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Leaching characteristics of nitrate nitrogen in an apple orchard andosol under significant snow accumulation

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ABSTRACT

The purpose of this study was to clarify nitrogen (N) leaching behavior as affected by snowmelt percolation in an Andosol soil planted with an established apple orchard, with the aim of supporting fertilization management that preserves the soil environment while maximizing apple production. Simultaneous measurements of electrical conductivity (EC), pH, NO_3-N, and NH_4-N (inorganic-N concentration) of the apple orchard soil pore water were taken. The adsorption nature of NO_3-N and NH_4-N were also monitored using Langmuir type and Logistic type adsorption isotherms. Numerical analysis relevant to the spatiotemporal dynamics of inorganic-N in soil pore water was also conducted during the growing and non-growing period for apples. The level of soil pore water EC resulting from fertilizer application was characteristically altered by downward leaching over time. Regarding the NO_3-N concentration of soil pore water in the investigated area with heavy snow accumulation, the bulk of the fertilizer applied from January to July 2016 was leached down to z = 100 cm within 5 to 6 months. In the apple orchard during and after snowfall, the numerical results revealed that when NO_3-N < 100 mg L^{-1}, NO_3-N was leached without being adsorbed by the soil. In addition, since the NO_3-N concentration in soil water after the disappearance of snow was very low, it is necessary to apply N fertilizer in early April (initial growth stage of current shoots and anthogenesis) in order to maximize apple tree growth. Extreme N-leaching due to percolated snowmelt in early spring (a 35-cm movement within 0.5 months) was observed in the apple orchard planted on Andosol soil. Therefore, it was inferred that concentrations of inorganic-N in the soil during April were reset to zero, and that N supplementation in the apple orchard is necessary for maximizing apple production.

1. Introduction

Apple production in Japan is prosperous, particularly in Aomori Prefecture, in the northernmost part of the Tohoku region. In 2014, the apple cultivation area in Japan was approximately 37,100 ha and annual fruit production was 816,300 tons, of which Aomori Prefecture produced 57% (470,000 tons) (MAFF, 2015). Fertilization in Japan is generally conducted from the fall to winter seasons, similar to that in Nagano Prefecture (Nagano Prefecture, 2000), which is the second largest apple-producing region in Japan. Because Aomori Prefecture experiences heavy snowfall, spring fertilization in mid-April is recommended in this area (Aomori Prefecture, 2014). Fertilization is conducted during the spring season because the nitrogen (N) fertilizer that was not taken up by apple trees will have been leached to deeper soil by the snowmelt during the period of apple dormancy. Domestic demand for N-fertilizer has been declining because of the reduction in orchard production area and the policy of reducing the amount of fertilizer used. Conversely, the amount of N-fertilizer used on farmland for crops, such as vegetables and forage, has increased. Currently, in Japan, large amounts of fertilizer are being applied depending on the orchard crop (MAFF, 2009). Endo et al. (2009) reported on N-fertilization in Andosol upland fields and developed a numerical model regarding inorganic-N transport in the soil. They reported that the amount of drainage water and leached N, based on field conditions and numerical experiments, were almost equivalent. Mishima and Kohyama (2010) found that the N-balance of surface soil from 1985 to 2005 depended on the amount of applied fertilizer and yield from agricultural fields. They pointed out that surplus N on agricultural land did not substantially decrease during the period analyzed. Moreover, Endo et al. (2013) revealed that surplus N had negative environmental influences, using numerical analysis to quantify NO_3-N leaching from a depth of 100 cm in fields (paddy, crop land, orchard, and grassland). They reported that the average annual amount of leached nitrogen (NO_3-N) was 150 kg N ha^{-1} for conventional fertilization. Methods that can be used to reduce the amount of N-leaching from crop fields include the application of less fertilizer, using a controlled-release

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fertilizer, using a nitrification inhibitor, and using biochar, which has inorganic-N adsorption properties (Hardie et al., 2015; Ventura et al., 2013). Endo et al. (2017) estimated the spatiotemporal dynamics and inorganic-N leaching in apple orchards attributable to the infiltration of snowmelt in early spring in a Gray lowland soil in Aomori Prefecture. Kato et al. (2016) evaluated the effects of fertilization on the soil environment in a humic Andosol after fertilization by monitoring the electric conductivity (EC) of a soil solution and volumetric water content over a long period. In areas with significant snow accumulation, such the Aomori Prefecture in Japan, apple orchards on Andosol, which have high permeability characteristics, are affected by snowmelt infiltration, and it is thus predicted that appreciable N-leaching will occur. The objective of this study was to clarify N-leaching behavior in an Andosol apple orchard due to the effects of snowmelt infiltration between mid-March and early April, which has yet to be clarified. By achieving this objective, it will eventually be possible to design a fertilization system that is beneficial to both the soil environment and apple growth.

2. Materials and methods

2.1. Soil profiles and basic soil properties in the study area

The study was conducted in an apple orchard growing on an Andosol soil in Tsuruta, Aomori Prefecture, Japan (Fig. 1), at N40°45′34″, E140°20′55″ and an elevation of 48.3 m above sea level. This area is located in the Tohoku region of Japan, which has a subarctic zone-humid climate and commonly experiences substantial snow accumulation in the winter season. On August 12, 2014, the authors excavated the orchard soil surface to a depth of 60 cm for soil sampling. To determine the physical and chemical properties of the apple orchard soil, 100-mL soil core samples and disturbed soil samples were collected at depths of 10, 30, 50, and 60 cm. Soil particle density and soil particle size distribution were measured to determine the texture of the apple orchard soil according to the Japan Industrial Standards (JIS) A1204 and A1202 (The Japanese Geotechnical Society), respectively. Measurement of saturated hydraulic conductivity and soil-water retention curves (SWRC) necessary to estimate unsaturated hydraulic conductivity were performed based on JIS A1218 and JGS 0151, respectively. For soil hydraulic characteristics, SWRC parameters (vanGenuchten, 1980) were calculated using nonlinear regression (Mathcad 15, PTC). The pH and EC of soil subjected to extraction with 1:2.5 and/or 1:5 deionization water were measured using the glass electrode method (B-712, Horiba) and electrical conductivity method (B-771, Horiba), respectively. Water-soluble NH_4-N and NO_3-N extracted from 1:5 soil-water were quantified by ion chromatography analysis (ICS-90, Dionex). Total carbon (T-C) and total nitrogen (T-N), necessary to calculate the C/N ratio, were quantified using an elemental analyzer (vario EL cube, Elementar). Cation exchange capacity (CEC) and phosphate absorption capacity were measured using the semi-micro Kjeldahl method (SuperKjel-1300, Actac) and phosphovanadomolybdate method, respectively.

2.2. Installation of soil sensors and soil pore water sampling tubes

To simultaneously measure volumetric water content, soil bulk EC, and soil temperature in the study field, multifunctional soil sensors (5TE, Decagon) were installed at depths of 4, 8, 16, 32, and 64 cm. In order to convert the soil bulk EC (output of sensor) to the soil pore water EC, we adopted a theoretical model described as follows (Hilhorst, 2000):

$$EC_p = \frac{\varepsilon_p \bullet EC_b}{\varepsilon_r - \varepsilon_{EC_b=0}} \tag{1}$$

$$\varepsilon_p = 80.3 - 0.37 \times (T - 20) \tag{2}$$

where EC_p and EC_b are soil pore water and bulk soil EC (mS cm^{-1}), respectively. ε_r, $\varepsilon_{EC_b} = 0$, and T are real dielectric constant of soil and dielectric constant at $EC_b = 0$, and soil temperature (°C), respectively. Based on the sensor calibration test related to the EC_p, we adopted $\varepsilon_{EC_b} = 0 = 7.90$ (Kato et al., 2016).

Soil pore water sampling tubes (DIK-8390, DAIKI) used to monitor the inorganic-N concentration in soil pore water were also installed at depths of 4, 8, 16, 32, 64, and 100 cm. The soil sensors and pore water sampling tubes were located at approximately 1.5 m in a radial direction from the trunks of apple trees. The soil sensors were used to measure physical quantities at 30-min intervals (Kato et al., 2016). Soil pore water was sampled at approximately 1- to 2-week intervals, and the concentration of cations (e.g., NH_4^+) and anions (e.g., NO_3^-) in diluted water samples were determined by ion chromatography analysis.

2.3. Adsorption isotherm (AI) analysis of NH_4-N and NO_3-N

The magnitude relationship of anion adsorption intensity in the soil solution was expressed as HPO_4^{2-}, $H_2PO_4^- \gg SO_4^{2-} > Cl^- > NO_3^-$ (Imai and Okajima, 1980).

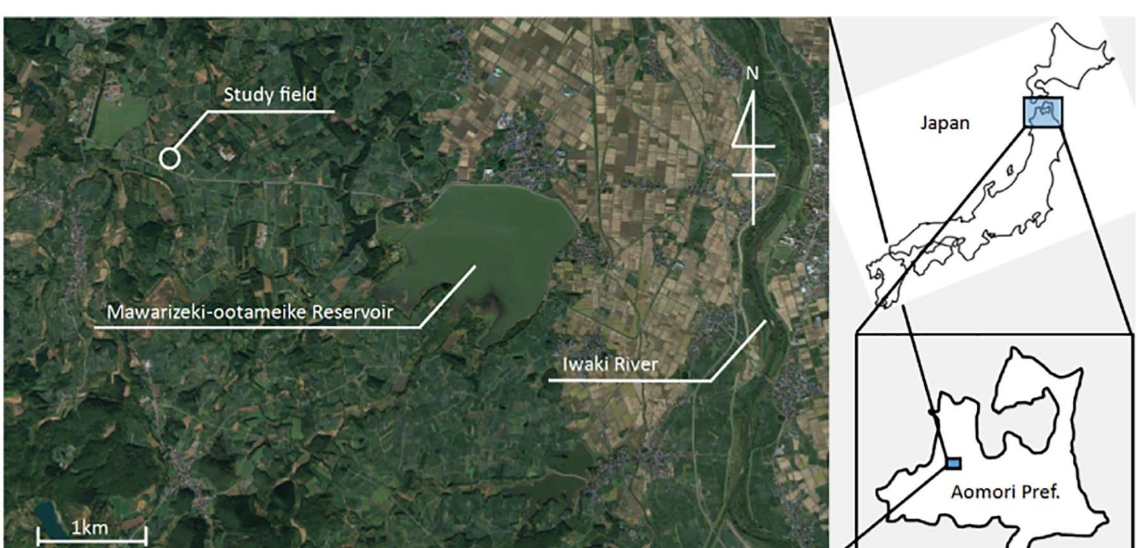

Fig. 1. The study area of Apple orchard for monitor the soil pore water quality.