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Relationship between exchangeable acidity and persistence of orchardgrass (*Dactylis glomerata*) in temperate pastures under different management

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Key words: Botanical composition; pasture management; pasture persistence; soil exchangeable aluminum; soil exchangeable acidity.

Abstract
Orchardgrass is a high productive, highly nutritive grass, but its persistence is low under acid soil condition. Therefore, to obtain the information on the effect of soil acidity on the persistence of orchardgrass in acid soil grasslands, we investigated the relationship between exchangeable acidity (y_1) and orchardgrass in sown pastures. Eight temperate pastures (four cutting meadows [CMs] and four cattle grazing pastures [GPs]) were used for vegetation survey and soil samplings. Six or three line transects (50 m each) were fixed in each meadow or pasture, and measurement location (three quadrats 20 cm×20 cm in size and 50 cm apart from each other) was set along the transect at a 10 m interval. The most dominant plant species was recorded after first cut of the meadows in 2018. Soil samples were collected in the area around quadrats, at depth of 0–5 cm for measurement of y_1 and other chemical properties. Orchardgrass was dominated in 78% and 37% of CM and GP, respectively. Tall fescue (*Festuca arundinacea*) was also dominated in 2% and 22% of CM and GP, respectively. In CM, the locations with higher y_1 showed a tendency of higher frequency of orchardgrass ($P<0.1$) and significantly low frequency of tall fescue ($P<0.05$). In contrast in GP, soil y_1 did not show significant relationship to the frequency of orchardgrass and tall fescue. Soil chemical properties such as pH, NO_3-N, K_2O, CaO and MgO show negative relationship to y_1 ($P<0.05$) in CM or GP, although they did not show significant relationship to the frequency of orchardgrass. These results suggest that survival rate of orchardgrass increases with increase of y_1, through preventing establishment of other plant species such as tall fescue under cutting condition, while this trend is not clear under grazing.

Introduction
Orchardgrass (*Dactylis glomerata*) is a widely used temperate forage grass because of its high productivity and nutritive value. However, the persistence of orchardgrass is reduced under acid soil condition (Hojito et al. 1987, Poozesh et al. 2010). The low persistency of orchardgrass in acid soils may be due to the direct effects of soil exchangeable aluminum (Al) or the indirect effects of other plant species (with higher acid tolerance) which have more tolerance to acid soil conditions with high exchangeable Al (Wheeler et al. 1992, Poozesh et al. 2007). The accumulation of inorganic nitrogen and deficiencies in the plant-available phosphorus and exchangeable cations induced by soil acidification can affect the persistence of sown pasture species (Hojito et al. 1987, Aciego Pietri and Brookes 2008). The different pasture management practices, such as cutting and livestock grazing, can also have an impact on the soil and pasture plants. However, there is little information on spatial variation of exchangeable Al in actual production fields and its relationship to orchardgrass persistence and soil nutrients, under different pasture management. Therefore, we conducted a field survey to obtain information on the variabilities of the soil exchangeable Al concentration within each pasture and its relationship to orchardgrass dominance and soil nutrients and compared these relationships under cutting and cattle grazing managements.

Methods and Study Site
This study was conducted at the Kawatabi Field Science Center, Graduate School of Agricultural Science, Tohoku University (Ohsaki, Miyagi, Japan; 38.75°N, 140.76°E, 220–250 m above sea level). The soil type is classified as a Haplic non-allophanic Andosol. Four CMs (areas of 1.0–3.0 ha) and four GPs (areas of 1.0–1.3 ha) grazed with cattle were selected as survey sites. All the CMs and the GPs were renovated in 2012 to 2014 with orchardgrass and tall fescue (*Festuca arundinacea*). The CMs were harvested three times from late May to early October, and beef cows were rotationally grazed from late April to late October in the GPs. Chemical fertilizer was applied in late April, after the first and second cuts in the CMs (total rate of 153:66:72 kg $N:P_2O_5:K_2O$ ha^{-1}), and three to five times during the grazing period in the GPs (total rate of 63:29:30 kg $N:P_2O_5:K_2O$ ha^{-1}). Cattle manure compost was also applied to all of the CMs and the GPs from November to December.

All measurements were conducted at fixed locations along line transects (50 m) established in the CMs and the GPs. Parallel six- and three-line transects were fixed in each CM and GP, respectively, at a distance of 10 m. Five measurement locations for the vegetation survey and soil sampling were set along each transect at 10 m intervals. Each location had three plots (20 cm×20 cm), and the center of each plot was set at a 50 cm interval. Vegetation surveys and soil sampling were conducted after the first cut (June 8-July 17, 2018). The most dominant plant species was recorded as the species with the highest coverage in each plot. To compare the botanical compositions of CMs and GPs, the dominance proportion was calculated separately for orchardgrass, tall fescue and the other plant species by dividing the number of dominant plots by the total number of plots in each CM (n=90) and GP (n=45). The dominance frequency of each plant was also calculated in each location by dividing the number of dominant plots by the total number of plots (n=3). Three soil cores collected at 0–5 cm depth in each location were subjected to measurement of soil pH and exchangeable acidity (y_1) (Mori and Shimada 1970). The value of y_1 was used as an indicator of exchangeable Al. To analyze the soil nutrient contents (Total-N, NO_3-N, NH_4-N, P_2O_5, K_2O, CaO, and MgO), additional soil samples were collected after the third cut (November 20, 2018) at 0–5 cm depth in a single measurement location of each line transect.

Results

Dominance proportion of plant species

The dominance proportion of orchardgrass ranged from 54–94% in the CMs and 29–42% in the GPs. The proportion of tall fescue, which was sown as an accompanying grass species when the pastures were established, was smaller in the CMs (0–4%) than in the GPs (9–33%). The other dominant plant species were redtop (*Agrostis alba*), broad-leaved dock (*Rumex obtusifolius*), sweet vernalgrass (*Anthoxanthum odoratum*), and mugwort (*Artemisia princeps*) in the CMs, and water-pennywort (*Hydrocotyle ramiflora*), redtop, sweet vernalgrass, broad-leaved dock, and reed canarygrass (*Phalaris arundinacea*) in the GPs.

Soil acidity

Soil pH in the CMs and the GPs ranged from 4.18 to 6.20 and 4.62 to 5.59, respectively. The y_1 value ranged from 0.55. to 25.83 in the CMs, which was greater than the values in the GPs (1.85–16.29). Although the proportion of strongly acidic soil (y_1>5) was 50% in the CMs and 65% in the GPs, that of very strongly acidic soil (y_1>15) in the CMs was 25.8% and only 1.6% in the GPs.

Effects of soil exchangeable acidity on the dominance frequency of plants and soil nutrient contents

In the CMs, the dominance frequency of orchardgrass tended to increase with the rise in y_1 ($p<0.1$), whereas the dominance frequency of tall fescue decreased ($p<0.05$). In the GPs, no significant relationship was found between y_1 and dominance frequencies of the species ($p>0.1$). Although soil pH, K_2O, CaO, and MgO in the CMs and pH and NO_3-N in the GPs decreased with increasing y_1 ($P<0.05$), these soil chemical properties did not show any significant relationship to the frequency of orchardgrass.

Discussion

The dominance frequencies of orchardgrass increased with the rise in y_1 while tall fescue decreased, suggesting that the higher tolerance of orchardgrass to soil acidity may increase its relative dominance to tall fescue in the strongly acidic soils of CMs. Soil chemical properties that decreased with increasing y_1 were not related to the dominance frequencies of orchardgrass both in the CMs and the GPs, which indicates that a decrease in these properties caused by exchangeable Al did not increase orchardgrass.

The dominance frequency of orchardgrass did not increase with increasing y_1 in the GPs, probably because the locations with extremely high y_1 were not observed in the GPs. Dung pats of grazing cattle may have suppressed soil acidification (During et al. 1973). Selective grazing by cattle may also give negative effect to the dominance of orchardgrass because of its high preference to cattle, and less tolerance to frequent defoliation. Moreover, competition with other acid-tolerant plant species may have reduced the dominance of orchardgrass in the locations with high y_1 in the GPs. For example, red-top, sweet vernal grass and broad-leaved dock, whose dominance rank next to orchardgrass and tall fescue, have a high tolerance to acid soil conditions and Al toxicity (Pakeman et al. 2019, Miyagi et al. 2013) as well as they adapt to frequent defoliation or are not preferred by cattle (Leege et al. 1981, Davies and Snaydon 1973, Hejcman et al. 2014).

From this study, it is indicated that orchardgrass is more persistent than other plant species in locations with high exchangeable Al under cutting conditions, whereas such trend is not seen under grazing conditions. To clarify the mechanism that causes the difference between cutting and grazing conditions, further research works need to focus on the effect of grazing cattle on chemical properties of strongly acidic soil and growth of orchardgrass, and the competition among pasture plant species with different acid-tolerance.

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