Research article

Cover Crop Mixtures Effects on Soil Physical and Chemical Properties in Japan

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Abstract Agricultural management practices such as cover crop could restore soil physical and chemical properties, and in turn positive effect of crop productivity. However, it can vary with soil type, climate, and type of cover crop species. In addition, different cover crops provide different benefits to agricultural land. For instance, legumes (e.g. clover (*Trifolium repers* L.)) fix atmospheric nitrogen (N) for their own use. After terminating the legume cover crop, it will release N into the soil as the residues decompose and provide available N to the main crops. Some of cover crop (e.g. phacelia (*Hydrophylloideae*)) are able to suppress weeds or prevent insect damages by competition, shading, and allelopathy. Recently, researchers reported that cover crop mixture may provide greater diversity of benefits than monoculture cover crop. Therefore, the objective of this study was to demonstrate soil physical and chemical properties assessment under cover crops (clover, phacelia, and their mixture) vegetation.

Keywords cover crop, mixture, soil organic carbon, soil physical and chemical property

INTRODUCTION

Cover crops have numerous benefits for agriculture practices (Murrell et al., 2017). According to the Soil Science Society of America (SSSA), cover crops are defined as a “close-growing crop that provides soil protection, seeding protection, and soil improvement between periods of general crop production, or between trees in orchards and vines in vineyard, and when plowed under and incorporated into the soil, cover crops could be referred to as a green manure crop” (SSSA, 2008).
In addition, cover crops have the potential to enhance ecosystem services such as 1) increasing food, feed, fiber, and fuel productivity 2) soil organic carbon and other nutrient and water cycling, and 3) soil, water, and air quality/health improvement (Blanco-Canqui et al., 2015). Cover crop may be alternative for chemical fertilizer and pesticide. While actively growing, cover crops increase solar energy harvest and carbon flux into the soil, providing food for soil microorganisms, while simultaneously increasing evapotranspiration from the soil (Dabney et al., 2007). Moreover, cover crops have been proposed in the United State to increased soil organic carbon (SOC) stock of eroded and degraded soils and sequester SOC and according to the research, the result showed that cover crop management could increase SOC by 1.12 Mg-C ha^{-1} yr^{-1} with no-tillage agricultural practices (Olson et al., 2014).

Different cover crops provide different benefits to agricultural land. For instance, legumes (e.g. clover (*Trifolium repers* L.)) fix atmospheric nitrogen (N) for their own use. After terminating the legume cover crop, it will release N into the soil as the residues decompose and provide available N to the main crops. Some of cover crop (e.g. phacelia (*Hydrophylloideae*)) are able to suppress weeds or prevent insect damages by competition, shading, and allelopathy. Cover crop may be alternative for chemical fertilizer and pesticide.

Recently, researchers reported that cover crop mixtures could provide greater diversity of benefits than monoculture cover crop (Murrell et al., 2017; Tribouillois et al., 2016). Cover crop mixtures increase plant species diversity, in turn, potentially increasing ecosystem services that directly or indirectly improve main crop productivity (Zhang et al., 2007; Clark et al., 1994; Murrell et al., 2017). Yet the effects of cover crop mixtures on soil physical and chemical properties vary by climate, soil type, management practices, and a species of cover crops. Thus, there is a need for site, soil, and cover crop species-specific research on cover crop mixtures.

OBJECTIVE

The objective of this study was to demonstrate soil physical and chemical properties assessment under cover crops (clover, phacelia, and their mixture) vegetation.

METHODOLOGY

Experimental Design

The experiment was carried out at the field research plot, Tokyo University of Agriculture (35°38’29’’N, 139°37’56’’E, 40.3m elevation) during July to October in 2018 (Fig. 1). On average this site received 1464 mm of precipitation annually and mean annual temperature was 15.0 °C, respectively. Treatments included four cover crop systems: clover (*Trifolium repers* L.), phacelia (*Hydrophylloideae*), their mixture (clover and phacelia), and control (without cover crop) using Wagner pot (diameter = 256 mm, height = 297 mm, 1/2000a-scale). In this study, soils were taken from subsoil under arable land and were relatively the sterile soils. Soil are classified as Andosol and silty loam (sand 69.1 %, silt 19.9 %, and clay 11.0 %) by IUSS (International Union of Soil Sciences) classification.

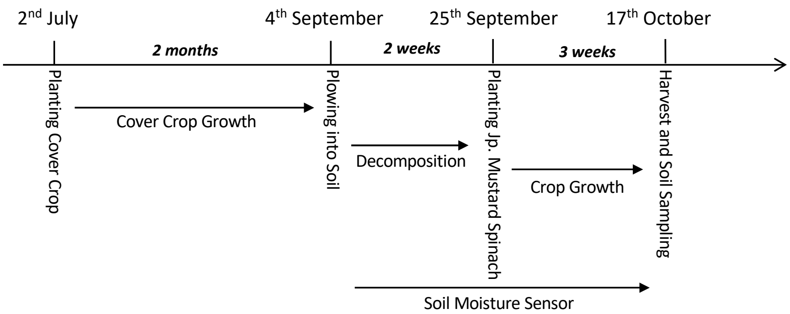

Fig. 1 Experimental schedule

Soil Analysis

Soil pH and electrical conductivity (EC) were determined using 1:1 soil to water ratio (Glendon and Dani, 2002). Concentration of SOC and total nitrogen (TN) were measured following the dry combustion method (960°C) using an automatic nitrogen-carbon analyzer (Sumika Chemical Analysis Service, Ltd., Tokyo, Japan). Briefly, the soil samples preparation was as follow; oven-dried (below 60°C) samples were ground with a mortar and pestle to allow passage through a 250 μm sieve, and then roller ground to yield a fine and homogeneous sample. Soil hardness was measure using yamanaka soil hardness tester (Daiki Rika Kogyo Co., Ltd, Tokyo, Japan). Saturated hydraulic conductivity (K_s) was measured with a mini disk infiltrometer (METER Group Inc., USA). Temporal changes of water content were measured by TDR (time-domain reflectometer) (5TE, METER Group Inc., USA).

Statistical Analysis

Analysis of variance was conducted comparisons between clover, phacelia, mixture, and control. The data were analyzed statistically using Tukey's test in R-Studio (Studio 2012). Statistical significance was computed at $p \leq 0.05$, unless otherwise stated.

RESULTS AND DISCUSSION

Soil Physical and Chemical Properties

Data of soil physical and chemical properties of different cover crop treatments (clover, phacelia, and mixture, and control vegetations) are shown in Table 1. Cover crop vegetation did not significantly affect pH. A similar trend in EC was observed at different cover crop treatments. Cover crop treatments significantly affect SH ($p < 0.05$). Cover crop with Mixture can alleviate soil compaction by penetrating compact layers and acting similar to tillage tools or bio drill. Blanco-Canqui et al (2015) stated that cover crop can alleviate compaction and reduce the susceptibility of the soil compaction. this benefit depends on the length of cover crop, and the amount and characteristics of the length and the size of roots. In addition, cover crop may improve soil compatibility by improving soil aggregation and increasing SOC concentration. Cover crop treatments significantly affected the K_s ($p < 0.05$). K_s under Control treatment was higher than other treatments. Cover crop may have intact bio-channel (e.g. root) which increase the subsurface channel network and may enhance the K_s. Cover crop mixture can positive impacts on Japanese mustard spinach. However, weather conditions (e.g. precipitation and temperature) and soil type are also important factors impacting vegetable yields response to cover crop management. The cover crop treatment especially Mixture improved the overall soil physical and chemical properties and Japanese mustard spinach in this study.

Table 1 Effects of cover crops on soil, pH, electrical conductivity (EC), soil hardness (SH), saturated hydraulic conductivity (K_s), and yield of Japanese mustard spinach

	pH	EC	SH	*Ks*	Japanese mustard spinach
	-	mS cm^{-1}	mm	cm s^{-1}	Mg ha^{-1}
Clover	6.82^{a}	0.129^{a}	19.5^{b}	2.36×10^{-3}	13.6^{ab}
Phacelia	6.83^{a}	0.136^{a}	19.5^{b}	2.51×10^{-3}	8.52^{b}
Mixture	6.87^{a}	0.131^{a}	20.8^{ab}	3.69×10^{-3}	15.6^{a}
Control	6.80^{a}	0.125^{a}	26.5^{a}	6.63×10^{-4}	10.8^{ab}

**Means with different letters among before vs. after logging soil for each depth are not significantly different at $p \leq 0.05$.*

The data in Fig. 2 show the soil organic carbon and total nitrogen contents under clover, phacelia, their mixture, and control treatments. The largest SOC concentration was observed in Mixture treatment, while the lower SOC concentrations were observed in Control and Clover. Similarly, the greatest TN concentration was obtained in Mixture treatment, while lower TN concentrations were obtained Clover, Phacelia, and Control. In general, cover crop residues and root accumulate on the soil surface layer. It leads to increase SOC concentration. Moreover, belowground biomass such as root inputs may particularly be important to increase SOC concentration (Blanco-Canqui et al., 2015). In turn, for the long-term strategy, cover crop mixture increases the SOC concentration, and it may improve the vegetable production.

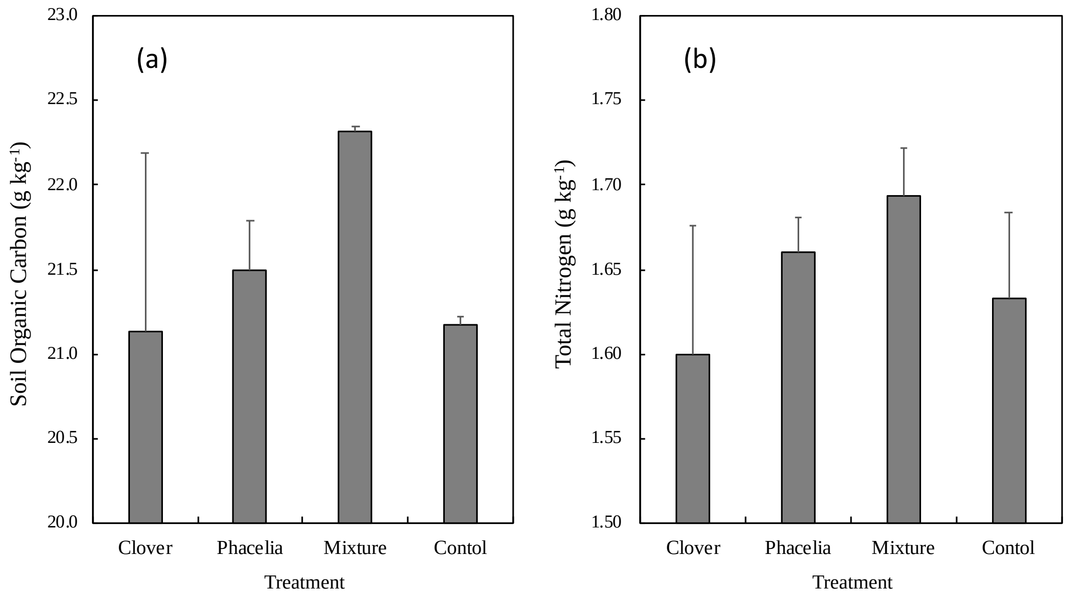

Fig. 2 Soil organic carbon (a) and total nitrogen (b) contents under clover, phacelia, their mixture, and control treatments

Means with same letter within treatments do not differ significantly with p ≤ 0.05.
Error bars represent ± one standard deviation.

Figure 3 shows that temporal changes of water content under clover, phacelia, and their mixture treatments. Phacelia and Mixture had higher the volumetric water content than Clover during the experiment. In general, cover crop roots and surface residues improve soil macro-porosity which increase water retention capacity (Blanco-Canqui *et al*., 2015). Cover crop also can improve soil hydraulic properties such as water infiltration, water retention capacity, and saturated hydraulic conductivity through improved the soil structure, especially, soil aggregation.

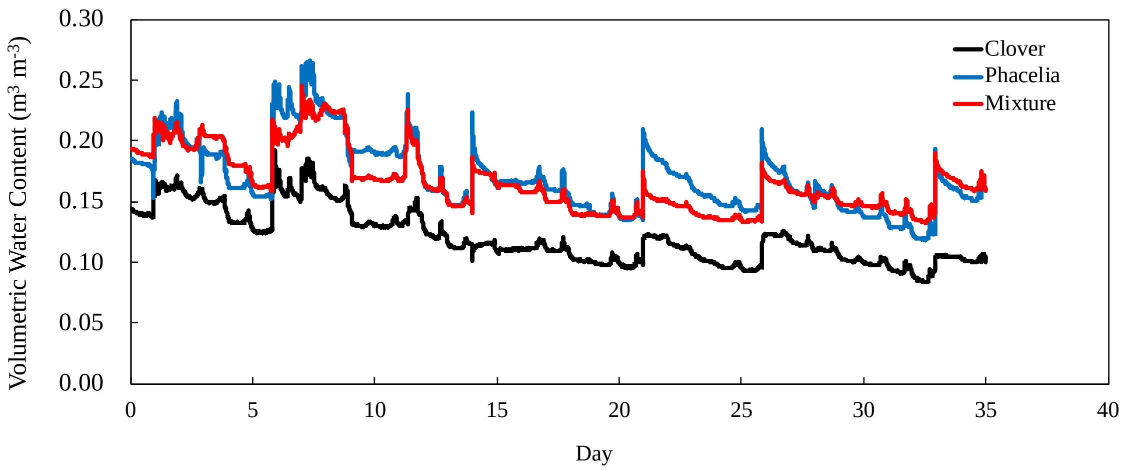

Fig. 3 Temporal changes of water content under clover, phacelia, and their mixture treatments

CONCLUSION

The hypothesis that that the cover crop mixtures could provide greater diversity of benefits than monoculture cover crop and increase plant species diversity, in turn, potentially increasing ecosystem services that directly or indirectly improve main crop productivity is proven. The data also support following conclusions: 1) Cover crop with Mixture can alleviate soil compaction by penetrating compact layers and acting similar to tillage tools or bio drill 2) Cover crop mixture can positive impacts on Japanese mustard spinach 3) Cover crop also can improve soil hydraulic properties such as water infiltration, water retention capacity, and saturated hydraulic conductivity through improved the soil structure, especially, soil aggregation.

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