥替代化肥比例来增加土壤有机碳的累积量, 提高土壤有机碳的稳定性.

3.3 不同施肥处理对土壤活性有机碳的影响

有研究结果表明, 施肥能显著增加土壤中活性有机碳含量^[34~36]. 尽管土壤活性有机碳只占 SOC 含量的一小部分, 但它们是土壤质量和养分循环的敏感指标^[37~39]. 本研究结果表明, 施肥可增加土壤中 ROC、DOC 和 MBC 含量, 其中 50% 有机肥替代化肥结果最显著, 这与王鹏等^[40]和张玉军等^[41]的

研究结果一致, 其原因可能是施肥促进了作物根系的生长, 从而使残留在土壤中的根系更多, 根系的分解增加了土壤中的活性有机碳含量; 而有机肥分解后给土壤提供了大量直接有机碳源, 提高了土壤中微生物的数量和活度, 且在微生物分解作用下释放出更多的活性有机碳.

3.4 土壤有机碳矿化与土壤基本性质和活性有机碳含量的关系

土壤基本性质通过影响土壤微生物的生存环境从而影响微生物活性和种类^[10, 42], 施肥通过影响土壤微生物的数量、活性以及群落组成从而影响有机碳矿化^[43, 44]. 本研究中, 土壤有机碳累积矿化量与土壤 pH 值和 SOC 含量呈显著正相关, 这与吕真真等^[45]的研究结果一致, 但土壤有机碳累积矿化量与土壤 TN 和 C/N 无显著相关性, 这可能是因为土壤结构不同, 从而进一步导致土壤微生物生存的微环境不同.

有研究表明, 土壤中活性有机碳含量与有机碳矿化密切相关. 如张文娟等^[21]的研究发现土壤有机碳矿化速率与土壤 SOC 和 MBC 表现为正相关, 本研究与其研究结果相似. 本研究中, 土壤活性有机碳 ROC 和 DOC 与有机碳累积矿化量的相关性较弱, 但有机碳累积矿化量与 MBC 有极显著正相关. 其原因是 ROC 和 DOC 虽然作为微生物有效碳源但对有机碳矿化的贡献较小, MBC 作为微生物的直接碳源对有机碳矿化做出很大贡献. 在实际生产中, 合理调控影响 MBC 含量的因子可以作为提高土壤质量的有效措施之一. 此外, 影响土壤有机碳矿化的因素纷繁复杂, 土壤微生物和土壤团聚体也可能是影响旱地黄壤有机碳矿化的重要因素.

4 结论

(1) 100% 有机肥替代化肥显著促进土壤有机碳矿化, 降低土壤有机碳的稳定性; 50% 有机肥替代化肥抑制土壤有机碳矿化, 有利于土壤固碳培肥.

(2) 50% 有机肥替代化肥显著增加土壤活性有机碳含量, MBC 在土壤有机碳矿化过程中被作为主要碳源所利用.

(3) 贵州旱地黄壤有机碳累积矿化量与 pH 和 SOC 显著正相关, 与 MBC 初始值及培养前后的变化值极显著正相关.

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