

ISSN 1000-0933
CN 11-2031/Q

生态学报

Acta Ecologica Sinica

中国生态学会 2013 年学术年会专辑



第 33 卷 第 19 期 Vol.33 No.19 **2013**

中国生态学会
中国科学院生态环境研究中心
科学出版社

主办
出版



中国科学院科学出版基金资助出版

生态学报

(SHENGTAI XUEBAO)

第33卷第19期

2013年10月 (半月刊)

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期刊基本参数: CN 11-2031/Q * 1981 * m * 16 * 464 * zh * P * ¥ 90.00 * 1510 * 55 * 2013-10



封面图说: 毛乌素沙地南缘沙丘的生物结皮——生物土壤结皮广泛分布于干旱和半干旱区, 它的形成和发育对荒漠生态系统生态修复过程产生重要的影响。组成生物结皮的藻类、苔藓和地衣是常见的先锋植物, 它们不仅能在严重干旱缺水、营养贫瘠恶劣的环境中生长、繁殖, 并且能通过其代谢方式影响并改变环境。其中一个重要的特点是, 生物结皮表面的凝结水显著大于裸沙。研究表明, 凝结水是除降雨之外最重要的水分来源之一, 在水分极度匮乏的荒漠生态系统, 它对荒漠生态系统结构、功能和过程的维持产生着重要的影响。

彩图及图说提供: 陈建伟教授 北京林业大学 E-mail: cites.chenjw@163.com

DOI: 10.5846/stxb201305121021

薛建福, 赵鑫, Shadrack Batsile Dikgwatlhe, 陈阜, 张海林. 保护性耕作对农田碳、氮效应的影响研究进展. 生态学报, 2013, 33(19): 6006-6013.

Xue J F, Zhao X, Dikgwatlhe S B, Chen F, Zhang H L. Advances in effects of conservation tillage on soil organic carbon and nitrogen. Acta Ecologica Sinica, 2013, 33(19): 6006-6013.

保护性耕作对农田碳、氮效应的影响研究进展

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摘要:作物产量的高低主要取决于土壤肥力, 如何保持并提高土壤肥力是确保我国粮食安全和农业可持续发展的重要任务, 也是众多学者关注的焦点。土壤有机碳和氮素是评价土壤质量的重要指标, 其动态平衡直接影响土壤肥力和作物产量。随着全球气候变化及环境污染问题的愈加突出, 农田土壤固碳及提高氮效率成为各界科学家研究的热点。目前, 保护性耕作已成为发展可持续农业的重要技术之一, 对土壤固碳及氮素的利用具有很大的影响。深入了解保护性耕作对土壤有机碳固持与氮素利用效率提高的影响机制, 对于正确评价土壤肥力有着重要意义。但由于气候、土壤及种植制度等条件不一致, 关于保护性耕作对农田碳、氮效应结论不一。阐述了国际上保护性耕作对农田系统土壤有机碳含量变化及其分解排放(如 CO_2 和 CH_4)、氮素变化及其矿化损失(如 NH_3 挥发、 N_2O 排放与氮淋失)和碳氮素相互关系(如 C/N 层化率)影响的研究进展, 并分析了其影响因素和相关机理。尽管国内保护性耕作的研究已进行 30 多年, 但在土壤有机碳与氮素方面与国外相比依然有较大的差距。保护性耕作对土壤固碳与氮素利用的影响机制, 碳素和氮素在土壤-植株-大气系统中的转移变化, 及结合农事管理等综合评价其生态效应的研究很少。在此基础上, 提出未来我国保护性耕作在土壤有机碳固定和氮素利用方面的重点研究方向: (1) 在定位试验基础上进一步探讨保护性耕作对土壤有机碳及氮素利用的影响机制; (2) 深入研究土壤有机碳和氮素的相互关系及其对土壤肥力的影响; (3) 结合环境保护与土壤可持续管理对保护性耕作农田土壤固碳及氮素高效利用的系统评价研究; (4) 加强保护性耕作对农田碳、氮效应的宏观研究, 合理评价保护性耕措施下对农田碳、氮综合效应。

关键词:保护性耕作; 土壤肥力; 土壤质量; 土壤有机碳; 氮利用

Advances in effects of conservation tillage on soil organic carbon and nitrogen

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Abstract: Soil fertility is one of the most important factors determining crop production. Maintaining and improving soil fertility, which has become an increasing focus for agricultural scientists, is crucial for food security and sustainable agricultural development in China. Soil organic carbon (SOC) and nitrogen (N) directly affect soil fertility and ultimately crop yield, and thus are considered as important soil quality indicators. With the concerns on global warming and environmental pollution, more attention is being paid on enhancing SOC sequestration and improving N use efficiency (NUE) in cropland. Currently, conservation tillage is widely regarded as an important part of sustainable agriculture and has been adopted by many countries, due to its benefits in conserving soil, saving water, fuel and energy, and protecting the environment. Numerous studies have indicated that conservation tillage (i.e., no-till and minimum tillage) increases SOC and total N storages by reducing soil disturbance and increasing residue retention. Thus, a deep understanding of the mechanisms of conservation tillage on enhancing SOC sequestration and NUE is of fundamental significance for soil fertility assessment. However, there are still controversies about the effects of conservation tillage on SOC sequestration and NUE, mainly due to the diverse climates, soil types, cropping systems, and experimental durations. This paper provides a review

基金项目:公益性行业(农业)科研专项(201103001)

收稿日期:2013-05-12; 修订日期:2013-07-23

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about the research progresses of conservation tillage effects on SOC content and decomposition (e.g., CO_2 and CH_4 emission), total N content and mineralization (e.g., NH_3 volatilization, N_2O emission, and NO_3^- leaching), and the relationships between SOC and N processes (e.g., C/N stratification) in farmland systems. Meanwhile, this article also assessed factors and mechanisms that influence SOC and N use. Although studies on conservation tillage have been conducted more than 30 years, there are some gaps between China and the other countries, especially on SOC and N processes under conservation tillage systems. Because of the large differences in experiment conditions, the mechanisms of tillage effects on SOC sequestration and N use are not well understood. Furthermore, systematic studies on carbon and N transformations in the soil-plant-atmosphere-continuum are rare under different tillage systems, which make it difficult to conduct in-depth studies of conservation tillage. Meanwhile, considering the emissions of agricultural practices, few papers have assessed the ecological effects of conservation tillage on the interactions between C and N processes. Therefore, it is necessary to study the underpinning mechanisms that govern tillage effects on SOC sequestration and N use. Our analysis showed that the potential researchable areas and priorities on the influences of conservation tillage on SOC and N processes in China were: (1) strengthen the on-site studies on the mechanisms of conservation tillage effects on SOC sequestration and N use; (2) enhance the study of relationships between SOC and N and their interaction effect on soil fertility under conservation tillage; (3) link environmental protection, sustainable soil management, SOC sequestration and N use; and (4) deepen the study of conservation tillage effects on SOC sequestration and N use in macro-scale.

Key Words: conservation tillage; soil fertility; soil quality; soil organic carbon; nitrogen use

土壤肥力是土壤的基本属性和本质特征,对作物生长及产量有重要的影响。目前,我国耕地的平均有机质含量严重下降^[1],成为我国农业可持续发展的限制因素。土壤有机质矿化分解产生 CO_2 和 CH_4 等释放到大气中影响全球气候变化;而我国氮肥过量施用且利用率较低,约有 52% 的活性氮流入生态系统^[2],造成严重的环境问题。在人类活动的强烈干扰下,碳循环与氮循环间的直接或间接作用变得更加复杂^[3]。保护性耕作已成为发展可持续农业的主要技术之一^[4],综合研究此措施下农田碳、氮效应对于深入了解土壤肥力变化及其生态效应具有重要意义。

1 保护性耕作对农田土壤碳效应的影响

保护性耕作改变了农田地表微环境,影响土壤有机碳含量及其矿化损失^[5]。保护性耕作对土壤有机碳、农田碳排放损失的影响机制、土壤碳组分的变化及其与土壤质量的关系是目前的研究热点。

1.1 保护性耕作对农田土壤有机碳含量的影响

一般认为保护性耕作能够增加土壤表层有机碳含量,但对深层土壤有机碳含量是否增加及其是否随耕作年限的增加而持续变化结论不一致^[4]。Kahlon 等^[6]对 22 a 的耕作试验研究得出,0—20 cm 免耕土壤全碳含量较翻耕增加约 30%,且随着秸秆覆盖量的增加而增加。Ussiri 和 Lal 通过 43a 长期定位试验研究认为^[7],免耕由于减少了对土壤的扰动而降低了土壤有机碳的矿化率,显著增加 0—15 cm 土层有机碳含量;但不同的耕作措施 15—30 cm 土层有机碳含量差别不大。关于较深土壤剖面有机碳含量的研究很少,且大多结果表明不同耕作间深层土壤有机碳含量差异不大^[8],同时由于土壤类型、种植作物等试验条件不一致,导致分析结果的误差较大。Blanco-Canqui 和 Lal 等^[9]研究认为,保护性耕作能够提高表层(0—10 cm)土壤有机碳含量,但对深层土壤碳含量的影响不大,甚至有降低的趋势。VandenBygaart 等^[10]研究认为大多取样深度超过 30 cm 的试验中,与翻耕相比,免耕深层土壤有机碳含量较低。West 和 Post 对全球 67 个长期定位耕作试验点的 276 对结果进行分析^[11],其中绝大多数研究测定的土壤有机碳取样深度较浅(小于 30 cm),而种植作物的根系大多超过 30 cm,且植株地下根系对土壤固碳的贡献较地上秸秆更大^[12],进一步研究深层土壤有机碳对于正确评价土壤固碳非常必要。

1.2 保护性耕作对农田碳排放的影响

传统翻耕措施破坏土壤结构,增加土壤有机碳暴露而加快土壤有机碳分解^[13],而保护性耕作措施减少对土壤的扰动,降低了部分农资投入,从而直接或间接降低农田碳排放^[4]。

一般认为保护性耕作能够减少农田土壤 CO_2 排放量。Ussiri 和 Lal 研究认为^[7],免耕由于作物残茬覆盖在地表,减少与土壤接触而分解较慢,并减弱了土壤向大气排放 CO_2 ,降低了土壤 CO_2 排放量。Franzluebbers 等^[14]研究认为,免耕能够保持表层土壤较高的水分和有机碳含量而有利于微生物分解活动,较翻耕有等量或者更大的 CO_2 排放量。Li 等^[15]在华中稻田研究认为,当气温和土壤温度较高且没有差异时,耕作对土壤 CO_2 排放没有影响;但在正常气候条件下,免耕增加土壤 CO_2 排放,这可能与不同耕作条件下土壤微生物活性和碳素矿化等有关。田慎重等^[16]在华北平原研究认为, CO_2 日均排放通量为翻耕秸秆还

田>翻耕秸秆不还田>免耕,土壤地表和 5 cm 温度显著影响 CO_2 排放。耕作方式对土壤 CO_2 排放的影响复杂^[17],短期耕作与长期耕作对土壤产生不同的效应,进一步加强分析试验年限对土壤 CO_2 排放的影响十分必要。

许多研究表明旱地生态系统 CH_4 排放损失很少,甚至为弱 CH_4 吸收汇^[16,18-19],而淹水稻田则为 CH_4 的主要排放源。这可能由于耕作改变土壤性质、植株特性和微生物活性,引起土壤氧化还原电势与土壤水分发生变化而导致土壤 CH_4 排放不同。Hanaki 等^[20] 研究得出,与翻耕相比,免耕稻田土壤电子受体浓度较低而抑制 CH_4 排放。Pandey 等^[21] 研究认为减少耕作可以显著降低 CH_4 排放量。Ahmad 等^[22] 研究认为,免耕土壤容重较高而降低土壤大孔隙度,从而减少 CH_4 排放;而在施肥条件下,与 Hanaki 和 Harada 等^[20,23] 的研究结果相似,但由于土壤特性等条件不一致, CH_4 排放量降低的程度稍有不同。魏海苹等^[24] 分析认为,中国稻田单位面积 CH_4 排放量总体为单季稻>双季晚稻>双季早稻,单季稻与晚稻的 CH_4 排放无显著差异。Li 等^[25] 研究江西双季稻田认为,免耕土壤较低的可溶性有机碳含量和较高的土壤容重是 CH_4 排放降低的原因。张海林等^[26-27] 在湖南双季稻田的研究认为,不同耕作条件下双季稻生长季为 CH_4 的主要排放期,而冬闲季节所占比重不到全年的 1%,早稻和晚稻生长季 CH_4 排放量均以保护性耕作最低,且认为土壤含水量变化、晒田和间歇灌溉等影响稻田 CH_4 排放。

关于保护性耕作对碳排放的研究主要集中在农田土壤排放,而农田各项投入的碳排放损失考虑较少。国外学者认为,在评价农田碳排放时应考虑能耗引起的 CO_2 排放量^[28-29]。West 与 Marland 认为^[28] 农业投入部分应当考虑到农田碳效应研究中,他们基于美国平均农资投入数据,在宏观尺度下比较不同耕作方式下农资投入对碳排放的贡献,结果表明传统耕作转换为免耕可以减少化石燃料使用而降低碳排放。Lal 认为^[29],不同的耕作措施间消耗的能源有很大差异,传统翻耕产生的碳排放约为 35.3 kg/hm^2 ,而免耕仅为 5.8 kg/hm^2 。伍芬琳等^[30] 对我国华北平原的研究认为,与翻耕相比,少免耕明显降低了农田碳排放量。但由于国内相关研究大多基于国外的碳排放系数,未能真实体现国内相关的碳排放量,进一步研究国内农田各项投入的相关参数对于准确评价农田碳效应很有必要。近年来,众多学者通过农业碳足迹评价方法系统定量计算人类在一定时间和空间边界内,从事农业生产过程中的温室气体排放总量以及各生产环节的分量,这对于明确农业生产系统是碳源还是碳汇具有重要意义^[31]。

1.3 保护性耕作对土壤有机碳组分与土壤质量关系的影响

一般认为保护性耕作措施有利于土壤团聚体形成,并能够提高表层土壤大团聚体的有机碳含量^[32-33]。Zhang 等^[34] 对土壤团聚体中有机碳研究表明,较传统翻耕而言,垄作增加了所有粒级团聚体中的有机碳含量,免耕则增加了微粒团聚体中的有机碳含量。Zhao 等^[35] 进行 26a 试验研究认为,与免耕、深松等保护性措施相比,翻耕土壤 500—1000 μm 粒级团聚体中活性碳含量分别降低 53.03% 与 72.72%,慢性有机碳分别增加 18.77% 与 24.86%,惰性有机碳含量没有显著不同;而耕作措施对 50—500 μm 粒径团聚体中各有机碳组分的含量没有显著影响。Zhao 等^[35] 利用 CPMAS ^{13}C NMR 技术分析不同耕作措施下土壤有机碳化学结构认为,免耕提高烷基碳含量,深松增加烷氧基碳的含量,而翻耕则羰基碳含量较高;因此,保护性耕作土壤有机碳化学结构组成较翻耕复杂,土壤有机碳更加稳定。

2 保护性耕作对农田氮素利用效率的影响

关于保护性耕作对氮素利用率的研究主要集中在土壤氮素含量的变化, NH_3 挥发、 N_2O 排放与氮淋失等损失及其影响机制方面。

2.1 保护性耕作对土壤氮素含量的影响

一般实施保护性耕作能够提高表层土壤的全氮含量。许多研究表明,大多干旱半干旱区种植系统中,相对翻耕措施,免耕可以保持甚至提高土壤全氮含量^[36-37]。Sainju 认为^[38] 免耕通过降低氮素侵蚀等损失而增加全氮含量。目前,对于深层土壤全氮含量是否增加的看法并不一致。López-Fando 和 Pardo 研究认为^[39],免耕显著提高表层 0—5 cm 的全氮含量,但对 5—30 cm 土壤全氮含量影响较小。Varvel 等^[40] 则认为,相比较翻耕,免耕等保护性耕作措施提高 0—150 cm 土壤全氮含量。对于不同的结果可能与试验区域条件、作物种类与种植制度等因素有关,需要进一步探讨分析。另外,耕作试验年限亦对土壤全氮含量有一定影响。Dalal 等^[37,41] 比较 22 a 与 40a 的耕作试验认为,长期实施保护性耕作对 0—150 cm 土层全氮含量的影响较小,土壤全氮含量并不随着耕作年限的增加而持续增加。Lou 等^[42] 在我国东北地区进行不同年限的多点耕作试验认为,与翻耕相比,免耕秸秆还田措施均显著提高 0—5 cm 土层全氮含量,而对 5—100 cm 土层影响不大。罗珠珠等^[43] 在我国西北对不同轮作系统研究认为,免耕秸秆还田显著提高 0—10 cm 土层全氮含量,对 10—30 cm 土层全氮含量影响不大,并认为脲酶活性与全氮含量呈显著正相关。与国外相比,国内相关的试验设计考虑的因素相对较少,且年限较短,由于我国不同地区气候、土壤及种植制度等差异较大,关于保护性耕作对土壤全氮的影响机制需要进一步深入研究。

2.2 保护性耕作对农田氮素损失的影响

目前,关于保护性耕作对农田 NH_3 挥发、 N_2O 排放及氮淋失等损失的影响是此领域的研究热点,而氮素通过农田径流损失的研究很少。

很多研究表明保护性耕作能够增加农田 NH_3 挥发。Rochette 等^[44] 研究认为,免耕能够提高表层土壤脲酶活性,施入农田的

肥料更容易水解为铵态氮,同时,免耕土壤表面秸秆覆盖度增加而减少了肥料和土壤颗粒的接触,降低了土壤颗粒对铵态氮吸附;而土壤 pH 升高导致免耕措施 NH_3 挥发显著增加;此外,翻耕肥料易进入到土壤孔隙中,也导致土壤 NH_3 挥发降低。Mkhabela 等^[45]研究认为,相对免耕,翻耕措施能够将施入农田的肥料掺混到土壤而降低 NH_3 挥发。曹凑贵等^[46]研究认为,免耕可以显著增加稻田土壤 NH_3 挥发。众多结果表明,免耕增加了施入农田有机肥^[45]、尿素^[47]和复合肥^[48]等肥料的 NH_3 挥发损失;但不施肥情况下,免耕与翻耕土壤 NH_3 挥发差异不显著^[47,49]。Griggs 等^[50]进行水稻旱播与推迟灌溉试验认为,耕作措施对 NH_3 挥发没有影响,但砂壤土比粘土 NH_3 挥发更快。一般农田土壤 NH_3 挥发的高峰主要发生在施肥后的 1—3 d,但由于土壤类型、气候条件、种植模式及施肥位置等条件不同, NH_3 挥发日峰值与年挥发量在不同的试验中结果不一致。

一般认为保护性耕作能够增加农田土壤 N_2O 排放。保护性耕作通过提高土壤表面微生物活性而改变硝化和反硝化过程,从而影响土壤 N_2O 排放^[51]。Mutegi 等^[52]研究认为,在地表秸秆覆盖条件下,翻耕 N_2O 排放量较深松或旋耕显著提高,而地表无覆盖条件下不同耕作间 N_2O 排放量差别不大。免耕土壤容重和土壤含水量较高,较低的通气性产生厌氧环境导致土壤反硝化作用增强^[53-54]。Rochette^[55]按作物生长季土壤排水和降水将土壤划分为通气性良好、中等和不良 3 个等级分析加拿大 25 个试验点数据认为,相比较翻耕,免耕对通气性良好及中等的土壤 N_2O 排放影响不大;但在通气不良的土壤上免耕能够增加土壤 N_2O 排放,这可能与通气不良的免耕土壤充水孔隙度更容易达到反硝化作用的临界值有关,同时,土壤质地与气候条件也可能与免耕土壤 N_2O 排放有关^[55-57]。Sheehy 等^[57]认为土壤质地对 N_2O 排放有一定影响,在粘质土壤免耕 N_2O 的累计排放量高于翻耕,而在粗质土壤则相反。Elder 和 Lal 则认为^[58],与翻耕相比,免耕土壤容重较大、充气孔隙度/总孔隙度之比较小,导致土壤通气性差,限制土壤 N_2O 向大气排放,导致免耕土壤较低的 N_2O 排放;同时,翻耕后土壤有机物质的暴露有利于有机氮的矿化分解,产生较多的硝态氮有利于反硝化作用而释放更多的 N_2O ^[58-59],这可能与耕作年限较短有关。Gregorich 等^[60]研究认为,免耕土壤连续 3a 的总 N_2O 排放量较翻耕降低,但由于年际间施肥时间、施肥位置及气候条件等因素不同,年际间不同耕作措施土壤 N_2O 排放情况不同。Choudhary 等^[61]研究认为,免耕与翻耕土壤 N_2O 排放差异不大,这可能由于土壤差异性和测量方法有关。Zhang 等^[48]研究认为,不施肥条件下免耕与翻耕稻田 N_2O 排放量差别不大,而施用复合肥条件下免耕较翻耕 N_2O 排放量显著增加,这可能与免耕+复合肥措施下土壤较大的团聚体和较高的反硝化率有关。相比较国外,国内的相关农田土壤 N_2O 排放的研究较少且对于影响因素及其机制不够深入。

保护性耕作能够降低渗漏水中的硝态氮含量,但增加渗水量而导致硝态氮淋失量增加。大量研究表明^[62-63],相比翻耕,免耕土壤反硝化率更大而消耗较多的硝态氮,导致土壤渗漏水中硝态氮含量降低。Zhang 等^[48]则认为,由于免耕土壤更高的 N_2O 排放与 NH_3 挥发,而导致其渗漏水中硝态氮和铵态氮含量高于翻耕土壤。一般施行免耕容易使土壤形成连续的大孔隙而造成渗水量显著增加^[64-65],而 Mkhabela 等^[45]认为耕作对渗漏水的影响不显著,这可能与不同的作物种类、耕作年限、土壤类型与种植制度等有关。大多学者认为,免耕土壤渗水量高是导致渗漏水中氮淋失量增加的主要原因^[66],但部分学者认为,翻耕能够增加土壤氮素矿化,同时,免耕土壤的厌氧环境促进反硝化作用,导致翻耕土壤更高的淋失量^[63,66]。时秀焕等^[67]在我国东北黑土区进行玉米→大豆轮作研究认为,试验期间耕作对玉米小区土壤硝态氮淋失影响不大,而与翻耕相比,免耕实施 4 年后对大豆小区土壤硝态氮淋失的影响开始显现,这主要是根系生长造成土壤孔隙大小的差异而导致硝态氮淋失发生变化。崔思远等^[68]在湖南双季稻区研究表明,由于免耕秸秆还田明显提高土壤饱和导水率,导致硝态氮和铵态氮的淋失量增加,且铵态氮渗漏量高于硝态氮。由于在大多文献试验中,农田水分渗漏量主要通过渗漏仪测定或水平衡法等估算得出,利用水平衡法估算受很多农田试验不可预测的因素影响(如风对蒸散的影响),导致估算的渗漏水淋失量与仪器测量结果不一致。

3 保护性耕作对农田系统碳、氮素关系的影响

人类活动强烈干扰地球碳循环和氮循环而加剧温室效应,而温室效应间接影响植株初级生产力、生物固氮、土壤硝化反硝化作用及 C/N 变化等生物化学循环过程,但影响机制却还不十分清楚^[69]。保护性耕作增加表层土壤有机碳和全氮含量,在土壤剖面出现层化现象^[70-71],了解土壤 C/N 层化现象对理解土壤碳氮关系有着重要意义。

土壤层化率通常被用来作为评价土壤质量或土壤生态功能的一个指标^[70],特别是有由于耕作所造成的土壤理化性状的变化,如土壤有机碳^[11]、孔隙度^[72]和团聚体稳定性^[73]等,通过分析保护性耕作对各土壤性质层化率的影响,能够有助于理解保护性耕作对生态效应的影响。一般认为翻耕扰动土壤而使养分在耕层分布均匀^[74],而免耕秸秆残留在土壤表面而使养分在表层富集。Franzluebbers 认为^[70],退化的土壤有机质层化比率很少大于 2,高层化率表示土壤质量较好,通常免耕土壤有机碳和全氮的层化率大于 2,而翻耕土壤则小于 2。有研究表明,短期耕作(< 9a)对土壤氮库的层化率没有显著影响,而此后随着年限的增加,免耕土壤氮库层化率显著高于翻耕,且免耕 19a 后其比率大于 2^[41]。Corral-Fernández 等^[71]对 85 个土壤剖面分析得出,长期少免耕能够提高土壤有机碳、全氮及 C/N 的层化率,其认为由于作物秸秆残茬比根系更有利于增加土壤 C/N 率^[75];免耕措施秸秆主要覆盖在土壤表面,因此,随着土壤深度的增加土壤 C/N 呈降低趋势。Lou 等^[42]认为免耕表层土壤有机碳腐解力较翻耕有所降低,而相对提高土壤有机碳、全氮及 C/N 层化率。孙国峰等^[76]研究南方双季稻田认为,长期免耕后,实施翻耕、旋耕降低表层(0—5 cm)土壤有机碳含量,提高了 5—20 cm 层次土壤有机碳含量,进而降低耕层土壤有机碳层化率。相比

较国外,国内关于土壤有机碳、全氮及 C/N 的层化率的研究较少,由于土壤 C/N 受多种因素的影响(如气候、土壤条件、植被种类、农田管理措施等),分析不同环境条件下保护性耕作土壤 C/N 层化率对于正确评价土壤质量有重要作用。

4 中国保护性耕作对农田碳、氮素肥力影响研究展望

多年来有关土壤碳、氮素肥力的研究一直是国内外学者探讨的热点。保护性耕作作为生态友好型技术,对于农田土壤碳、氮素肥力的维持和改善起着重要的作用。目前,我国保护性耕作对土壤碳素与氮素肥力效应的研究与国外依然有一定的差距。综合分析认为,未来我国在相关领域的研究应重点集中在以下几个方面:

(1)加强保护性耕作对农田土壤碳、氮素肥力影响及其机制的研究。由于我国幅员辽阔,气候条件复杂与种植制度多样化等因素不同,导致不同区域农田土壤碳、氮素含量变化及其转化损失的主导影响因素有所差异。加强不同区域相关的研究,了解各区域农田土壤肥力保持与损失机制,对于正确评价保护性耕作对我国农田碳、氮素相关肥力的影响有重要的意义。同时,随着我国栽培技术水平的提高和区域农业结构的调整,应考虑在不同层次生产力水平上的研究,以适应未来农业的发展。由于实施保护性耕作年限的长短对土壤性质的影响程度不同,短期与长期定位试验相结合进行对比研究,对于揭示保护性耕作对土壤肥力的影响有重要的意义。

(2)结合土壤肥力以及碳素和氮素在作物体内和大气中转移变化及其相互影响机理,系统研究保护性耕作对土壤肥力的影响及利用效率。目前,保护性耕作对土壤肥力的研究主要集中在土壤碳、氮含量的变化与损失方面,而关于地上部分作物对养分吸收及其利用效率的研究较少。结合作物种类、土壤类型、气候条件和种植制度等因素,综合考虑多元条件分析“土壤-植物-大气”系统保护性耕作对碳、氮素肥力变化的影响机理,才能正确理解保护性耕作对作物碳、氮素等养分利用机制。同时,土壤碳素和氮素在土壤中主要是以腐殖质的形式存在,耕作能够影响土壤理化特性,影响土壤碳、氮素的矿化分解、转化引起土壤肥力发生变化,但保护性耕作对农田系统碳素和氮素的相互关系尚不明确。关于保护性耕作对农田碳、氮素相互关系的研究主要集中于土壤 C/N 及其层化率分布,探索新的评价指标及研究方法,对分析农田土壤肥力变化有着重要作用。

(3)综合环境效应进行保护性耕作对农田碳素和氮素影响的综合研究。目前大多研究只注重农田的排放部分,很少考虑各项农资投入消耗能源产生的碳、氮排放;同时,由于过量施肥造成大量的氮素通过挥发、硝化反硝化过程等损失,并造成了地下水体污染、富营养化、臭氧层破坏等严重的环境问题,耕作能够改变土壤理化特性而影响各环节的损失量。因此,在加强保护性耕作对农田土壤肥力研究的同时,结合其生态效应进行综合分析对于系统评价农业可持续发展有着更加重要的意义。

(4)加强关于保护性耕作对农田碳素和氮素效应的宏观研究。目前,大多关于耕作对农田碳、氮效应影响的研究多从微观农田尺度比较分析,进行全国或区域尺度的研究对于准确评估实施保护性耕作对农田碳、氮素综合效应及环境保护政策的制定与发展有重要意义。由于缺乏全国或区域尺度的土壤参数数据及适当的模拟模型或评估方法,对我国农田碳、氮效应宏观尺度的研究主要利用已有文献中的数据来进行分析。利用模型进行区域模拟与评估发展相对滞后,相关的模型及模拟的指标较少,且模型需要的参数不易获得,其结果缺乏一定的综合性、系统性及可靠性,因此探索适合我国种植制度的模型参数,对于正确评价保护性耕作对土壤碳、氮效应具有重要的意义。

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《生态学报》为半月刊,大 16 开本,300 页,国内定价 90 元/册,全年定价 2160 元。

国内邮发代号:82-7,国外邮发代号:M670

标准刊号:ISSN 1000-0933 CN 11-2031/Q

全国各地邮局均可订阅,也可直接与编辑部联系购买。欢迎广大科技工作者、科研单位、高等院校、图书馆等订阅。

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本期责任副主编 陈利顶

编辑部主任 孔红梅

执行编辑 刘天星 段 靖

生 态 学 报

(SHENGTAI XUEBAO)

(半月刊 1981 年 3 月创刊)

第 33 卷 第 19 期 (2013 年 10 月)

ACTA ECOLOGICA SINICA

(Semimonthly, Started in 1981)

Vol. 33 No. 19 (October, 2013)

编 辑	《生态学报》编辑部 地址:北京海淀区双清路 18 号 邮政编码:100085 电话:(010)62941099 www.ecologica.cn shengtaixuebao@rcees.ac.cn	Edited by	Editorial board of ACTA ECOLOGICA SINICA Add: 18, Shuangqing Street, Haidian, Beijing 100085, China Tel: (010)62941099 www.ecologica.cn shengtaixuebao@rcees.ac.cn
主 编	王如松	Editor-in-chief	WANG Rusong
主 管	中国科学技术协会	Supervised by	China Association for Science and Technology
主 办	中国生态学学会 中国科学院生态环境研究中心 地址:北京海淀区双清路 18 号 邮政编码:100085	Sponsored by	Ecological Society of China Research Center for Eco-environmental Sciences, CAS Add: 18, Shuangqing Street, Haidian, Beijing 100085, China
出 版	科 学 出 版 社 地址:北京东黄城根北街 16 号 邮政编码:100717	Published by	Science Press Add: 16 Donghuangchenggen North Street, Beijing 100717, China
印 刷	北京北林印刷厂	Printed by	Beijing Bei Lin Printing House, Beijing 100083, China
发 行	科 学 出 版 社 地址:东黄城根北街 16 号 邮政编码:100717 电话:(010)64034563 E-mail: journal@cspg.net	Distributed by	Science Press Add: 16 Donghuangchenggen North Street, Beijing 100717, China Tel: (010)64034563 E-mail: journal@cspg.net
订 购	全国各地邮局	Domestic	All Local Post Offices in China
国外发行	中国国际图书贸易总公司 地址:北京 399 信箱 邮政编码:100044	Foreign	China International Book Trading Corporation Add: P.O.Box 399 Beijing 100044, China
广告经营 许 可 证	京海工商广字第 8013 号		



ISSN 1000-0933
CN 11-2031/Q

国内外公开发行

国内邮发代号 82-7

国外发行代号 M670

定价 90.00 元