Soil & Tillage Research 181 (2018) 110–116

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Grass cultivation alters soil organic carbon fractions in a subtropical orchard of southern China

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ARTICLE INFO

Keywords:
Sod cultivation
Floor management in orchards
SOC stabilization

ABSTRACT

Understory management is evidently important for improving the ecological and economic effects of orchards, and grass maintenance in orchards is a potentially preferable floor management measure relative to clean tillage. It is widely accepted that grass maintenance increases soil organic carbon (SOC) content, but whether different SOC fractions respond consistently is less understood. To clarify the potential effects of grass maintenance on SOC fractions, three grass species, including a leguminous species (*Stylosanthes guianensis cv. Reyan*) and two gramineous species (*Paspalum notatum Alain ex Flugge.* and *Pennisetum americanum x P. purpureum*), were planted under young Litchi trees in a subtropical orchard of southern China for eight months using clean tillage as a control. The labile and non-labile SOC fractions and microbial C mineralization were investigated. Relative to the control, grass cultivation significantly increased or trended to increase the SOC content and this was mainly due to increases in the labile SOC fractions. The increased C lability and substrate supply support higher soil microbial biomass C, consequently accelerating the soil C mineralization process and resulting in a greater biologically mineralizable C pool. However, grass cultivation significantly decreased the non-readily oxidizable OC content, although it was relatively more chemically recalcitrant. Our results suggest that grass cultivation may favorably accelerate nutrient cycling in orchards due to higher labile C substrate availability and soil microbial biomass and activity. Nevertheless, grass cultivation could decrease SOC stabilization as indicated by the increased SOC lability in the grass-planting systems.

1. Introduction

The global land area consists of a substantial proportion of agroecosystems, which are most vulnerable to anthropogenic activities (Cole et al., 1993). It has been estimated that up to 2 billion hectares of cropland will be necessary to meet the increasing needs (i.e., food and resources) of the growing population in 2025 (Sauerbeck, 1992). Agroecosystems are mainly distributed in the temperate, subtropical and tropical regions of the world, with roughly a half in temperate regions and the other half located in tropical and subtropical climatic zones (Cole et al., 1993). Orchard is a traditional agroecosystem that is widely maintained worldwide and accounts for a considerable area (NBSC, 2014; Rey, 2011). In China, for example, the area of orchards has reached 12.4 million hectares by 2014 (NBSC, 2014), a figure accounting for approximately 18% of the total planted area in China (Chen et al., 2014; NBSC, 2014) and 4.5% of that around the world (278.5 million hectares; FAO, 2015). Compared with those short-period cropping systems (such as rice field), the orchard ecosystem has semi-permanent nature and higher stability (Altieri, 1999). Applicable field measures can amplify the ecological services supplied by orchard ecosystems. However, clean tillage (i.e., weeding to keep the orchard floor clean) is still a popular practice for orchard floor management in many places, e.g., in rainfed orchards of Spain (Ramos et al., 2011) and across China (Wang et al., 2015).

Relative to clean tillage, understory maintenance in orchards gives rise to different ecological consequences that could be positive or negative. One the one hand, understory maintenance probably causes declines in the tree growth and fruit productivity (Hoagland et al., 2008; Sánchez et al., 2007); with a given amount of resources, the understory would inevitably absorb a portion of water and nutrients and therefore result in competitions with fruit trees (Gao, 2005; Lipecki and Berbec, 1997). Such competitions for resources could have given

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https://doi.org/10.1016/j.still.2018.04.009
Received 6 June 2017; Received in revised form 8 April 2018; Accepted 10 April 2018
0167-1987/

rise to negative effects as observed previously. Contrastingly, positive effects have also been noted in literature where cover plant maintenance in orchards was in favor of fruit production at both the aspects of yield and quality (He et al., 2005; Lipecki and Berbec, 1997; Sánchez et al., 2007). These contrasting observations imply that complex interactions are underlying between fruit trees and understory species. Moreover, understory maintenance in orchards may alter many aspects of soil properties, such as increasing the soil nutrient contents (Gao, 2005; Sánchez et al., 2007), stimulating soil biological activities (Hoagland et al., 2008; Ramos et al., 2011), and changing soil fauna and microbial community composition (Rieux et al., 1999; Yao et al., 2005). As a result, understory management is very likely to affect the ecosystem functions of orchards, such as soil carbon (C) and nitrogen (N) cycling and nutrient supplies (Liu et al., 2013; Sánchez et al., 2007).

Grass cultivation and maintenance is an effective measure for increasing groundcover in orchards. Consequently, this practice could be beneficial for conserving water and soil, stabilizing soil aggregate, increasing soil nutrient availability, and improving a number of soil physical, chemical and biological properties (Hoagland et al., 2008; Ramos et al., 2011; Wang et al., 2015; Wei et al., 2017). Moreover, grass cultivation and maintenance is probably able to influence the community composition of insects and fauna that live in the soil or tree canopy, thereby changing the interactions between pests and their predators (Rieux et al., 1999; Stephens et al., 1998; Wang et al., 2015). Consequently, fruit trees could benefit from such altered interactions within the food web, because grass maintenance enhances the biological control on pests, e.g., by increasing their natural predators or supporting more beneficial over phytophagous insects that live in tree canopy (Rieux et al., 1999; Stephens et al., 1998).

However, effects of grass maintenance on tree growth as well as fruit productivity and quality remain inconclusive (Gucci et al., 2012; Hoagland et al., 2008; Sánchez et al., 2007). In spite of positive effects reported previously (Gu et al., 2009; Sánchez et al., 2007), grass cultivation could contrarily lead to declines in tree growth and fruit productivity (Gucci et al., 2012; Hoagland et al., 2008). The potential risk in economic loss may make farmers unwilling to maintain living grasses in orchards. Moreover, maintenance of different kinds of grass could have different effects that depend on compatibility of trees and grasses (i.e., complementarity > competition or versa) as well as local climatic and soil conditions (Firth et al., 2002; Wang et al., 2015; Wei et al., 2017). Therefore, comparative studies are necessary to determine a suitable combination of fruit trees and grasses along with floor management strategies that are based on specific regional conditions, consequently clarifying multiple aspects of ecological effects (Gucci et al., 2012; Wang et al., 2015).

Ecosystem C balance is currently a hotspot in ecological studies, because any tiny shift in the ecosystem C balance would tremendously affect the global climate system (Cox et al., 2000; Fontaine et al., 2004). Many attempts have been made to quantify the soil C pool and promote soil C sequestration in recent decades, as soil is the largest C pool in terrestrial ecosystems. As estimated, the one-meter-depth of global surface soil stores approximately 1500 Pg of C (Jobbágy and Jackson, 2000; Scharlemann et al., 2014), a figure much higher than that stored in the vegetational and atmospheric C pool (Fontaine et al., 2004). Previous studies have reported that floor grass maintenance in orchards could increase the soil organic C (SOC) content in diverse climatic zones (Gucci et al., 2012; Ramos et al., 2011; Sánchez et al., 2007), including the subtropical ecosystems of southern China (Liu et al., 2013; Wei et al., 2017). Consequently, this may raise the potential for regional C sequestration in southern China, make it a larger C sink than it has been (Piao et al., 2009). In spite of the frequently observed SOC increases, however, potential changes in the SOC fractions originating from grass maintenance in orchards have currently been less studied. Therefore, we investigated different SOC fractions and microbial C mineralization to clarify these changes because the SOC stabilization depends on the combinations of physical, chemical and microbial protection (Kuzyakov, 2002; Six et al., 2002; von Lützow et al., 2006).

This study was conducted in a subtropical orchard in southern China to explore how grass cultivation influenced SOC fractions. Firstly, we expected that grass cultivation would increase the total SOC content, as reported in literature (Liu et al., 2013; Ramos et al., 2011; Wei et al., 2017). Multiple SOC fractions and C-mineralization parameters were analyzed to investigate the SOC lability (Blair et al., 1995; Six et al., 2002; von Lützow et al., 2006). We expected that the non-labile SOC fraction would be increased, because grass cultivation can promote microbial activity (Hoagland et al., 2008; Ramos et al., 2011) and then microbial products that contribute a great amount of mineral SOC (Cotrufo et al., 2013). Moreover, previous studies reported that species could greatly determine magnitude or even direction of the effects (Firth et al., 2002; Qian et al., 2014; Wang et al., 2014), and therefore three grass species in the gramineae or legume family were planted in the current study. We expected that the leguminous species would increase the SOC content more than the gramineous species, as shown in a recent meta-analysis study (Wei et al., 2017).

2. Material and methods

2.1. Site description

This study was conducted in Zengcheng Teaching and Experimental base (113°38′ E, 23°14′N) of South China Agricultural University. This region has a typical subtropical monsoon climate, with a mean annual temperature of 22 °C that is unevenly distributed over the year. The annual precipitation is 1976.8 mm, with most precipitation occurring in the wet season (from April to September) of each year and the remaining occurring in the other months of a calendar year (hereafter called the dry season). As a result of long-term human disturbances, this type of low-mountain and hilly landscape that covers a large area in southern China has been suffering severe soil and water losses. To restore the vegetation coverage, terraces were established and four types of widely-distributed native fruit trees, i.e., litchi (*Litchi chinensis* Sonn.), longan (*Dimocarpus longan* Lour.), mango (*Mangifera indica* L.) and guava (*Psidium guajava* Linn.), were planted in 2013 with a space interval being 4 m between each two trees. Soil in the study site is lateritic red soil in the ferralsol group according to Chinese soil taxonomic classification; it approximates to humults in the Ultisols group according to USDA soil taxonomy. The soil constitutes of 64.7% sand, 30.9% silt and 4.4% clay. It has a pH of 5.9, SOC content of 16.2 g kg^{-1}, and total N content of 1.1 g kg^{-1}. The contents of soil available N, phosphorus (P), and potassium (K) are 60.0, 10.7 and 0.5 mg kg^{-1}, respectively.

2.2. Experimental design and soil sampling

Quadrats were established in the terraced Litchi orchard as a randomized block design, with three blocks in three terraces and four quadrats (including the control) in each block (please see the experiment scheme in Fig. S1). A total of 12 quadrats, with a length of 8 m and four Litchi trees in two rows included in each quadrat, were established for clean tillage control and three grass-planting treatments and the four treatments (including the control and grass-planting treatments) were randomly assigned in one of the four quadrats in each block. Three replicates were set for each treatment. Prior to this study, the orchard received the same field management, with the understory cleaned periodically. Three grass species included two gramineae species, *Paspalum notatum Alain ex Flugge.* and *Pennisetum americanum x P. purpureum*, and a legume species, *Stylosanthes guianensis cv. Reyan* (hereafter abbreviated as *P. notatum, P. americanum* and *S. guianensis*, respectively) were planted, because all of them are the commonly recommended pasture species that are suitable to grow in tropical and subtropical regions of China. Clean tillage was chosen as the control because it has been widely used in China. Before sowing the grasses, all