

CHANGES IN THE SOIL PH, EC, AVAILABLE-P, DOC AND INORGANIC-N AFTER LAND USE CHANGE FROM RICE PADDY IN NORTHEAST JAPAN

Patria Novita Kusumawardani^{1,2}, Weiguo Cheng², Benito Heru Purwanto¹, and Sri Nuryani Hidayah Utami¹

¹Faculty of Agriculture, Gadjah Mada University, Bulaksumur, Yogyakarta 55281, Indonesia

²Faculty of Agriculture, Yamagata University, 1-23 Wakaba-machi, Tsuruoka, Yamagata 997-8555, Japan

ABSTRACT

The objective of this study was to determine the changes in the basic soil chemical properties including pH, electrical conductivity (EC), available phosphorus (P), dissolved organic carbon (DOC) and inorganic nitrogen (NH₄-N and NO₃-N) after approximately 15-40 years' land use change from rice paddy field to orchard, wetland and upland in northeast Japan. Five land use change fields were investigated, including, forest, rice paddy, orchard, wetland, and upland near Kumagai shrine, Shonai-machi, Yamagata, Japan. Soil samples were collected from surface layer (0-15 cm) and sub-surface layer (15-30 cm) in October 2015. Soil chemical properties of pH, EC, available-P, DOC and inorganic-N (NH₄-N and NO₃-N) were analyzed on air-dried samples. The pH increased significantly in the upland after 15 years conversion from rice paddy in both layers, with other land use changes only increasing pH in sub-surface layer. EC significantly decreased in the surface layer of orchard and upland fields and in sub-surface layers of all the converted fields. Available-P significantly decreased in the converted fields, except in the upland sub-surface layer. DOC amounts were not significantly different after land use changes from paddy fields. The NH₄-N decreased significantly only in the surface layer of upland, while NO₃-N increased significantly only in the surface layer of wetland. Significant changes in soil properties were observed after 15 years conversion to upland and 40 years conversion to orchard and wetland from former rice paddy field in this study.

Keywords: Land use change, orchard, rice paddy, soil properties, upland, wetland.

INTRODUCTION

Land use change is a key factor to global change through its many environmental processes which influence basic resources within the landscape, including the soil resources. Inadequate soil management can quickly reduce vast amounts of land, which often becomes a major threat to rural livelihood in many developing and developed countries (Gonzalez et al., 2014). In Japan and other Asian countries, consecutive paddy rice (*Oryza sativa* L.) cultivation has been conducted for a long time. However, rice consumption is decreasing in Japan due to changes in the Japanese dietary transition since 1970s, with people now consuming more milk, meat, and bread than before in 1970s (Smil and Kobayashi, 2012). As a

result, rice cultivation area decreased from 3.3 million ha in 1960s to 1.6 million ha in 2015, simultaneously the abandoned agricultural land area is increasing in Japan (MAFF, 2017). For increasing the percentage of self-sufficient food supply and preserving agricultural land, upland crops (soybean, buckwheat, and so on) are cultivated in drained paddy fields. The crop rotation of paddy rice and upland crops (paddy-upland crop rotation) is also widely conducted in Japan. Drainage of rice paddy fields over the years in accordance with the introduction of upland crop cultivations may cause significant changes in various soil properties and soil till ability (Takahashi et al., 1999).

Human cleared forest land for cultivation for a long time. It significantly influences the soil properties and modifies soil forming processes. Land use change can drastically affect the soil environment, which in turn

Correspondence: Weiguo Cheng and Benito Heru Purwanto
Email: cheng@tds1.tr.yamagata-u.ac.jp, benito@ugm.ac.id

markedly influences soil properties (Chen et al., 2000). Changes in pH, EC, available-P, soil dissolve organic-C (DOC), inorganic-N (NH_4^+ and NO_3^-) have been investigated in many regions around the world (Filep and Rekasi, 2011; Sheng et al., 2015; Tete et al., 2015; Cheng et al., 2016). Sheng et al. (2015) found out that DOC was the most sensitive indicators to land use change. A study carried out by Chibsa and Ta (2009) on assessment of soil organic matter (SOM) contents in four land use systems in major soils of Bale highlands, southeast Ethiopia, showed that the major soil parameters affecting SOM storage were affected by land use systems at 0-5, 5-15, 15-30 and 30-60 cm soil depths. The result indicated that the distribution and abundance of soil organic carbon were varied independently in all land use systems. Geissen et al. (2009) investigated on the effect of change in land use on soil chemical properties in tropical regions in south-east Mexico, and declared that the changes in land use in 15 years had no significant effect on soil properties. The land use change is known for resulting in significant perturbation of agroecosystems functioning but very recently no studies were conducted on the conversion of paddy fields which are very specific agroecosystems due to permanent flooding during the growth season.

The objective of this study was to determine the changes in pH, EC, available-P, DOC and inorganic-N after 15–40 years land use change from rice paddy fields to wetland, orchard, and upland in the same place at northeast of Japan.

MATERIALS AND METHOD

Site description and the land use change types

The investigation was conducted in the area near Kumagai shrine, Shonai-machi, Yamagata, northeast Japan ($38^{\circ}43'N$; $140^{\circ}01'E$), an area within a typical humid temperate climate zone. In winter season, the site was covered by snow for more than three months from the end of December to early March. According to data recorded at Karikawa Meteorological Station, 8 km from

Kumagai Shrine (<http://www.data.jma.go.jp/>), the mean annual temperature near the site was 11.7°C , annual precipitation was 2009.9 mm, and annual depth of snowfall was 573 cm in the past 30 years (1981-2010). Only single cropping can be cultivated a year in this region. The fields near Kumagai Shrine were paddies used for cultivating rice for over a hundred years during summer season from the end of May to early October. Since 1970s, parts of the fields were converted to chestnut (*Castanea crenata*) orchard in 1975. Parts of chestnut could not grow in the high moisture field, where spring water from the adjacent mountain flows through. About 10 years later the high moisture field changed to natural wetland. The plant grown in the wetland area is a C4 plant, Amur silver-grass (*Miscanthus sacchariflorus* B.). Since 2000, most rice paddies were converted to upland to cultivate buckwheat (*Fagopyrum esculentum*). In this study, we selected five kinds of land use change types in this area as treatments for our research, (1) forest, around the former rice paddies; (2) rice paddy, continuing rice production more than a hundred years; (3) orchard, 40 years after cultivating chestnut; (4) wetland, about 30 years after abandoned from chestnut; and (5) upland, 15 years after cultivating buckwheat. Forest is a reference as the origin land of rice paddy field.

Soil sampling and analysis

The soil samples were collected on 23rd October 2015 using auger sampler from surface (0-15 cm) and sub-surface layers (15-30 cm depth) on each field. Nine core soil samples were taken from each fields, forest, orchard, and wetland. Three cores of each field were mixed to make up one replicate. Eighteen and 27 core soil samples were taken from rice paddy and upland, respectively, then six and nine cores were mixed to make up one replicate for rice paddy and upland fields since the field areas were about two and three times more than the others. Soil samples were air dried in a glasshouse and sieved using 2 mm sieve to measure pH, EC, available-P, DOC, and inorganic-N ($\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$) at Laboratory of Soil Science and Plant Nutrition, Faculty of Agriculture,

Yamagata University, during October 2015 to August 2016.

Available-P was analyzed by Truog method extracted by 0.002 N H₂SO₄ (JSSSPN, 1986). DOC and inorganic-N (NH₄-N and NO₃-N) extracted by 10 % KCl solution and then filtered through a filter paper. DOC was measured by TOC analyzer (Shimadzu, Japan). NH₄-N and NO₃-N were analyzed by colorimetric techniques at 655 nm and 450 nm by using a UV-1200V spectrophotometer (Shimadzu, Japan).

Data calculation and statistical analysis

The data obtained from the experiment was then calculated with analysis of variance (ANOVA) to determine the statistical significance of measurement parameters among five land use change fields (treatments). If the result from ANOVA showed significant differences ($P < 0.05$) among treatments, Duncan's multiple range test (DMRT) was continually used to compare each treatment. The analysis was done using R statistical analysis software. The stratification ratios (SR) of all parameters were calculated as ratio of surface and sub-surface layers.

RESULTS

Changes in soil pH and EC

Only conversion to upland significantly increased soil pH in both soil depths. After 15 years of land use change from rice paddy to upland the surface layer pH increased from 5.27 to 5.76, while that in sub-surface layer from 5.2 to 5.9. All converted fields' sub-surface layers had a significantly higher soil pH than rice paddy (Fig. 1). The stratification ratio of soil pH in rice paddy was higher (1.01) than those of all land use change fields (0.93~0.98, Fig. 1).

The soil EC in surface layers of orchard and upland was significantly lower than in the rice paddy. While the EC in surface layers of forest and wetland were similar to rice paddy. In sub-surface layer, EC was significantly lower in all fields after land use changes from rice field (Fig. 2). The stratification ratios of EC in all fields were larger than 1. The highest was 2.59 in wetland and the lowest was 1.32 in rice paddy (Fig. 2).

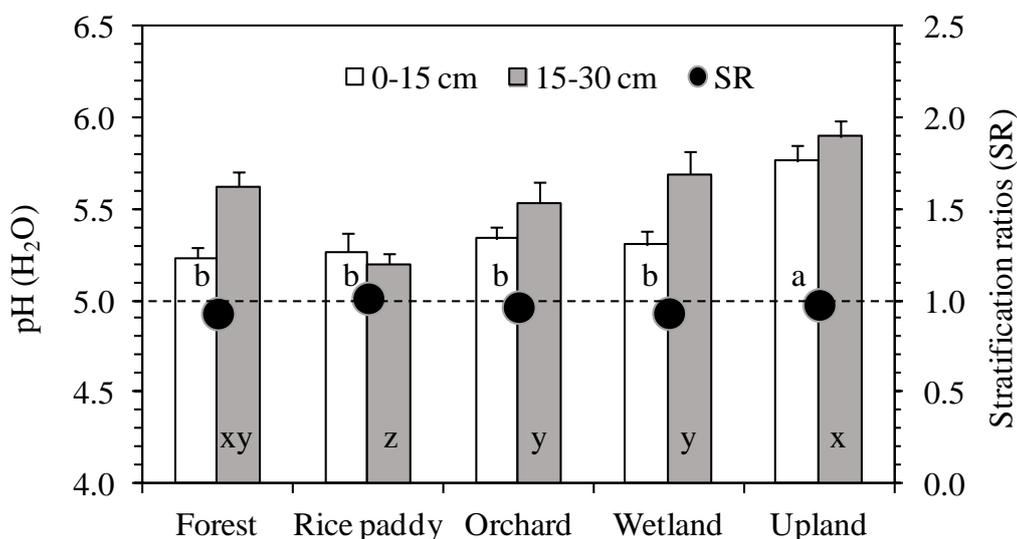


Figure 1. The changes in pH at surface layer (□ 0-15 cm), sub-surface layer (■ 15-30 cm), and the stratification ratios (● surface/sub-surface) among five kinds of fields with different land use changes. Bars indicated standard deviation ($n = 3$). The letters of a, b and x, y, z indicate significant differences for surface and sub-surface layers, respectively, among kinds of fields at the 5% level.

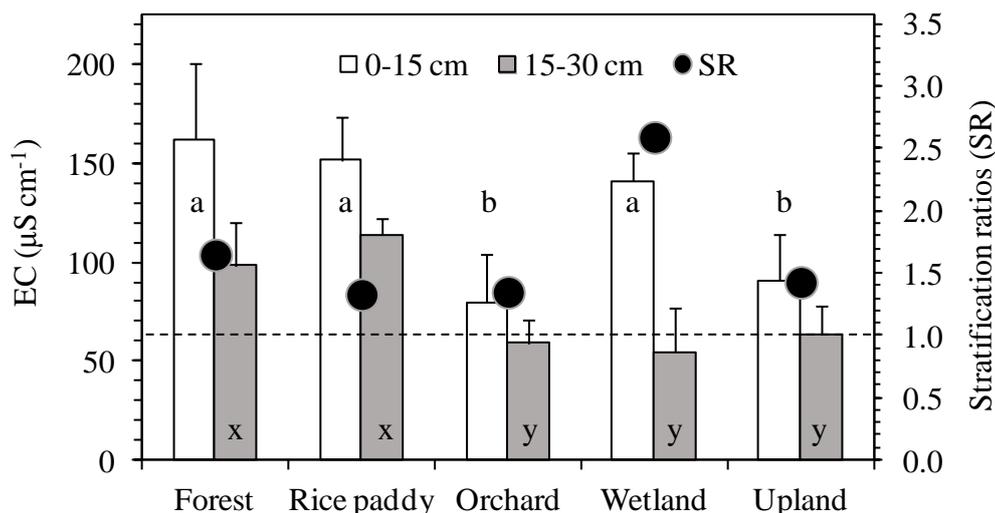


Figure 2. The changes in EC at surface layer (□ 0-15 cm), sub-surface layer (■ 15-30 cm), and the stratification ratios (● surface/sub-surface) among five kinds of fields with different land use changes. Bars indicated standard deviation ($n = 3$). The letters of a, b and x, y indicate significant differences for surface and sub-surface layers, respectively, among kinds of fields at the 5% level.

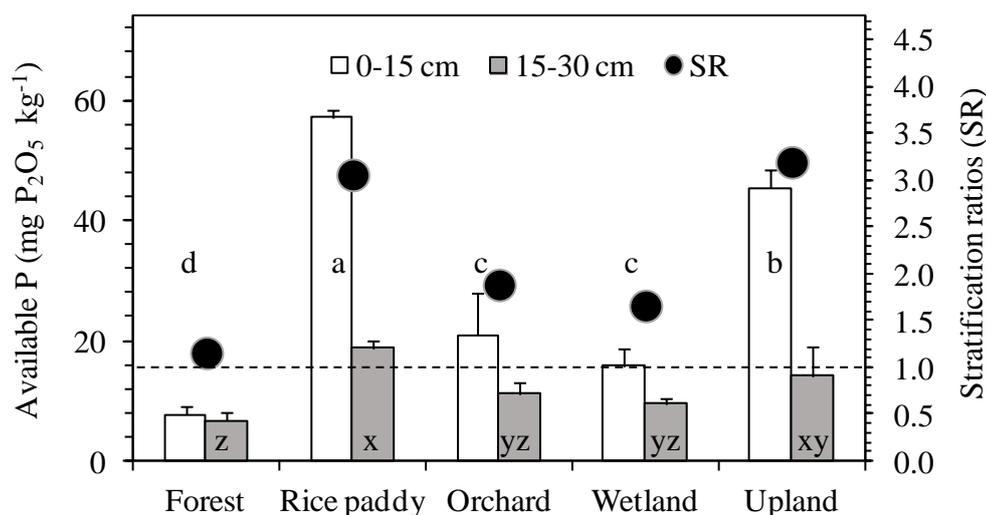


Figure 3. The changes in available-P at surface layer (□ 0-15 cm), sub-surface layer (■ 15-30 cm), and the stratification ratios (● surface/sub-surface) among five kinds of fields with different land use changes. Bars indicated standard deviation ($n = 3$). The letters of a, b, c, d and x, y, z indicate significant differences for surface and sub-surface layers, respectively, among kinds of fields at the 5% level.

Changes soil available P

The available-P varied largely between land use types in the surface layer. It was significantly decreased in wetland (15.79), orchard (20.89), and upland (45.35) compared to Rice (122.61 mg P₂O₅ kg⁻¹) in surface layer. While in the sub-surface layer, conversion of rice field only changed available-P concentration in wetland (9.52

and orchard (11.09) from rice field (18.70 mg P₂O₅ kg⁻¹). Available-P concentration was highest in the surface layer than that in sub-surface layer in all land use change fields. The stratification ratios of available-P were larger in upland (3.16) and rice paddy (3.06) than those in orchard (1.88), wetland (1.66) and forest (1.16 mg P₂O₅ kg⁻¹) (Fig. 3).

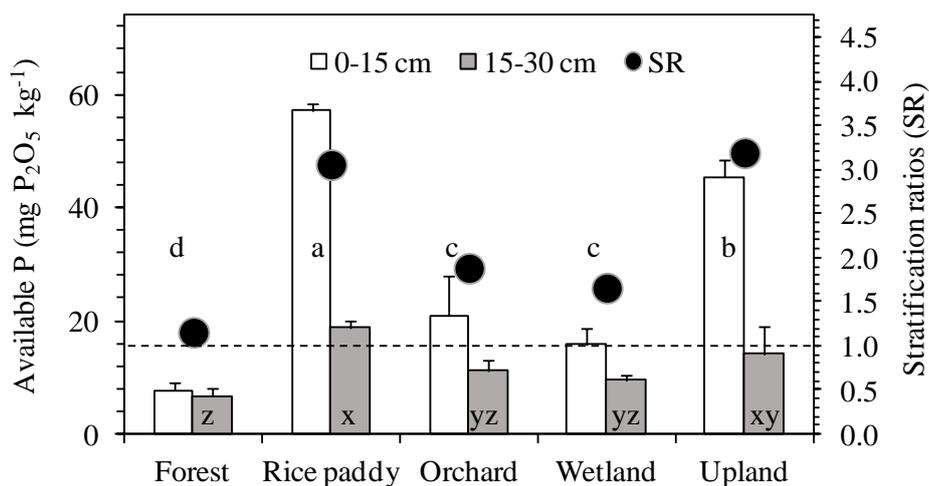


Figure 4. The changes in DOC at surface layer (□ 0-15 cm), sub-surface layer (■ 15-30 cm), and the stratification ratios (● surface/sub-surface) among five kinds of fields with different land use changes. Bars indicated standard deviation ($n = 3$). The letters of a, b and x, y indicate significant differences for surface and sub-surface layers, respectively, among kinds of fields at the 5% level.

Changes in dissolves organic C

Conversion of rice field to wetland, orchard and upland did not have a significant effect toward DOC in both soil layers. Generally, the DOC amount in surface layer was higher than those in sub-surface layer, except in the forest, where the DOC in surface layer was lower than that in sub-surface layer at 187.44 mg C kg⁻¹ (Fig. 4).

Changes in Soil NH₄-N and NO₃-N

The NH₄-N decreased significantly only in upland at surface layer by 8.88 mg kg⁻¹ (Fig. 5). The NO₃-N increased significantly only in wetland at surface layer by 27.63 mg kg⁻¹ (Fig. 6). There were no significant differences in NH₄-N and NO₃-N in sub-surface layer among the five land use change fields (Fig. 5 and 6). The stratification ratios of NH₄-N and NO₃-N were around 0.84~1.72 and 1.03~1.40, respectively (Fig. 5 and 6).

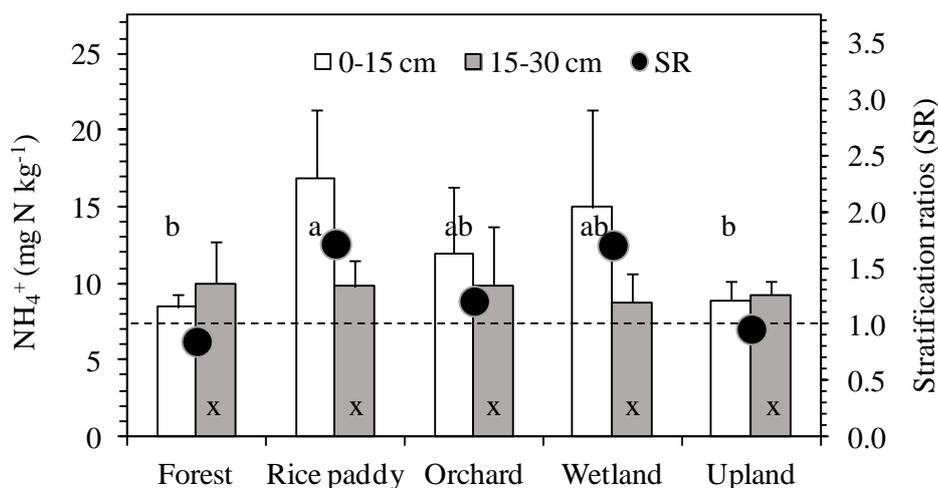


Figure 5. The changes in NH₄-N at surface layer (□ 0-15 cm), sub-surface layer (■ 15-30 cm), and the stratification ratios (● surface/sub-surface) among five kinds of fields with different land use changes. Bars indicated standard deviation ($n = 3$). The letters of a, b and x, y indicate significant differences for surface and sub-surface layers, respectively, among kinds of fields at the 5% level.

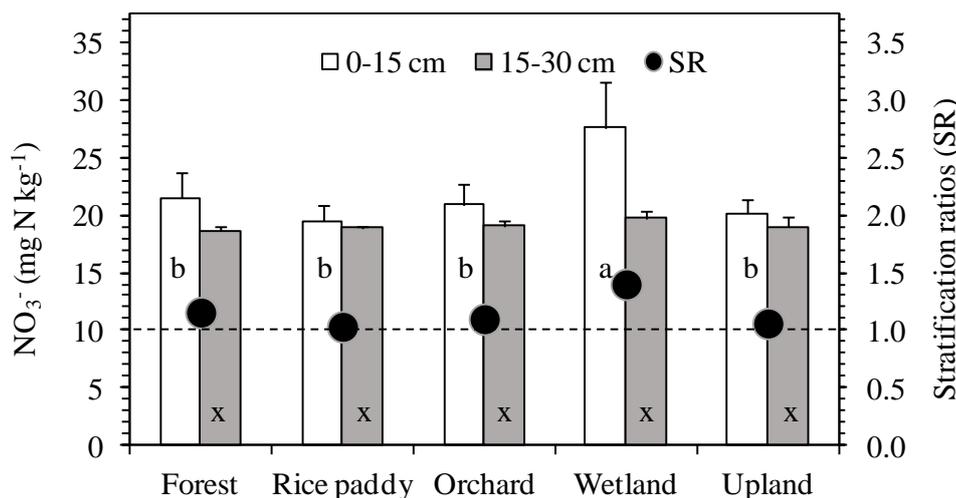


Figure 6. The changes in NO₃-N at surface layer (□ 0-15 cm), sub-surface layer (■ 15-30 cm), and the stratification ratios (● surface/sub-surface) among five kinds of fields with different land use changes. Bars indicated standard deviation ($n = 3$). The letters of a, b and x, y indicate significant differences for surface and sub-surface layers, respectively, among kinds of fields at the 5% level.

DISCUSSION

Effects of rice paddy field conversion on Soil pH, EC, and available P

Soil pH is one of the most important soil properties indicating the acidity or alkalinity in soil. The decomposition of soil organic matter, despite its impacts on soil pH, it could be influenced by soil pH and land use change. Differences in soil pH under different plant species have been observed in previous studies (Alriksson and Eriksson, 1998; Oostra et al., 2006). Our results showed that the soil pH of upland field was the highest compared to other land use change types. Soil pHs of wetland and chestnut orchard fields were higher than in rice paddy even though not significant (Fig. 1). The conversion of rice paddy to buckwheat upland had been started 15 years ago shorter than that of conversion to wetland and chestnut orchard which was changed 40 years ago. It implies that when the rice paddy was changed to cultivate upland crop, the soil pH increased more quickly than it did when converted to orchard or abandoned to natural wetland. Su et al. (2009) also showed that the lower pH value at the surface soil in cropland relative to abandoned fields was probably related to applications of fertilizer and organic manure. Changing land

use change types via changing land-cover (e.g., plant species) or agricultural activities (e.g., fertilizer, weeding) can have significant and long-lasting effects on soil pH (Post and Mann, 1990; Murty et al. 2002). Our results also showed that, soil pHs of the sub-surface layers of converted fields were higher than those of the surface layers compared to both layers of rice paddy (Fig. 1). The pH increased with depth maybe due to extensive leaching and removal of basic cations from the upper horizons.

Soil EC is an indirect measurement that correlates very well with several soil physical and chemical properties. Soil EC indicates the amount of soluble salt ions in soil. Our result showed the EC of surface layer were always higher than those of sub-surface layer among all fields (Fig. 2). It was similar to the study by Zhang et al. (2014), in which the land use changes happened in the west of Loess Plateau, Northwest China.

Our result showed that land use change from rice paddy field after approximately 15-40 years significantly decreased the amount of available-P, especially in chestnut orchard and wetland area which had been converted and abandoned since 40 years ago. The large difference between rice paddy and wetland or

rice paddy and chestnut orchard can be considered due to long-term absence of fertilization. The amounts of available-P in chestnut orchard and wetland were higher than those in forest area indicating that part of the former fertilized-P is still remaining even though the fertilization was stopped before 40 year ago. The amounts of available-P were larger in surface layers than those in sub-surface layers in our study. A study from Rezaei et al. (2012) also found out that the amount of available-P decreased significantly with the soil depth after forest was converted to tea plantation.

Effects of rice paddy field conversion on Soil DOC and inorganic-N

Soil DOC is readily decomposable C and can be preferentially utilized by the microorganisms than the recalcitrant fraction of soil organic C (Kalbitz et al., 2003; Cleveland et al., 2007; Ghani et al., 2013). Our result showed that after 15 years conversion to buckwheat upland and 40 years conversion to chestnut orchard and natural wetland from rice paddy did not significantly affect DOC. However, DOC in the rice paddy and its conversion fields were higher than forest in the surface layer, but lower than forest in sub-surface layer. This result is similar to the study by Sheng et al. (2015), which they reported DOC in subsoil were significantly increase in the forest and orchard soil but decreased in the plantation soil after the land use changes in sub-tropical China. Filep et al. (2011) revealed that the DOC pathways may be different in arable ecosystems than in forest soils. Our result showed that the DOC was lower in the sub-surface layer on 15-30 cm depth than in surface layer on 0-15 cm depth. Zhang et al. (2006) reported that the DOC decreased with soil depth in the different land use change ecosystems from former wetland in the Sanjiang Plain of northeast China, and the amounts of SOC were largely different among land use change types. However, land use changes from rice paddy field to natural wetland, chestnut orchard, and buckwheat upland did not significantly affect on the amount of soil DOC in our study.

The soil inorganic-N is one of the most important parameters indicating soil fertility and becomes a sensitive parameter in the land use change. Land use and management practices can affect soil N mineralization, nitrification, and denitrification. Our results showed that after 15 years of conversion to, the amount of $\text{NH}_4\text{-N}$ in the air-dried soil sample taken from surface layer at buckwheat upland field was significantly lower than that from rice paddy (Fig. 5). The amounts of $\text{NO}_3\text{-N}$ were similar among all land use change fields, except in wetland at surface layer (Fig. 6). $\text{NH}_4\text{-N}$ formed as the result of N mineralization, it is produced slowly under aerobic conditions and fast in sub-merged condition. $\text{NO}_3\text{-N}$ is formed in aerobic conditions via nitrification pathways. In the sub-merged condition, nitrification is suppressed by the anaerobic situation. Since the amounts of $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ shown in paper were from the air-dried soil samples taken from the different land use change fields, the data could not represent the inorganic-N dynamics in the real fields. For example, amount of $\text{NO}_3\text{-N}$ in the surface layer of natural wetland was significant higher than that in other fields. But the wetland was more waterlogged; this increment could be caused by the air dried treatment of the soil samples before measurement. Considering that all of the land uses are at the same climate zone, the different pathways of N dynamics under land use change types could be attributed to various management practices, especially the application of N fertilizer (Knops et al., 2002; Wang et al., 2015). More researches are needed to solve the N dynamics in the conversion fields from rice paddy in future.

ACKNOWLEDGEMENTS

First author, Patria Novita Kusumawardani appreciated the Japan Student Services Organization (JASSO) for supporting her studies in the Faculty of Agriculture, Yamagata University, Japan, during September 2015 to August 2016. We thank all members in Cheng Lab and Mr K. Sugawara for helping with the soil sampling,

and Mr. S.M. Kimani for improving the manuscript. This research was funded in part by the COC (Center of Community) Program Grant from Yamagata University.

REFERENCES

- Alriksson A, Eriksson HM. 1998. Variations in mineral nutrient and C distribution in the soil and vegetation compartments of five temperate tree species in NE Sweden. *Forest Ecology and Management*. 108: 261-273.
- Chen CR, Condon LM, Davis MR, Sherlock RR. 2000. Effects of afforestation on phosphorus and biological properties in a New Zealand grassland soil. *Plant and Soil*. 220: 151-163.
- Cheng W, Padre AT, Shiono H, Sato C, Nguyen-Sy T, Tawaraya K, Kumagai K, 2016. Changes in the pH, EC, available P, SOC and TN stocks in a single rice paddy after long-term application of inorganic fertilizers and organic matters in a cold temperate region of Japan. *Journal of Soils and Sediments*. doi:10.1007/s11368-016-1544-9 (First Online: 17 September 2016).
- Chibsa T, Ta AA. 2009. Assessment of soil organic matter under four land use systems, in Bale Highlands, Southeast Ethiopia A. Soil organic matter contents in four land use systems: Forestland, grassland, fallow land and cultivated land. *World Applied Sciences Journal*. 6: 1231-1246.
- Cleveland CC, Nemergut DR, Schmidt SK, Townsend AR. 2007. Increases in soil respiration following labile carbon additions linked to rapid shifts in soil microbial community composition. *Biogeochemistry*. 82: 229-240.
- Filep T, Rekasi M, 2011. Factors controlling dissolved organic carbon (DOC), dissolved organic nitrogen (DON) and DOC/DON ratio in arable soils based on a dataset from Hungary. *Geoderma*. 162: 312-318.
- Geissen V, Sanchez-Hernandez R, Kampichler C, Ramos-Reyes R, Sepulveda-Lozada A, Ochoa-Goana S, de Jong BHJ, Huerta-Lwanga E, Hernandez Dumas S. 2009. Effects of land use change on some properties of tropical soils - An example from Southeast Mexico. *Geoderma*. 151: 87-97.
- Gonzalez AP, de Abreu CA, Tarquis AM, Roldan EM. 2014. Impacts of land use changes on soil properties and processes. *The Scientific World Journal*. Article ID 831975.
- Ghani A, Sarathchandra U, Ledgard S, Dexter M, Lindsey S. 2013. Microbial decomposition of leached or extracted dissolved organic carbon and nitrogen from pasture soils. *Biology and Fertility of Soils*. 49: 747-755.
- JSSSPN (Japanese Society of Soil Science and Plant Nutrition), 1986. Soil Normal Analysis Methods, Hakuyusha Press, Tokyo (in Japanese).
- Kalbitz K, Schmerwitz J, Schwesig D, Matzner E. 2003. Biodegradation of soil-derived dissolved organic matter as related to its properties. *Geoderma*. 113: 273-291.
- Knops J, Bradley K, Wedin D. 2002. Mechanisms of plant species impacts on ecosystem nitrogen cycling. *Ecology Letters*. 5: 454-466.
- MAFF. 2017. About Promoting Forage Rice (Shiryoyoumei no Suishin ni Tsuite). Ministry of Agriculture, Forestry and Fisheries (MAFF), February 2017 (in Japanese).
http://www.maff.go.jp/j/seisan/kokumotu/pdf/siryomai_meguji_2902.pdf.
- Murty D, Kirschbaum MUF, Mcmurtrie RE, Mcgilvray H. 2002. Does conversion of forest to agricultural land change soil carbon and nitrogen? A review of the literature. *Global Change Biology*. 8: 105-123.

- Oostra S, Majdi H, Olsson M. 2006. Impact of tree species on soil carbon stocks and soil acidity in southern Sweden. *Scandinavian Journal of Forest Research*. 21: 364-371.
- Post WM, Mann LK. 1990. Changes in soil organic carbon and nitrogen as a result of cultivation. In: *Soils and the Greenhouse Effect*. pp.401-406. John Wiley. New York
- Rezaei N, Roozitalab MH, Ramezani H, 2012. Effect of land use change on soil properties and clay mineralogy of forest soils developed in the Caspian Sea region of Iran. *Journal of Agricultural Science and Technology*. 14: 1617-1624.
- Sheng H, Zhou P, Zhang Y, Kuzyakov Y, Zhou Q, Ge T, Wang C. 2015. Loss of labile organic carbon from subsoil due to land-use changes in subtropical China. *Soil Biology and Biochemistry*. 88: 148-157.
- Smil V, Kobayashi K. 2012. Japan's dietary transition and its impacts. The MIT Press, Massachusetts Institute of Technology, Cambridge, Massachusetts 02142 USA.
- Su YZ, Liu WJ, Yang R, Chang XX. 2009. Changes in soil aggregate, carbon, and nitrogen storages following the conversion of cropland to alfalfa forage land in the marginal oasis of northwest China. *Environmental Management*. 43: 1061-1070.
- Takahashi T, Park CY, Nakajima H, Sekiya H, Toriyama K. 1999. Ferric iron transformation in soils with rotation of irrigated rice-upland crops and effect on soil tillage properties. *Soil Science and Plant Nutrition*. 45: 163-173.
- Tete E, Viaud V, Walter C. 2015. Organic carbon and nitrogen mineralization in a poorly-drained mineral soil under transient waterlogged conditions: An incubation experiment. *European Journal of Soil Science*. 66: 427-437.
- Wang J, Liu Q, Zhang J, Cai Z. 2015. Conversion of forest to agricultural land affects the relative contribution of bacteria and fungi to nitrification in humid subtropical soils. *Acta Agriculturae Scandinavica, Section B - Soil Plant Science*. 65: 83-88.
- Zhang JB, Song CC, Yang WY. 2006. Land use effects on the distribution of labile organic carbon fractions through soil profiles. *Soil Science Society of America Journal*. 70: 660-667.
- Zhang L, Zhao R, Xie Z. 2014. Response of soil properties and C dynamics to land use change in the west of Loess Plateau. *Soil Science and Plant Nutrition*. 60: 586-597.