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Review

Effects of sod cultivation on soil nutrients in orchards across China: A *meta*-analysis

Hui Wei[a,c,d,1], Yangzhou Xiang[b,*,1], Ying Liu[e], Jiaen Zhang[a,c,d]

[a] Department of Ecology, South China Agricultural University, Guangzhou, 510642, China
[b] Guizhou Institute of Forest Inventory and Planning, Guiyang, 550003, China
[c] Key Laboratory of Agro-environment in the Tropics, Ministry of Agriculture, South China Agricultural University, Guangzhou, 510642, China
[d] Guangdong Engineering Research Center for Modern Eco-agriculture and Circular Agriculture, Guangzhou, 510642, China
[e] Guiyang College of Chinese Traditional Medicine, Guiyang, 550002, China

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ABSTRACT

Plantation of fruit trees is an important measure of agriculture and vegetation restoration as it produces economic output with obvious ecological effects, making orchards contribute greatly to increased vegetation coverage around the world. Sod cultivation in orchards is a popular management measure but whether it affects soil nutrient condition in different ways, e.g., among different climatic zones or under different soil types, remains unclear. This *meta*-analysis was conducted to clarify effects of sod cultivation in orchards on soil nutrients (including carbon [C], nitrogen [N], phosphorus [P] and potassium [K]) across China which covers different climatic zones and soil types. Results showed that sod cultivation significantly increased soil organic C (SOC), total and available N, available P and total K contents, but significantly reduced total P and available K contents in orchard soils. These changes of soil nutrients were not a result of cultivation-induced modifications in soil pH and bulk density but instead were probably led by changed nutrient demands and inputs of plants in associated with altered microbial processes. Moreover, climate, edaphic properties and the cultivated grass species apparently affected responses of soil nutrients to sod cultivation. Discrepancies in substrate supply and microbial properties induced by grass cultivations in different systems could have contributed to the observed patterns. Further studies, e.g., simultaneously investigating soil nutrient condition, plant productivity and soil microbial properties, remain needed to improve our understanding of the potential mechanisms by which sod cultivation could change soil nutrient conditions.

Contents

* Corresponding author.
E-mail address: yzhxiang18@126.com (Y. Xiang).
[1] These authors contributed equally to this work.

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1. Introduction

With fast growth of human population and increasing demands for wood and resources, global forest area has been declining for a long time. In 1990, for instance, 4128 million ha of forest existed around the world. By 2015, however, this figure had fallen to 3999 million ha, with a net loss rate of 0.13% per year (FAO, 2015). To retard forest loss and restore forest coverage, a number of reforestation and afforestation programs have been enacted across many countries. As a result, plantation forest has increased by over 110 million ha on the global scale from 1990 through 2015, with a peak annual increase of 5.2 million ha per year in the period from 2000 to 2010 (FAO, 2015). As a huge country that experienced severe deforestations induced by wars or other anthropogenic activities, China has proposed several large-scale reforestation and afforestation measures, such as the northwest-north-northeast China networks of shelterbelts and reforestations, to increase forest coverage and restore degraded ecosystems, and established roughly 80 million ha of plantation forest in the last 60 years (FAO, 2012). This represents more than one third of global total area covered by plantation forest (278.5 million; FAO, 2015) and therefore makes China the largest acreage of plantation forest (Piao et al., 2009).

Relative to other tree species utilizable to increase vegetation coverage, fruit trees are chosen by farmers due to their economic and ecological effects, and therefore extensively used to reforest and restore habitats in China. The area of orchards in China has been increasing since 1995 and by 2013, orchard area had increased to 12.4 million ha, a number which accounts for 17.8% of the total plantation area in China (Chen et al., 2014; NBSC, 2014). Although orchards have contributed greatly to the total vegetation coverage in China, orchard management (including understory management in orchards) remains outdated compared with those developed countries such as America, Japan and France. Total weeding control (clean tillage) is still the most popular field management measure in China (Wang et al., 2015a). Sod cultivation in orchards is an effective field practice that could help improve orchard habitats and fruit production and quality (Huang et al., 2013; Liu et al., 2014; Yan et al., 2011). To date, however, orchards with sod cultivation account for less than 10% of the total orchard area in China (Wang et al., 2015a).

The slow implementation of such an effective orchard management system is likely due to the fact that farmers and decision-makers have not clearly realized potential effects of sod cultivation in orchards, although implications could be noted from existing studies aiming to detect ecological effects of understory groundcovers (Liu et al., 2013). Therefore, we used *meta*-analysis technique in this study to clarify effects of sod cultivation in orchards on soil nutrients across China. Soil nutrient indices including carbon (C), nitrogen (N), phosphorus (P) and potassium (K) were selected in this study because all of them are important and highlighted nutrients, which play critical roles in maintaining lives and ecosystem functioning. Relative to existing measures, we hypothesized that sod cultivation in orchards would significantly raise soil C, N, P and K content because cultivated sods have reportedly provided extra nutrients to the soil (Liu et al., 2013; Palviainen et al., 2005; Qiao et al., 2014). On the other hand, sod cover could potentially accelerate nutrient releases to form soil organic matter by maintaining greater microbial communities with higher-efficient substrate utilization capacity (Du et al., 2015; Wang et al., 2016, 2015a). Both the total and available soil nutrients were analyzed to compare their response magnitude to the sod cultivation treatment, because most attention has been paid to the available rather than the total nutrient contents in previous studies. We expected that the available soil nutrients would respond greater than their according total soil nutrients, taking into account that soil available nutrients are likely more sensitive to habitat and environmental changes.

2. Materials and methods

2.1. Data compilation

Literature reporting effects of sod cultivation in orchards on soil nutrients in China before February 2016 were searched in the China National Knowledge Infrastructure (CNKI) and Web of Science databases. The case studies used in this *meta*-analysis were chosen according to the following criteria: only studies conducted in China were included; at least one of the targeted soil nutrients was reported under both conditions of a sod cultivation treatment and a control; only field studies were included; most studies provided one-time measurements but only the latest observations were taken to meet the standard of independency of samples when variables were measured at multiple-time (Hedges et al., 1999; Liu and Greaver, 2009); mean, standard deviation or standard error, and sample size were provided or could be extracted and therefore response ratio of variables could be calculated; multiple cultivated sod species, cultivation duration or soil depth in one study were considered as independent observations (Bai et al., 2013). Finally, a total of 360 observations that originated from 73 studies were collected (please see details in sheet RefList of Supplementary dataset) and the compiled dataset contained 7 variables for this *meta*-analysis, i.e., soil organic carbon (SOC), total nitrogen (TN), available N, total phosphorus (TP), available P, total potassium (TK) and available K. Additionally, variables including mean annual temperature (MAT), mean annual precipitation (MAP), vegetation such as fruit and grass type and edaphic properties such as pH, bulk density and initial nutrient contents of C, N, P and K were also taken to explain the observed response of soil nutrient contents.

Response ratio (RR) and 95% confidence interval (CI) were calculated to present treatment effect and significance level. For each of the investigated soil nutrients, RR was also compared when pooling data into different categories according to climatic zone, precipitation, initial soil acidity, grass source, grass life history, (non-) N-fixation species, or cultivation duration. Finally, the used observations were pooled in two climatic zones (temperate or subtropics), three precipitation gradients (humid zone with precipitation >800 mm yr^{-1}, semi-humid zone with precipitation ranging from 400 to 800 mm yr^{-1} and arid zone with precipitation of less than 200 mm yr^{-1}), five soil acidity conditions (strongly alkaline soil with pH > 8.5, alkaline soil with pH ranging from 7.0 to 8.5, neutral soil with pH from 6.5 to 7.0, acid soil with pH from 5.5 to 6.5 and strongly acid soil with pH < 5.5), two grass sources (wild or cultivated), two grass life histories (annual or perennial), two subgroups with non- or N-fixation capacity, and nine cultivation durations from 1 to 9 years of sod cultivation.

2.2. Data calculations and statistical analyses

Data were processed as described by Hedges et al. (1999).The RR of each variable was calculated using equation 1 to determine the effect magnitude of sod cultivation in orchards. Natural logarithm transformation was conducted to improve statistical power by lowering estimate bias and normalizing sampling distribution (Bai et al., 2013; Hedges et al., 1999):

$$RR = Ln\left(\frac{Mean_t}{Mean_c}\right) = LnMean_t - LnMean_c \quad (1)$$

In which subscripts t and c indicate the treatment and control groups, respectively, and Mean is mean of a given variable.