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Effect of no-tillage with weed cover mulching versus conventional tillage on global warming potential and nitrate leaching

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ABSTRACT

Abandoned agricultural land could potentially accumulate soil organic carbon (SOC) when it is no longer used for cultivation and is allowed to revert to natural vegetation. In Japan, no tillage with weed mulching will be adopted in marginal farmland as a new organic farming system because this system minimizes the disturbance of the soil ecosystem and reduces the cost for crop production. The present study aimed to compare the effects of two organic farming systems, namely no-tillage with weed cover mulching and conventional tillage (CT), and two organic fertilizer application modes, namely no fertilizer (N−) and organic fertilizer (N+; 50 kg N ha^{-1} during 2010 and 2011 and 80 kg N ha^{-1} during 2012) on greenhouse gas (GHG) fluxes, soil carbon sequestration, net global warming potential (GWP), and nitrate leaching. Pumpkin (*Cucurbita* spp.) was cultivated as the main crop in 2010 and 2011, whereas mixed cropping of okra (*Abelmoschus esculentus* L.), bell pepper (*Capsicum annuum* L.), and eggplant (*Solanum melongena* L.) was implemented in 2012. Tillage management increased CH4 uptake immediately after the tillage; however, the effects did not continue in the long term. On the contrary, NTW increased CH_4 uptake, and the soil carbon content at the soil surface linearly increased every year after conversion to NTW indicating that improving soil physics by continuing NTW contributed to enhanced CH_4 uptake. N_2O emissions in NTW were higher only immediately after a weed mowing; however, NTW did not increase the annual N_2O emission. In addition, the difference between initial and final SOC (ΔSOC) was greater in NTW than in CT, which significantly decreased net GWP in NTW in comparison with CT. Nitrate leaching was 48.6% and 47.3% lower in NTW than in CT at soil depths of 30–60 and 60–90 cm, respectively. These results show that no-tillage with weed cover mulching contributed to conserve the regional and global environment by reducing nitrate leaching and net GWP from the agro-ecosystem by increasing the annual CH_4 uptake and soil carbon sequestration. This system will be adopted for abandoned agricultural land because it reduces net GWP shortly after conversion to this management.

1. Introduction

With increasing intensification of agriculture, commercial farmers have succeeded in increasing yield by adopting new agricultural technologies such as the use of high-yielding varieties, chemical fertilizers, pesticides, irrigation, and mechanization. However, farmers with fewer resources, i.e., small-scale farmers, have gained little from these technological developments (Pearse, 1980) because they have been excluded from access to credit, information, technical support, and modern technologies such as the use of synthetic fertilizers, pesticides, herbicides, and mechanization (Shiva, 1991).

International Year of Family Farming was set in 2014 by Food and Agriculture Organization of the United Nations (FAO), aiming to raise the profile of family farming and small-scale farming by focusing world attention on its significant role in eradicating hunger and poverty (FAO, 2014). In Japan, most farmers are small-scale farmers, who produce inefficiently in terms of economic gain per area (Muramoto et al., 2009). These farmers usually live in marginal places located very far from markets, e.g., in meso-mountainous areas. Most farmers in these areas are older, and

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there is insufficient labor available, resulting in the situation that abandoned agricultural land in these areas has rapidly increased from 217 million ha in 1990 to 396 million ha in 2010.

Many measures have been taken to return this abandoned land to cultivated land; however, this requires energy, the cost for plowing, weed management, and the introduction of machinery. Abandoned agricultural land can be effectively utilized as a fertile natural ecosystem; however, a bottom-up approach is required that builds upon available resources such as the local people, their knowledge, and natural resources without much dependence on modern technology to utilize these lands effectively (Altieri, 2002). More small-scale farmers have recently started to adopt "natural farming" (no-tillage with weed cover mulching; NTW), which was started by Fukuoka in the 1940s (Fukuoka, 1978) and later modified by Kawaguchi and Toriyama (2000) into an acceptable method for farmers. This type of farming is highly based on productivity of the natural ecosystem, which is independent of agricultural industry products, and requires only sickles to cut weeds or to harvest (Kawaguchi and Toriyama, 2000) because farmers raise crops without tillage, chemical fertilizers, or other chemical inputs and do not remove weeds completely. Instead, weeds are used as soil cover based on the observation that weed cover mulching enhances carbon (Arai et al., 2014) and nutrient cycling (Komatsuzaki et al., 2012), contributing to improve crop growth. Therefore, this type of farming system is a more productive method for small-scale farmers in marginal environments because of lower labor and energy requirements and little dependence on external input into the system. In particular, this farming practice can involve people who do not have sufficient investments to start commercial farming because it reduces the cost for farm machinery and chemicals.

Weed cover mulch techniques have been a focus in the US, Africa, and Asian countries because they benefit soil conservation and crop growth by modifying the agro-ecosystem. Altieri et al. (1985) reported that compared with clean cultivation, soil covering by weeds and clover was effective on increasing numbers of ground predators (Carabidae, Staphylinidae, and spiders). Arai et al. (2014) reported that carbon input into the soil from aboveground weed biomass and >2 mm increases in the water stable aggregate may be responsible for soil carbon sequestration by adopting NTW over a longer term. These results indicate that NTW systems could be a useful approach for increasing soil biological diversity and soil carbon sequestration after a long-term trial.

In addition, abandoned agricultural land can be viewed as an opportunity for ecological restoration to a state prior to agriculture. Henebry (2009) reported that the collapse of the Soviet Union had diverse consequences not only for the abandonment of crop cultivation in many areas but also for abandoned agricultural land and vast accumulation of soil organic carbon (SOC). Potter et al. (1999) determined the rate of increase in SOC over time by establishing grasses in soils that were previously tilled and primarily cropped to cotton, i.e., surface soil SOC concentrations were 4.44–5.95% in native grassland compared with 1.53–1.88% in soils that remained in row crop production. Converting abandoned agricultural land to modern farming agriculture could accelerate climate change by emitting stored carbon and reducing biological diversity in the local environment. We hypothesized that both problems could be potentially avoided by adopting an NTW system on abandoned agriculture lands. However, limited information is available on the effect of NTW systems on SOC shortly after conversion to an NTW system.

In general, no-till and minimum tillage management increases N_2O production compared with conventional tillage because of higher soil moisture content, resulting in the promotion of microbial activity for N_2O production in no tillage (Liu et al., 2007; Rochette et al., 2008; Regina and Alakukku, 2010; Yao et al., 2009). Rochette et al. (2008) concluded that no-till management increases N_2O production in loam soil but not in fine-textured soil. Six et al. (2004) reported that the decrease in N_2O production after no-till management persisted for more than 20 years; however, these effects could not be achieved in the short term after conversion. In addition, soil physical properties play an important role not only in N_2O production but also in CH_4 oxidation in the soil because CH_4 oxidation is promoted by gas exchange between the soil and air (Ball et al., 1997). Thus, soil compaction by a tractor generally results in lower CH_4 oxidation (Hansen et al., 1993; Ruser et al., 1998). In contrast, Robertson et al. (2000) concluded that successional vegetation provides a net mitigation of global warming because of reduced N_2O production, increased CH_4 oxidation, and SOC accumulation, resulting in lowered net global warming potential (GWP). Therefore, NTW systems are expected to have similar mitigating effects with early succession because NTW systems offer natural vegetation with weed cover mulching without any soil disturbance. Yagioka et al. (2014) reported that soil physical properties was improved in NTW systems because of the elimination of machinery and the effects of soil weed cover mulching, which may contribute to net mitigation of global warming. However, the long-term effect of NTW systems on soil physical properties and their effect on greenhouse gas (GHG) emissions or net GWP have not been well investigated, particularly under Japanese climatic conditions.

Furthermore, nitrate leaching from agricultural land is a serious chemical hazard to the environment, particularly in intensive farming. However, abandoned agricultural land may become an N absorption agricultural area. Different conclusions have been reached with regard to the effect of no tillage on nitrate leaching, i.e., higher (Tyler and Thomas, 1977), similar (Kitur et al., 1984), lower in no tillage than in conventional tillage with weed removal (Constantin et al., 2010; Syswerda et al., 2012), or variable depending on climate conditions (Randall and Iragavarapu, 1995). Also, because winter cover crops are useful in preventing nitrate leaching (Wyland et al., 1996; Brandi-Dohrn et al., 1997; Constantin et al., 2010), weed cover mulching may reduce nitrate leaching from agro-ecosystems. However, little information is available on the effect of NTW systems on nitrate leaching. In addition, a holistic approach is required for evaluating ecosystem function such as GHG emissions, nitrate leaching, or SOC to completely understand the effectiveness of NTW systems for improving regional and global environmental quality.

Thus, the present study examined the effects of different tillage practices on (1) GHG (CH_4, CO_2, and N_2O) emissions, (2) SOC changes, (3) net GWP, and (4) nitrate leaching during the first 3 years after conversion to organic farming. We hypothesized that NTW systems would reduce GHG emissions, net GWP, and nitrate leaching while enhancing SOC over time in comparison with general organic farming systems using conventional tillage.

2. Materials and methods

2.1. Site description and experimental design

The experiment was conducted at the Center for Field Science Research and Education, Ibaraki University, Japan. The experimental field was established in October 2009 as a long-term organic farming research experimental site on volcanic ash soils in the Kanto region of Japan. The soil was a typical Andosol (World Reference Base for Soil Resources) with a sandy loam texture in the upper surface and a gradual increase in clay with depth.

The experimental design was a split–split plot design, consisting of two tillage systems as main factors and two fertilizer applications as split factors with four replications. The size of each plot was 25 m^2 (5 m × 5 m). The tillage systems used were no-tillage with weed cover mulching (NTW) and conventional tillage