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Intensive organic vegetable production increases soil organic carbon but with a lower carbon conversion efficiency than integrated management

Yi Zhao[1,3], Shuxia Wu[2], Roland Bol[3], Mansoor Ahmed Bughio[1,4], Wenliang Wu[1], Yecui Hu[5], and **Fanqiao Meng[1*]**

[1] Beijing Key Laboratory of Biodiversity and Organic Farming, College of Resources and Environmental Sciences, China Agricultural University, Beijing 100193, China
[2] Institute of Agricultural Resources and Regional Planning, China Academy of Agricultural Sciences, Beijing, 100081, China
[3] Institute of Bio- and Geosciences, Agrosphere (IBG-3), Forschungszentrum Jülich GmbH, 52425 Jülich, Germany
[4] Agriculture Extension Wing, Agriculture, Supply and Prices Department, Government of Sindh, Pakistan
[5] School of Land Science and Technology, China University of Geosciences, Beijing 100083, China

Abstract

Intensive vegetable production in greenhouses has rapidly expanded in China since the 1990s and increased to 1.3 million ha of farmland by 2016, which is the highest in the world. We conducted an 11-year greenhouse vegetable production experiment from 2002 to 2013 to observe soil organic carbon (SOC) dynamics under three management systems, *i.e.*, conventional (CON), integrated (ING), and intensive organic (ORG) farming. Soil samples (0–20 and 20–40 cm depth) were collected in 2002 and 2013 and separated into four particle-size fractions, *i.e.*, coarse sand (> 250 µm), fine sand (250–53 µm), silt (53–2 µm), and clay (< 2 µm). The SOC contents and $\delta^{13}C$ values of the whole soil and the four particle-size fractions were analyzed. After 11 years of vegetable farming, ORG and ING significantly increased SOC stocks (0–20 cm) by 4008 ± 36.6 and 2880 ± 365 kg C ha^{-1} y^{-1}, respectively, 8.1- and 5.8-times that of CON (494 ± 42.6 kg C ha^{-1} y^{-1}). The SOC stock increase in ORG at 20–40 cm depth was 245 ± 66.4 kg C ha^{-1} y^{-1}, significantly higher than in ING (66 ± 13.4 kg C ha^{-1} y^{-1}) and CON (109 ± 44.8 kg C ha^{-1} y^{-1}). Analyses of ^{13}C revealed a significant increase in newly produced SOC in both soil layers in ORG. However, the carbon conversion efficiency (CE: increased organic carbon in soil divided by organic carbon input) was lower in ORG (14.4%–21.7%) than in ING (18.2%–27.4%). Among the four particle-sizes in the 0–20 cm layer, the silt fraction exhibited the largest proportion of increase in SOC content (57.8% and 55.4% of the SOC increase in ORG and ING, respectively). A similar trend was detected in the 20–40 cm soil layer. Over all, intensive organic (ORG) vegetable production increases soil organic carbon but with a lower carbon conversion efficiency than integrated (ING) management.

Key words: carbon conversion efficiency / $\delta^{13}C$ / greenhouse vegetable production / organic carbon stock / organic fertilizer / particle-size fraction

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1 Introduction

Soil is the largest carbon (C) pool on earth, with organic carbon (OC) of 1550 Pg and inorganic carbon (IC) of 950 Pg (*Lal*, 2007). A small change in soil C content can affect the global climate (*Luo* et al., 2010; *IPCC*, 2014). Land use/cover changes, especially agricultural activities, significantly affect ecosystem services including soil organic carbon (SOC) storage (*Gelaw* et al., 2014; *Wang* et al., 2016). It is important to understand the C dynamics within agro-ecosystems and identify appropriate farming practices to protect soil resources and provide adequate food and fiber for a growing population (*Stockmann* et al., 2013). Numerous studies have explored the impacts of irrigation (*Houlbrooke* et al., 2008; *Kelliher* et al., 2012), fertilization (*Purakayastha* et al., 2008; *Lemke* et al., 2012; *Yan* et al., 2012), tillage (*West* and *Post*, 2002; *Franzluebbers* and *Steiner*, 2016), and land use change (*Tan* et al., 2007; *Venkanna* et al., 2014; *Wiesmeier* et al., 2015) on SOC content and stocks in farmland soils. The findings so far have highlighted that there is great potential to increase C stocks in agricultural soil through various practices including organic farming (*Lal*, 2004; *Liao* et al., 2015; *Matsuura* et al., 2018). Other studies also suggested that the beneficial effects of organic farming on SOC are largely determined by disproportionately high applications of organic fertilizer compared with conventional farming (*Leifeld* and *Fuhrer*, 2010) and that the SOC increase due to organic fertilizer is not genuine C sequestration (*Powlson* et al., 2011).

In China, vegetable production in greenhouses has developed rapidly over the past two decades, driven by economic development and increased consumer demands (*Yu*, 2011;

* Correspondence: F. Meng; e-mail: mengfq@cau.edu.cn

