Soil & Tillage Research 138 (2014) 64–72

Contents lists available at ScienceDirect

Soil & Tillage Research

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

Tillage and cover crop species affect soil organic carbon in Andosol, Kanto, Japan

Tatsuya Higashi [a], Mu Yunghui [b], Masakazu Komatsuzaki [c,*], Shigenori Miura [d], Toshiyuki Hirata [e], Hajime Araki [e], Nobuhiro Kaneko [f], Hiroyuki Ohta [g]

[a] Unite Graduate School of Agriculture, Tokyo University of Agriculture & Technology, 3-21-1 Ami, Ibaraki 300-0393, Japan
[b] College of Agriculture, South China Agricultural University, Wushan, Guangzhou 510642, China
[c] Center for Field Science Research & Education, College of Agriculture, Ibaraki University, 3-21-1 Ami, Ibaraki 300-0393, Japan
[d] Agricultural Research Center, National Agriculture and Food Research Organization, 3-1-1 Kannondai, Tsukuba, Ibaraki 305-8666, Japan
[e] Field Science Center for Northern Biosphere, Hokkido University, Kita 11, Nishi 10, Kita-Ku, Sapporo 060-0811, Japan
[f] Soil Ecology Research Group, Yokohama National University, 79-7 Tokiwadai, Hodogaya, Yokohama 240-8501, Japan
[g] College of Agriculture, Ibaraki University, 3-21-1 Ami, Ibaraki 300-0393, Japan

ARTICLE INFO

Article history:
Received 30 August 2013
Received in revised form 22 December 2013
Accepted 27 December 2013

Keywords:
Soil carbon
No-tillage
Plow
Rotary cultivator
Cover crop

ABSTRACT

No-tillage, cover crops, and N fertilization play important roles in conserving or increasing soil organic carbon (SOC). However, the effects of their interaction are less well known, particularly in Asian countries. We examined the effects of three tillage management systems, moldboard plow/rotary harrow (MP), rotary cultivator (RC), and no-tillage (NT); three winter cover crop types (FL: fallow, RY: rye, and HV hairy vetch); and two nitrogen fertilization rates (0 and 100 kg N ha^{-1} for upland rice and 0 and 20 kg N ha^{-1} for soybean production) on changes in SOC. Vertical distributions at 0–2.5, 2.5–7.5, 7.5–15, and 15–30 cm depths of soil carbon content and bulk density were measured each year. From 2003 to 2011, NT and RC management increased SOC by 10.2 and 9.0 Mg ha^{-1}, whereas SOC under the MP system increased only by 6.4 Mg ha^{-1}. Cover crop species also significantly increased SOC in the same period by 13.4 and 8.6 Mg ha^{-1} for rye and hairy vetch, respectively, although SOC with fallow increased only by 5.4 Mg ha^{-1}. Continuous soil management for 9 years enhanced SOC accumulation. Summer crop species between upland rice and soybean strongly affected SOC; the SOC increases were 0.29 Mg ha^{-1} $year^{-1}$ for the upland rice rotation and 1.84 Mg ha^{-1} $year^{-1}$ for the soybean rotation. However, N fertilization levels did not significantly affect SOC. These results suggest that the NT system and rye cover crop enhance carbon sequestration in Kanto, Japan, but that their contributions differ depending on the combination of main and cover crops.

1. Introduction

In the Kanto region of Japan, a major agricultural area containing the largest plain in Honshu Island including the greater Tokyo area, moderate climate conditions support diverse agricultural production. A double-cropping system in which main crops were cultivated in summer followed by winter cereals was formerly practiced. However, winter cereals have disappeared in the region because they cannot compete with foreign products, and winter fallowing is now a common practice in upland fields. The predominant soil type in this region is Andosol, which contains mainly volcanic ash as parent material, as well as humus. Usually high soil carbon contents owing to low pH and formation of aluminum–humus complexes contribute to soil organic matter accumulation (Miyazawa et al., 2013). However, fixation causes high phosphorus absorption and these soils are prone to wind erosion owing to their weak structure, particularly in the winter fallow season. Andosols in upland field conditions often show improved soil pH and available phosphorus through the application of super phosphorus or lime, brought about by farming practices that promote the decomposition of soil organic matter (Takata et al., 2011). Therefore, maintaining the soil organic carbon in Andosols requires considerable inputs of C (Ohta, 2011).

Soil organic carbon (SOC) has various roles in producing crops and improving their environment (Franzluebbers, 2002; Lal, 2004a, 2004b; Weil and Magdoff, 2004; Baker et al., 2007). For improving SOC, manure application is a common practice (Shirato et al., 2004; Shimizu et al., 2009; Koga and Tsuji, 2009; Kimura et al., 2011). SOC can be increased by elevating biomass production, practicing crop rotation including cover crops, and practicing conservation

* Corresponding author. Tel.: +81 29 888 8707; fax: +81 29 888 8707.
E-mail address: komachan@mx.ibaraki.ac.jp (M. Komatsuzaki).

0167-1987/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.still.2013.12.010

tillage (particularly no-tillage) procedures that retain crop residues near the surface of the soil (Lal, 1998). The effects of tillage system and cover crop have not been well studied, particularly in Asian countries.

Soil tillage is performed with the goal of improving soil structure and quality. Moldboard plowing (MP), a conventional tillage system, turns the topsoil into the deep soil layer and thoroughly incorporates surface crop residues into the bottom of the tilled area, such that crop residues cannot be found on the surface. In Japan, more than 80% of cultivated crop land is tilled by rotary cultivator (RC) (Moriizumi et al., 1995). Soil is cultivated with a rotary blade and crop residues are mixed with soil, but not completely covered by soil. This system is simple and easy for farmers, particularly Asian farmers whose farming scale is relatively small, and results in an appropriate seedbed without great weed pressure. However, intensive tillage systems including MP and RC have greatly reduced SOC content in the last two decades (Ohta, 2011). These systems have also reduced infiltration owing to wheel traffic compaction (Meek et al., 1992), exposed the soil to erosion (Potter et al., 1995; Komatsuzaki and Suzuki, 2009) and reduced soil aggregate stability (Hajabbasi and Hemmat, 2000), Conservation tillage, particularly no-tillage (NT), was pioneered in Japan from 1980 to 1985, but these techniques were not implemented by farmers until the latter half of that decade. Conservation tillage systems have received increasing attention in the region over the last ten years because they enhance profitability by lowering machinery and other costs and are more environmentally appropriate than MP or RC (Sakai et al., 1988). Under NT, the planting operation is typically the only disturbance to soil layers, and this system has many environmental and economic benefits for the soil in Japan (Komatsuzaki and Ohta, 2007). The adoption of reduced tillage practices and the cultivation of crops with high potential for contributing to C biomass are further prerequisites for SOC accumulation (Sombrero and de Benito, 2010). Increases in SOC may also depend on the type of crop, crop rotation, and quality and quantity of crop residue (Bronick and Lal, 2005). Koga and Tsuji (2009) observed that under long-term management based on minimum tillage, soils failed to accumulate SOC, whereas minimum tillage not in conjunction with the use of cover crops yielded negative SOC accumulation rates, regardless of crop residue input or manure application. The relative contributions of tillage system and carbon input are heavily dependent on both soil and climate conditions. The effects of conservation tillage on SOC reported by Koga and Tsuji (2009) may not be applicable, owing to differences in temperature, rainfall, growing degree days, and crop rotation including cover crop. Owing to the existence of crop residue on the surface layer, no-tillage planter often fails to plant seed, but the use of such a planter with appropriate cover crop residue management can enhance germination under these conditions (Zhao et al., 2012). Thus no-tillage planting can be adopted when crop residues are applied to the soil surface.

Tillage enhances mineralization of soil organic C and N by incorporating crop residues, disrupting soil aggregates, and increasing aeration (Dalal and Mayer, 1986; Balesdent et al., 2000; Cambardella and Elliott, 1993), whereas cover cropping can increase C and N concentrations by increasing residue addition to the soil (Hargrove, 1986; McVay et al., 1989; Kuo et al., 1997; Kuo and Jellum, 2002). Practices such as NT that reduce residue incorporation and aggregate degradation also may conserve and/or maintain concentrations of organic C and N (Doran, 1987; Havlin et al., 1990; Franzluebbers, 2002). Similarly, N fertilization may increase concentrations of organic C by increasing plant biomass production (Blevins et al., 1983; Liang and Mackenzie, 1992; Gregorich et al., 1996; Omay et al., 1997).

Non-legume cover crops planted with N fertilization can fix more atmospheric C, and legume cover crops fix both C and N in plants by increasing biomass production, NT can reduce the rate of plant residue decomposition by placing residues at the soil surface or by reducing their incorporation in the soil (Doran, 1987; Havlin et al., 1990; Franzluebbers et al., 1996). Kirkby et al. (2013) showed that sequestration of non-legume cover crop residue material in the stable fraction of soil organic matter was improved by addition of supplementary nutrients to a residue-based rotation. However, little information is available about the effects of combination of tillage, cover crops, and N fertilization on the concentration of organic C and SOC storage, particularly in Andosols.

Our objectives were to (1) determine the amounts of C contributed by cover crops in the soil, (2) investigate the long-term effects of tillage, cover crop, and N fertilization on soil organic C concentration, (3) compare the effects of legume and non-legume cover crops and N fertilization rates on C concentration, and identify the management system that best conserved and/or maintained C concentration.

2. Materials and methods

This study was conducted from 2002 to 2011 on a volcanic soil in the Japanese province of Kanto region and is continuing. Before 1950, this experiment field was lowland forest, the site had been maintained as upland crop fields for over 40 years, and provided conventional tillage such as plowing and rotary cultivators. The soil is a typical Andosol with a sandy loam texture in the upper surface horizon, gradually changing to clay with depth. Its mean pH is 6.5, mean bulk density is 0.80 g cm^3, and soil carbon content is 3.37%, CEC is 315 meq kg^{-1}, CaO, MgO, K_2O and P_2O_5 (Brey method) are 315, 34, 119, and 546 mg kg^{-1}, respectively, in −0 to 30 cm soil layer.

The area has a humid subtropical climate suitable for double crop rotation for main crops in summer and cover crops in winter. The mean rainfall in the area from 1979 to 2000 was 1154 mm (Table 1). Distribution of precipitation across the season is an important consideration. The highest rainfalls recorded in the period studied were in 2004–2005 (1554 mm) and 2009–2010

Table 1
Monthly rainfall (mm) at Ibaraki, Japan in growing seasons, 2002–2011, and historic mean values, 1979–2000.

Year	October	November	December	January	February	March	April	May	June	July	August	September	Total
2002/2003	118	29	69	61	43	88	109	123	79	147	232	102	1200
2003/2004	128	154	42	6	11	101	63	130	75	110	99	150	1069
2004/2005	510	81	61	90	48	77	75	67	52	183	245	65	1554
2005/2006	184	50	2	52	86	65	89	91	138	220	72	188	1237
2006/2007	242	107	1071	32	47	55	100	149	54	188	38	190	1373
2007/2008	143	47	63	20	54	80	180	127.5	149.5	25	213	127.5	1262.5
2008/2009	109.5	54	61.5	105	42.5	55.5	121	09.5	159	55.5	17.5	17.5	1051
2009/2010	203	162.5	83	11	102	98	179.5	124	129	79	0.5	389	1560.5
2010/2011	161.5	71	212.5	1	99	75.5	83	178.5	125	216.5	134	212.5	1471
Historic mean	128.8	72	30.9	36.3	50.8	97.3	101.4	114.9	135.7	116.1	105.9	168.2	1154.4