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•综述•

有机种植对农田节肢动物多样性影响的整合分析

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摘要: 有机农业是生态环境友好的生产方式, 对农业生物多样性保护具有重要意义。个体研究的差异不利于有机农业的生态环境效益评估。本研究利用文献整合分析, 以对农田生态环境具有良好指示作用的节肢动物为研究对象, 探讨了有机种植对农田生物多样性的保护效果及影响因素。结果表明, 相比常规种植, 有机种植可使节肢动物的丰富度、多度及均匀度显著提升34.95%、64.95%及12.09%; 天敌和害虫的物种丰富度分别显著提升了22.50%和31.03%; 同时天敌的个体数量比常规显著增加了71.80%, 害虫减少了10.46%。经过3年及以上的有机种植后, 节肢动物的丰富度和多度均显著高于常规种植。常规种植化学农药施用频率可显著影响节肢动物丰富度和均匀度指数, 施药次数每增加1次, 节肢动物丰富度相比有机种植显著降低13.54%, 均匀度显著降低2.64%。有机水田对节肢动物多度的提升效果显著优于有机旱地, 为后者的4.7倍; 但二者的丰富度和均匀度没有显著差异。蔬菜和茶叶种植体系对节肢动物多样性指数的综合提升效果优于其他作物类型, 丰富度、多度和均匀度指数分别显著提升了81.46%、74.14%、18.55%和48.86%、49.06%、30.88%。鼓励常规种植减少农药施用频次, 加大有机和生态化管理措施的应用程度, 是保护农业生物多样性、实现农业绿色高质量发展的有效途径。

关键词: 农业生物多样性; 有机种植; 常规种植; 节肢动物; 整合分析

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Effects of organic planting on arthropod diversity in farmland: A meta-analysis

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ABSTRACT

Aims: Organic planting is widely considered an environment-friendly agricultural management pattern that plays a crucial role in the protection of agricultural biodiversity. The change of arthropod biodiversity is proposed as a key ecological indicator for agricultural sustainability. However, the effects of organic planting on arthropod biodiversity remain inconsistent in published studies, which may have resulted from the durations of organic planting, land use and cropping systems across the individual studies. The diverse results from previous studies could weaken the practicability of their conclusions in policymaking, which highlighted the necessity of conducting a meta-analysis to provide a generalized understanding of the effects of organic planting on arthropod diversity. This study aims to quantify the impact of organic planting on arthropod biodiversity using meta-analysis and provide scientific support for the formulation of ecological compensation policy under organic planting.

Methods: This meta-analysis conducted a literature review of peer-reviewed papers published before the end of 2020 which compared the impacts of organic and conventional planting on arthropod biodiversity. The results from 75 experimental sites, which contained 227 paired valid datasets, were selected for our analysis. To distinguish between the sources of variation for the responses of biodiversity to organic planting, the paired measurements were further subdivided into subgroups according to the factors of duration, land use, crop variety, pesticide application frequency in conventional planting, and arthropod functional groups.

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Results: The results showed that compared with conventional planting, organic planting significantly improved the richness, abundance, and evenness of arthropods by the rate of 34.95%, 64.95%, and 12.09%, respectively. The abundance of the natural enemies of arthropods increased by 71.80% ($P < 0.05$) while the abundance of pests decreased by 10.46% under organic planting. The richness of the natural enemies and pests under organic planting were both increased by 22.50% and 31.03% respectively, relative to conventional planting ($P < 0.05$). The application of pesticides significantly decreased the arthropod biodiversity in conventional planting. Compared with the organic planting, an increase in the time of pesticide application in the conventional planting lead to decreases in the arthropod richness and evenness of arthropods by 13.54% and 2.64%, respectively. The responses of arthropod richness and abundance to organic planting were significantly positive when the duration was equal to or exceeded three years. The positive effect of organic planting on arthropod abundance in paddy fields was 4.7 times higher than that in dryland ($P < 0.05$), but the responses of richness and evenness to organic planting were comparable between paddy and dryland ($P > 0.05$). The responses of arthropod richness, abundance, and evenness to organic planting under the vegetable system were 81.46%, 74.14%, and 18.55%, respectively ($P < 0.05$); and under the tea-planting system were 48.86%, 49.06%, 30.88% ($P < 0.05$), respectively. The benefits of organic planting on arthropod biodiversity under the cropping systems of vegetable and tea were demonstrated to be more significant than that under other cropping systems.

Conclusions: Our meta-analysis suggests that organic planting plays an important role in protecting and improving biodiversity in croplands by increasing the abundance of natural enemies and decreasing pests abundance. The frequency of pesticide application was observed to be the key factor which significantly regulates the change of arthropod biodiversity. To promote the positive effects of organic planting on the protection of biodiversity in cropland, policymakers should not only to encourage the implementation of organic planting in regions where necessary conditions are satisfied, but also facilitate the ecological innovation of conventional planting by introducing the principles, concepts, and technologies of organic planting into conventional planting. This will be of more practical significance to agricultural biodiversity conservation in China.

Key words: agricultural biodiversity; organic planting; conventional planting; arthropod; meta-analysis

农业生物多样性是生物多样性的重要组成部分，在保障粮食安全、耕地生态健康和应对气候变化等方面发挥着重要作用(陈海坚等, 2005; 初炳瑶等, 2020)。然而，集约化的农业管理中对化学农药的大量应用导致的农业生态环境简单化，已成为农业生物多样性降低的主要原因之一，严重制约了农业的可持续健康发展(Birkhofer et al, 2014; 潘扬等, 2020; 高磊等, 2021)。有机种植被认为是生态环境友好的种植方式，已在全球范围内大规模推广，截至2019年底全球有机农地种植面积达7,230万ha (国家市场监督管理总局和中国农业大学, 2019)。与常规种植相比，有机种植在生产过程中禁止使用化学合成的农药、化肥、生长调节剂、饲料添加剂等物质，采用农作物间作、轮作等农田管理措施以及生物或物理方式防治病虫害，有利于农田生态系统的平衡与修复、降低害虫发生频次，对保护农业生物多样性具有重要作用(周子杨, 2011[①]; 邢树文等, 2017)。

节肢动物在农田生态系统的传粉、微生物种群调节、有机物分解和生物营养循环中起着重要作用，影响着农田生物群落结构演替，是农田生态系统的重要组成部分(Doles et al, 2001)。因其世代周期短、直接或间接以植物为食、种群数量巨大等特点，节肢动物对栖息地生态环境变化具有良好的指示作用，可用作生态系统生物多样性的指示物，并有学者建议将其用于生物多样性保护(李巧等, 2006)。近年来有机农业对生物多样性的影响受到国内外学者的关注，其中对节肢动物多样性的研究开展相对较早(潘扬等, 2020)。但由于不同研究之间受有机种植年限、种植作物类型以及农田管理措施等客观条件影响，结论存在一定差异性。如Morente等(2018)对不同种植方式下节肢动物的多样性进行研究发现，相比常规种植，有机种植方式下节肢动物的物种丰富度较高，但均匀度较低。而张蓉等(2010)对有机与常规枸杞园中节肢动物群落进行系统调查，结果表明，有机种植园中节肢动物的丰富度、多度以及均匀度均高于常规种植园。不同研究结果的差异不利于政府对有机农业生态环境价值的评估。

文献整合分析是将同一主题下的多个独立实验(研究)进行综合的统计分析方法，通过增加样本

① 周子杨 (2011) 不同类型稻田非作物生境的节肢动物多样性. 硕士学位论文, 南京农业大学, 南京.

量以达到提高统计学检验功效的目的(彭少麟和郑凤英, 1999; 雷相东等, 2006)。本研究采用此方法定量分析有机种植对农田节肢动物多样性的影响, 并从有机种植年限、耕地利用方式、作物种类、常规种植田农药施用次数以及天敌和害虫功能类群的角度分析其影响因素差异, 以期在更大的时空尺度上定量、系统地回答有机种植如何影响节肢动物多样性, 为有机农业生态环境效益评估提供数据支撑。

1 材料与方法

1.1 数据来源

本研究的数据资料来自中国知网和Web of Science数据库所收录的有机种植对节肢动物多样性影响的相关文献, 文献出版时间为1980–2020年。检索关键词为有机农业、有机种植、节肢动物、物种多样性、生物多样性、organic agriculture、organic planting、organic farming、arthropod、biological diversity。根据研究目的, 检出的文献需符合以下筛选标准: (1)研究基于田间试验, 且试验同时设置了有机种植处理和常规种植处理; (2)有机和常规种植处理除农事操作不同外, 作物类型和试验区域应一致; (3)试验年数应在3年以上(含3年); (4)节肢动物多样性数据应可以从文献文字、图表中提取, 或者可以通过计算获得; (5)若同一点位的试验结果发表了多篇文章, 则不重复纳入文献样本。最终, 筛选出符合以上条件的有效文献54篇(附录1), 其中中文文献27篇, 英文文献27篇; 提取有效数据227组, 共计75个点位试验, 所涉研究区域如表1所示。

本研究从耕地类型、有机种植年限、常规种植每年杀虫剂的施用次数、种植作物类型以及节肢动物功能类群, 将试验样本按照不同水平分组(表2), 以期明确有机和常规种植对节肢动物多样性的影响机制。其中, 常规种植年施药次数指有机种植的对照处理(常规种植)中每年化学杀虫剂的施用次数; 害虫主要为植食性节肢动物, 天敌包括捕食性和寄生性节肢动物。

1.2 数据处理与分析

采用Margalef丰富度指数(richness, R)、多度(abundance, A)以及Pielou均匀度指数(evenness, E)作为节肢动物的多样性测度指数(钱迎倩和马克平, 1994)。其中, 多度(A)用于反映节肢动物群落全部物种的总个体数(Lichtenberg et al, 2017)。若文献图表或文字描述中已给出相应指数数值则直接采用, 若未直接给出但可通过文献结果计算得出, 则通过计算获取相应指数。Margalef丰富度指数(R)用以反映节肢动物群落的丰富度, 计算公式如下:

表1 整合分析纳入的文献所涉及的研究区域分布
Table 1 The distribution of research area contained in the meta analysis

样点分布区域(国内) Distribution of research area in China	试验点位数量 No. of experimental sites	样点分布区域(国外) Distribution of research area outside China	试验点位数量 No. of experimental sites
新疆 Xinjiang	1	克罗地亚 Croatia	1
宁夏 Ningxia	2	巴西 Brazil	3
四川 Sichuan	1	德国 Germany	2
贵州 Guizhou	1	法国 France	1
广西 Guangxi	2	美国 The United States	14
广东 Guangdong	5	葡萄牙 Portugal	2
湖南 Hunan	4	瑞士 Switzerland	5
江西 Jiangxi	2	西班牙 Spain	3
福建 Fujian	2	希腊 Greece	4
安徽 Anhui	2	意大利 Italy	1
上海 Shanghai	2	英国 The United Kingdom	5
江苏 Jiangsu	6		
山东 Shandong	2		
河北 Hebei	1		
北京 Beijing	1		

表2　影响因素的不同分组水平
Table 2　Classification of categorical variables as explanatory factors

亚组类别 Categorical variable	亚组水平 Categorical level
有机种植年限 Years of organic planting (years)	3–10、11–15、> 15
耕地类型 Land use	旱地、水田 Dryland, paddy
作物类型 Crop variety	粮食、茶叶、蔬菜、水果、药材、油料作物 Grain, tea, vegetable, fruit, crude drug, oil crop
常规种植年施药次数 Pesticide application frequency in conventional planting (times/year)	1–5、6–10、11–15、> 15
功能类群 Arthropod communities	天敌、害虫 Natural enemy, pest

$$R = (S-1)/\ln A \quad (1)$$

式中, S为群落内的物种数。

Pielou均匀度指数(E)用以反映节肢动物群落中不同物种的多度分布的均匀程度:

$$E = H'/\ln S \quad (2)$$

式中, H'为Shannon-Wiener多样性指数, 计算公式如下:

$$H' = -\sum\left(P_i \times \ln P_i\right) \quad (i = 1, 2, 3, \cdots, S) \quad (3)$$

其中, P_i是群落中第i个物种的个体数(N_i)与所有物种个体总数(N)的比值。

采用效应值反映实验组相比对照组的变化水平, 即有机种植相比常规, 其节肢动物多样性指数的变化水平。本研究采用反应比(lnR)来计算效应值(Rosenberg et al, 2000), 公式如下:

$$\ln R = \ln\left(X_e / X_c\right) = \ln X_e - \ln X_c \quad (4)$$

式中, X_e和X_c分别为一个独立研究中实验组和对照组的平均值。在本研究中, X_e为所获取的一项独立研究中有机种植处理的Margalef丰富度指数、多度或Pielou均匀度指数; X_c为常规种植处理的Margalef丰富度指数、多度或Pielou均匀度指数。为了更方便地从生物学角度理解和描述结果, 将反应比通过公式(5)转换为变化百分率:

$$V = \left(\exp\left(\ln R\right) - 1\right) \times 100\% \quad (5)$$

本研究采用随机效应模型, 利用MetaWin2.1软件对数据进行整合分析。因并非所有文献都报道了标准差, 为尽可能多地纳入研究样本, 本研究采用无权重分析法(Hedges et al, 1999; Chivenge et al, 2011)。运用靴襻法(bootstrapping)重复取样999次来计算效应值(lnR)及其95%置信区间(Rosenberg et al, 2000; 郑凤英等, 2004)。若计算所得效应值均值为正值则表明有机种植相比常规种植可提高节肢动物多样性, 若为负值则有机种植相比常规种植降低了节肢动物的多样性。若效应值的95%置信区间不包含0, 则此效应显著; 若包含0则效应不显著。如果两项效应值的95%置信区间没有重叠, 则可认为这两个因素之间存在显著差异(P < 0.05) (Chivenge et al, 2011)。在亚组分析中, 当组间异质性(Q_b)的P值小于0.05时, 效应值在各因素水平之间存在显著差异。

本研究采用SPSS 20.0对节肢动物多样性的变化量与常规种植年施药次数进行回归分析, 使用GetData软件提取文献图中的数据, 采用Origin 2019软件作图。

2　结果

2.1　有机种植对节肢动物生物多样性指数的影响

本研究从筛选后的54篇文献中提取了82组有机种植与常规种植节肢动物丰富度数据, 90组多度数据以及52组均匀度数据(图1)。与常规种植相比,

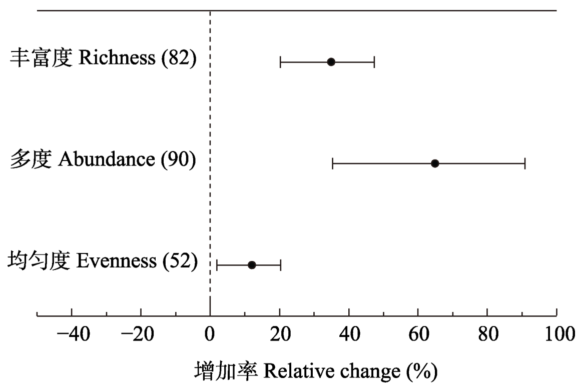


图1　有机种植相比常规种植节肢动物多样性指数的增加率。图中圆点为效应值, 即有机种植相比常规种植其节肢动物多样性指数的变化量, 误差线为效应值的95%置信区间, 括号内的数值为该效应值的样本量。若效应值的95%置信区间未跨越零轴, 则表示该效应与对照相比差异显著。
Fig. 1　The relative change of arthropod biodiversity under organic planting compared with conventional planting. The dots in the figure are the mean effect sizes, which represent the relative change of arthropod diversity under organic planting compared with conventional planting. The error lines indicate the 95% confidence interval (95% CIs) of the mean effect sizes, and the value in brackets is the sample size. Mean effect sizes were considered to be significantly different from the control if their 95% CIs did not cross the zero axis.

有机种植方式下农田节肢动物的丰富度、多度及均匀度指数均有显著提升($P < 0.05$), 分别为34.95%、64.95%及12.09%。

2.2　不同影响因素下节肢动物丰富度指数对有机种植的响应

由图2A可知, 3年以上的有机种植均可显著提升节肢动物的丰富度; 随有机种植年限的增加, 节肢动物丰富度效应值呈现降低的趋势。当种植年限为3–10年时, 有机种植节肢动物丰富度比常规种植高37.54%; 种植年限为11–15年时, 有机比常规高28.15%; 大于15年时为16.07%, 有机对节肢动物丰富度的提升水平不足3–10年的1/2; 但不同时期的效应值差异不显著($P > 0.05$)。在水田或者旱地上进行有机种植, 节肢动物丰富度指数均得到了显著提升, 但耕地类型对提升程度的影响无显著差异($P > 0.05$)。种植不同作物类型时节肢动物丰富度对有机种植的响应水平为蔬菜 > 茶叶 > 粮食 > 水果 > 油料作物 > 药材。其中, 蔬菜(81.46%)显著高于油料作物(14.66%)和药材(4.91%) ($P < 0.05$); 作物类型为茶叶时, 其效应值(48.86%)是粮食(25.56%)和水果作物(19.54%)的1.9和2.5倍, 但差异不显著($P > 0.05$)。

有机种植相比常规种植对节肢动物丰富度指数的提升效果与常规种植农药的施用次数密切相关。当常规种植年施药次数在1–5次时, 有机种植可使节肢动物丰富度提升14.50%; 施药次数为6–10次、11–15次时, 效应值分别为33.65%和35.80%; 常规种植年施药次数 > 15次时, 有机种植对丰富度的提升作用可达220.63%, 分别是年施药1–5次和6–10次分组的15.2倍和6.5倍(图2A, $P < 0.05$)。回归分析结果表明, 常规种植年施药次数能解释63%的节肢动物丰富度效应值的变异水平; 常规种植年施药次数每增加1次, 其节肢动物丰富度指数相比有机种植降低13.54% (图3, $R^2 = 0.63$, $P < 0.01$)。

2.3　不同影响因素下节肢动物多度指数对有机种植的响应

相比常规种植, 3年以上的有机种植均可显著提升节肢动物的多度; 种植年限为11–15年时, 节肢动物多度指数效应值(87.79%)高于3–10年(50.31%)和> 15年(61.67%), 但不同年限之间差异不显著($P > 0.05$)。在水田上进行有机种植, 节肢动物多度指数的提高幅度(194.08%)显著高于旱地(41.30%, $P < 0.05$), 约为旱地的4.7倍。种植不同作物类型时节肢动物多度对有机种植的响应水平为粮食(86.37%) > 蔬菜(74.14%) > 茶叶(49.06%) > 油料作物(37.82%) > 水果(22.38%), 但水果及油料作物对节肢动物多度指数的提升效果不显著($P > 0.05$)。当常规种植年施药次数< 15次时, 相应有机种植田的节肢动物多度指数比常规种植显著提高36.08%–92.50%; 值得注意的是, 当常规种植年施药次数大于15次时, 有机种植方式对节肢动物多度的提升作用并不显著($P > 0.05$) (图2B)。

2.4　不同影响因素下节肢动物均匀度指数对有机种植的响应

年限小于15年时有机种植对节肢动物均匀度的提升作用并不显著($P > 0.05$), 大于15年时可使均匀度指数显著提高22.01%。在水田上进行有机种植, 节肢动物均匀度的效应值有高于旱地的趋势, 但差异不显著。种植不同作物类型时节肢动物均匀度对有机种植的响应水平为茶叶(30.88%) > 蔬菜(18.55%) > 水果(13.92%) > 药材(12.15%) > 粮食(4.09%) > 油料作物(–3.89%), 但水果、粮食和油料作物对有机种植的响应不显著($P > 0.05$)。当常规种植年施药次数小于11次时, 有机种植对节肢动物均匀度无显著影响; 大于11次时, 则节肢动物均匀度指数显著提高24.48%–37.07% ($P < 0.05$) (图2C)。由回归分析可知, 常规种植年施药次数能解释33%的节肢动物均匀度效应值的变异水平; 常规种植年施药次数每增加1次, 其节肢动物的均匀度相比有机种植模式会降低2.64% (图4, $R^2 = 0.33$, $P < 0.01$)。

2.5　不同功能类群节肢动物多样性指数对有机种植的响应

根据文献描述和物种取食习性将获取的节肢动物样本划分为天敌类群和害虫类群, 分析其丰富度和多度指数对有机种植的响应, 结果表明(表3), 有机种植相比常规种植, 天敌和害虫的丰富度指数分别提升了22.50%和31.03%, 害虫丰富度提升程度虽高于天敌, 但二者差异不显著($P = 0.45$)。有机种植相比常规种植, 天敌的多度指数显著提升了71.80%, 害虫则降低了10.46%, 且二者差异显著($P = 0.001$)。因此, 相比常规种植, 采用有机种植的管理方式可显著提升节肢动物种群的多样性和天敌

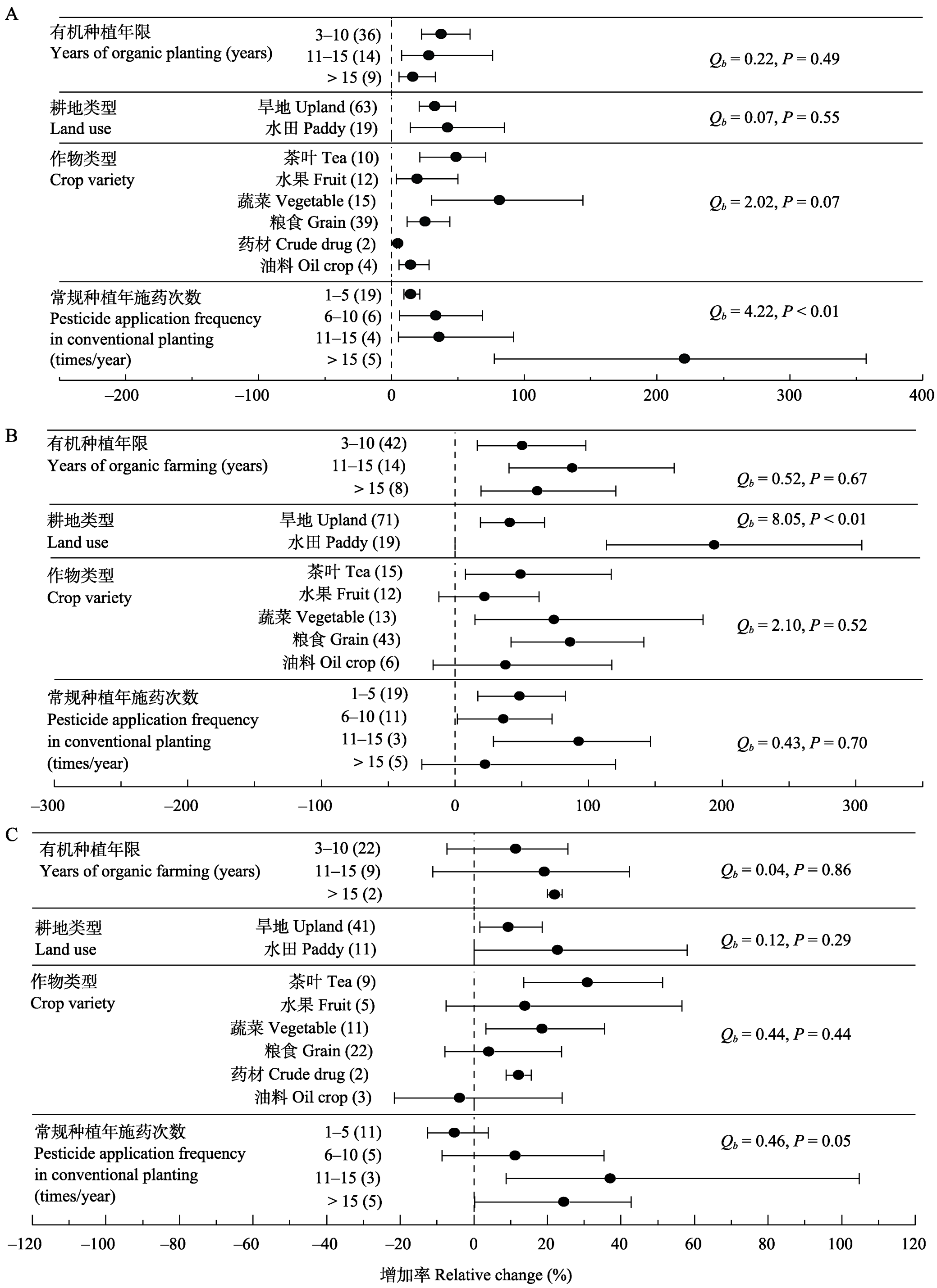
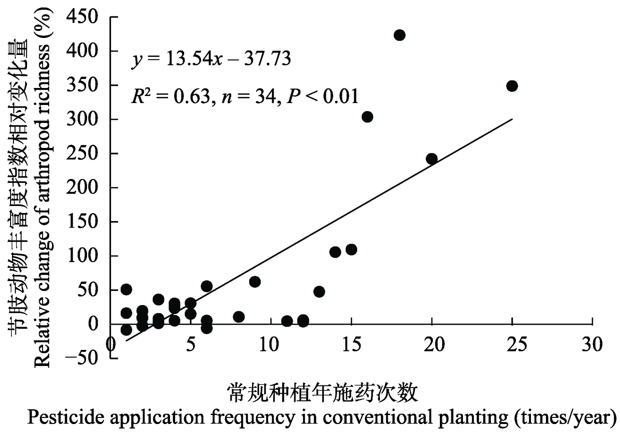


图2 有机种植相比常规种植对节肢动物丰富度(A)、多度(B)、均匀度(C)指数的增加率。图中圆点为效应值，即有机种植相比常规种植节肢动物多样性指数的相对变化百分率，误差线为效应值的95%置信区间，括号内的数值为该效应值的样本量。若效应值的95%置信区间未跨越零轴，则表示该效应与对照相比差异显著；若亚组内不同水平的效应值95%置信区间未重叠，则说明分类水平的差异显著。Q_b (组间异质性)和P值用来描述不同水平分类因素多样性指数效应值的统计学差异。

Fig. 2 The relative change of arthropod richness (A), abundance (B), and evenness (C) under organic planting compared with conventional planting. The dots in the figure are the mean effect sizes, which represent the relative change of different diversity index (%) under organic planting compared with conventional planting. The error lines indicate the 95% confidence interval (95% CIs) of the mean effect sizes, and the value in brackets is the sample size. Mean effect sizes were considered to be significantly different from the control if their 95% CIs did not cross the zero axis, and were considered to be significantly different if their 95% CIs did not overlap. Between-group heterogeneity (Q_b) and the probability (P) were used to describe statistical differences in the diversity index responses between different levels of the categorized factors.



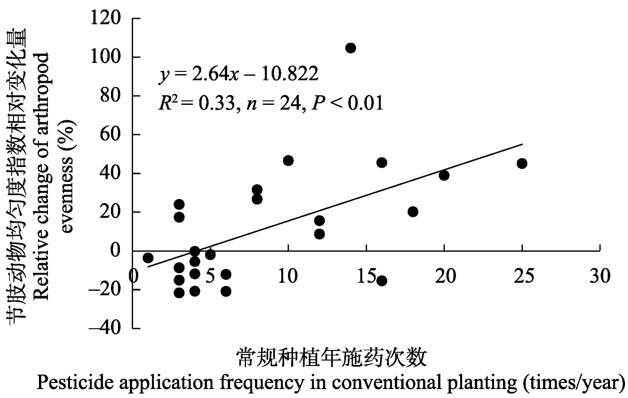


图3　有机种植相比常规种植节肢动物丰富度指数相对变化量与常规种植年施药次数的回归分析
Fig. 3　The relationship between the relative changes of arthropod richness under organic planting compared with conventional planting and the pesticide application frequency in conventional planting

图4　有机种植相比常规种植节肢动物均匀度指数相对变化量与常规种植年施药次数的回归分析
Fig. 4　The relationship between the relative changes of arthropod evenness under organic planting compared with conventional planting and the pesticide application frequency in conventional planting

表3　节肢动物害虫和天敌功能群多样性指数对有机种植的响应
Table 3　Responses of arthropod pest and natural enemy subcommunities diversity to organic planting over conventional planting

多样性指数 Diversity index	功能类群 Arthropod communities	总效应值 Total effect size (%)	95%置信区间 95% confidence interval (%)	样本量 Sample size (n)	组间异质性 Between-group heterogeneity (Q_b)	显著性差异 Probability (P)
丰富度 Richness	天敌 Natural enemy	22.50	13.76–33.62	40	0.81	0.45
	害虫 Pest	31.03	9.22–53.18	18		
多度 Abundance	天敌 Natural enemy	71.80	45.25–105.15	49	5.82	0.001
	害虫 Pest	–10.46	–38.62–28.19	19		

的数量，同时抑制害虫种群数量，降低了害虫种群数量暴发的几率。由于提取的样本中仅有5组为天敌均匀度数据，且未收集到害虫均匀度数据，因此没有对天敌和害虫的均匀度指数对有机种植的响应情况进行分析。

3　讨论

本研究表明，相比常规种植，有机种植能维持较高的节肢动物丰富度、多度及均匀度，有利于节肢动物群落稳定性的提高和多样性的保护，这与Lichtenberg等(2017)的研究结论一致。有机种植过程中禁止使用化学农药，对农田生态系统的恢复能力与保护作用均显著高于常规农业。常规集约化农业中对化学农药(杀虫剂)的不合理施用会显著降低节肢动物的物种丰富度，甚至导致部分物种灭绝(侯有明等，2001)。孔建等(2001)研究发现，果园常用化学杀虫剂对节肢动物中瓢虫、中华草蛉(*Chrysopa sinica*)等天敌幼虫的作用是毁灭性的，会造成70%–90%的虫卵无法孵化。常规农业的施药次数频繁，加重了对农田生态系统的人为干扰，导致节肢动物群落结构不稳定及个体数量下降。张清泉等(2014)研究表明，外界干涉越频繁，对农田节肢动物的分布及多样性越不利，致使节肢动物结构趋于单一化。本研究结果显示，只要施用化学农药，常规种植下节肢动物的丰富度指数就会显著降低；施药次数每增加1次，常规种植节肢动物丰富度相比有机种植减少13.54%，均匀度降低2.64%。施药次数若大于11次/年，常规种植的节肢动物均匀度相比有机种植会显著降低；若超过15次/年，常规种植下节肢动物丰富度指数相比有机种植急剧降低，降低程度分别是年施药水平1–5次和6–15次的15倍和6倍。值得注意的是，对照处理农药施用> 15次/年时，有机种植对节肢动物多度指数的提升作用不再显著，可能是由于常规田块耐药性强的害虫种群暴发，

导致常规种植节肢动物个体数高于不施用任何化学农药的有机种植(张翼翾和唐振华, 2005; 李浩, 2010①)。德国的一项研究表明，施用农药对植食性节肢动物多度的抑制效果仅能维持两周，在小麦生育季后期害虫种群密度甚至高于喷施农药之前，而捕食性节肢动物的多度则显著低于不施用农药的常规小麦(Krauss et al, 2011)。因此，保护农田生态系统生物多样性，一方面要推行有机的管理方式，另一方面在常规种植的管理中应尽可能地减少对农药的施用，建议不超过15次/年，最好控制在11次/年以下。

随着农业生物多样性保护越来越受到国际社会的重视，采用有机农业的理念和技术对常规农业进行生态化改造在农业发达国家和地区被广泛接受和推广(Bommarco et al, 2013)。如英国南部的常规小麦采用生态化措施防治害虫，减少了农药的使用，由此降低了与有机农场节肢动物多样性的差距(Moreby et al, 1994); 印度政府大规模推行不施用任何农用化学品的“零预算自然农业” (高磊等, 2021)，德国和荷兰鼓励农民建立多种类型的人工播种的农田边缘带(Marshall et al, 2002)等。目前我国农业生产中对绿肥种植、作物多样化栽培以及非作物生境维护等有机措施的重视和应用程度相比农业发达国家还有一定差距。在实际生产中，集约化农业往往大面积种植单一作物，作物生境趋于同质化; 滥用除草剂导致非作物生境的杂草和蜜源植物等植被多样性大大降低(Fritch et al, 2017)。有机农业重视作物的间套作和绿肥轮作，提倡保留一部分杂草，引入和镶嵌植物篱笆及灌木丛来区分农田的不同区域，这些措施增加了有机农田生境中的植被多样性，为天敌的繁殖、取食等提供了多样化的栖息环境，保障了农田生态系统中天敌种群的丰富度和数量(Altieri, 1999)，有利于农业害虫的生态化防治。本研究结果也显示有机种植模式下天敌和害虫的丰富度均有显著提升，天敌多度比常规种植显著提高了71.80%，而害虫多度则下降了10.46%。大量研究表明，景观异质性和生境多样性对节肢动物多样性有重要影响(Letourneau et al, 2011; Han et al, 2014)。如有机葡萄园通过构建多样化的行间植被，蜘蛛种类的丰富度显著高于常规葡萄园(Kolb et al, 2020); 冬闲时种植紫云英的水稻田，其蜘蛛群落多度明显高于闲田-水稻田(袁伟等, 2010); 在棉田套种玉米、高粱等诱集棉铃虫产卵的作物，使其集中产卵，有利于集中诱杀和保护天敌(陆萍等, 2004)。本研究中有机水田的节肢动物多度显著高于有机旱地，可能是由于相比旱地，水田的非作物生境增加了环境异质性、提高了稻田生态系统中的生境多样性与复杂性(刘雨芳等, 2000; 周子杨, 2011②)。非作物生境中的植被或杂草可为一些同翅目(如蚜虫)和鞘翅目(如甲虫和象虫)害虫生长和发育提供食物及避难场所(俞晓平等, 1996)，同时，也为有益节肢动物(如天敌、授粉昆虫)提供了替代猎物或寄主、营养来源和庇护场所(毛润乾等, 2000)。因此，在农业生产过程中，维护生境的植物多样性对保护节肢动物的群落多样性具有重要的作用。

从作物类型来看，在蔬菜和茶叶作物种植体系上进行有机种植，对节肢动物多样性指数的综合提升效果优于其他作物类型，尤其是蔬菜。相比常规种植，有机菜园节肢动物丰富度、多度和均匀度指数显著提升了81.46%、74.14%、18.55%，有机茶园显著提升48.86%、49.06%、30.88%。近年来我国有机产业呈现快速、稳定的发展态势，根据《中国有机产品认证与有机产业发展(2019)》，我国有机种植面积从2005年的46.4万ha上升到2019年的221.5万ha，增加了约4.8倍，而其中有机茶叶和蔬菜的种植面积仅为6.6万ha和3.7万ha，仅占总有机种植面积的2.98%和1.67%。2018年有机茶种植面积占全国茶叶总种植面积的2.38%，2019年有机蔬菜占全国蔬菜总种植面积的0.08% (http://zdscxx.moa.gov.cn:8080/nyb/pc/frequency.jsp)，蔬菜和茶叶的有机种植面积还存在巨大的增长空间。在蔬菜和茶叶这两种作物体系中优先推行有机生产，树立农田生物多样性保护的样本和典型，可对农田生物多样性起到示范和推动作用。

总体来说，有机种植显著提升了农田节肢动物多样性指数，有助于促进农田害虫的生态化防治。在常规种植中加大对有机和生态化管理措施如减少农药施用、维护生境植物多样性等的应用程度，

① 李浩 (2010) 有机果园与非有机果园节肢动物群落结构及多样性比较. 硕士学位论文，天津师范大学，天津.

② 周子杨 (2011) 不同类型稻田非作物生境的节肢动物多样性. 硕士学位论文，南京农业大学，南京.

对保护农业生物多样性具有重要的现实意义。我国应完善以绿色生态为导向的农业生态治理补贴制度，通过加强生态保护补偿等相关政策引导农业生产方式的绿色转型，以实现保障粮食安全和保护农业生物多样性的双赢目标。本文未对有机种植下节肢动物多样性提升的经济效益进行定量核算，后续研究可从采用有机管理措施所节约的以及额外支付的成本、授粉昆虫及天敌的增加带来的经济效益等角度进行生态成本与收益的核算和探讨，为生态补偿政策的制定提供参考。

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附录　Supplementary Material

附录1　本研究纳入的文献

Appendix 1　The literature included in the meta-analysis

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