Introduction

Nitrogen (N) is an essential element for plant growth. The application of N fertilizers has resulted in N losses from agricultural systems into groundwater, rivers, coastal waters, and the atmosphere (Galloway et al. 2003). Nitrate leaching and nitrous oxide (N_2O) emissions from agricultural soils are recognized as significant environmental threats (Tilman et al. 2002). Nitrate leaching into rivers and estuarine ecosystems is responsible for algal blooms, eutrophication and public health risk (Wolfe et al. 2002). The greenhouse gas N2O is produced mainly during nitrification and denitrification (Moiser et al. 1998).

Nitrate leaching and N_2O production from orchards have not been widely studied. If an orchard is located on light-textured and free-draining soils, receiving a high input of N the potential for leaching can be high (Clarke et al. 1986). Our objective was to evaluate the environmental impact of upland blueberry cultivation with two different soil organic amendments regarding NO_3^- leaching and N_2O emissions.

Materials and Methods

The structure of this experiment simulated the conventional raised bed cultivation of blueberry (*Vaccinium ashei* Read.) in upland soil. A 40 L container was equipped with a 5 cm thick quartz grain drainage layer on the bottom and 5 cm pine bark mulch on top of the media. A completely randomized block design with three replications was arranged for the following treatments: PM – Tateyama brown forest soil + peat moss (1:1), SC- Soil + sawdust sewage sludge compost (1:1) with 5 g ferrous sulfate per L soil and SO- soil only. This study used Rabbiteye blueberry cv. 'Tifblue' (*Vaccinium ashei* Read. 'Tifblue'). Ammonium sulfate was applied at the rate of 134 kg/ha, divided into two applications: 45 kg/ha in July 2008 and 89 kg/ha in March 2009. The soil and plant samples were collected every third decade of each month during the growing season. The leaching water was collected according to the precipitation. Gas fluxes at the soil surface were sampled by the closed chamber technique, and N_2O content was analyzed using a Shimadzu GC-14B. Drainage water and soil NO_3^--N concentrations were determined by the Hydrazin-reduction method (Sawicki *et al*. 1971). The pH of soil and drainage water was measured using 1:2.5 soil to water ratio and a Horiba D52 pH meter. The EC was measured using a 1:5 soil to water ratio with a TOA CM-14P EC meter. Leaf chlorophyll content was monitored using a SPAD meter (Minolta, Japan). The blueberry fruits were harvested throughout the ripening season in the ripe (R) stage of berry maturity.

Results and Discussion

Soil N

The NH_4^+ concentration of soil immediately responded to ammonium sulfate fertilization, particularly in the SC treatment. The ammonium sulfate input resulted in a higher NO_3^- concentration due to nitrification. Supposedly, the SC and PM treatments had reduced nitrifier activity, thus the soil NO_3^- peaks appeared one month after the SO treatment. An earlier peak of NO_3^- concentration in the month of fertilization in SO indicates higher activities of nitrification compared with other treatments. The highest NO_3^- concentration occurred in the PM treatment in August 2008. The pH patterns of soil strongly correlated with the amount of precipitation and fertilizer applications. The low cation content of the rainwater may enhance possibilities of leaching base cations in soil out of its profile due to their replacement. The high rainfalls in

June 2008, coupled with ammonium sulfate fertilization, apparently introduced an acidifying reaction in the soil solution.

NO_3^- leaching

The soil disturbance soon after the plantation of blueberry bushes to the containers generated a more aerobic and suitable environment for mineralization, resulting in the release of NO_3^- in the early stage of the experiment. The SC treatment originally contained high N contents derived from sewage sludge, which resulted in higher NO_3^- losses in May 2008. The nitrification induced nitrate loss occurred after the first ten days of August. The SC treatment had no leaching water released from the container in the second decade of August, probably because of the dense root mat having a very active water and nutrient uptake. The other possible reason is the fast root elongation in the phenological stage around the middle of August (Gough 1994). The total NO_3^- losses of PM, SC and SO treatments were 275, 475 and 453 mg, respectively. The gradually decreasing EC patterns indicated strong leaching of base cations from the soil profile. This cation impoverishment of the media gradually became moderate in the first decade of August when the fertilizer treatment resulted in a higher cation release from the soil cation exchange sites. This fertilizer induced higher EC stabilized around the first decade of September.

Plant response

The plant leaves in the PM and SO treatments were diagnosed as N deficient before the fertilization in May and June 2008. After the fertilization, the readily available NH_4^+-N increased chlorophyll content and healthy plant vigor.

Nitrous Oxide emissions

The plant transplantation to the containers increased the soil pore space, thus providing more aerobic conditions for microbial activity, and resulting in higher NO_3^- leaching. Higher N_2O emissions were detected in SC before fertilization. These may have been derived from the initially high NO_3^- content in the amended material. The emission factor in SC was 0.73%. After fertilization clear fertilizer-induced N_2O emissions were detected in SO and PM treatments. The emissions factors of SO and PM were 1.2 and 1.43 %, respectively. The SO represents a typical heavy textured soil widely known as having physical characteristics to emit higher N_2O, compared to the light textured ones (Bouwman, 1996). The SO treatment was under a stronger anaerobic condition for longer periods than in the PM and SC and resulted in higher N_2O emissions. Surprisingly, the light textured PM had also high fertilizer-induced N_2O flux. In general, an increase in acidity through various mechanisms may inhibit the N_2O flux. This may be related to the highest acidity of the media and the acidifying effects of fertilizer. As a recent study pointed out, the contributing microorganisms for N_2O emissions may be more abundant than previously known (Yanai et al. 2007). Especially, the tropical and boreal peat soils have a wide fungal diversity including denitrifiers. Peat moss as a soil amendment might be a potential source of fungal denitrifiers, which finally results in higher emission rates of N_2O.

In conclusion, the highest loss of NO_3^- was obviously generated by the soil amendment application and plant transplantation. Forasmuch as the blueberry is a perennial crop, this soil disturbance and heavy application of organic matter apply only in the establishment year. The subsequent years of plant management can be carried out without any deep tillage or organic amendment application that may release an excess amount of NO_3^-. Taking into account the above mentioned characteristics of soil-plant-water-gas relations, the sawdust compost amended treatment has the least environmental impact in upland soil cultivation of blueberry.

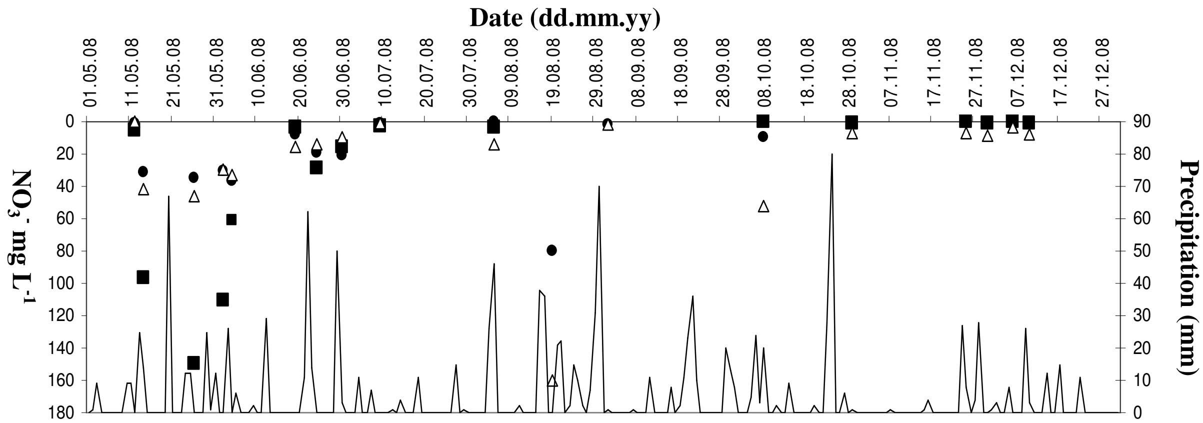

Figure 1. Nitrate leaching patterns and precipitation (■ SC-Sawdust Compost; ● PM-Peat Moss; ◊SO-Soil Only)

References

Bouwman AF, Direct emission of nitrous oxide from agricultural soils. Nutrient Cycling in Agroecosystems. 1996;46:53-70.

Clarke CJ, Smith GS, Prasad M et al, Fertilizer Recommendations for Horticultural Crops. MAF, Wellington, New Zealand; 1986

Galloway JN, Aber JD et al, The nitrogen cascade. BioScience. 2003;53: 341–356

Gough RE, The Highbush Blueberry and Its Management: Food Product Press; 1994

Tilman D, Cassman, K, Matson P, Naylor R, Polasky S et al, Agriculture sustainability and intensive production practices. Nature. 2002;418:671-667

Tilman D, Fargione J, Wolff B, D'Antonio C, Dobson A, Howarth R, Schindler D, et al, Forecasting agriculturally driven global environmental change. Science. 2001;292:281–284

Sawicki CR, Scarigelli FP, Colorimetric determination of nitrate. Microchemistry Journal. 1971;16:657-672

Yanai Y, Toyota K et al, Fungal N_2O production in an arable peat soil in Central Kalimantan Indonesia. SSPN. 2007;53,806-811.