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Monitoring nutrient accumulation and leaching in plastic greenhouse cultivation

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ABSTRACT

Plastic greenhouse cultivation is expanding in Korea due to increasing demand for value-added agricultural products. Potential pollutant accumulate in the root zone and may leach downward by irrigation water, causing soil and groundwater contamination. A nutrient management plan is needed to reduce the nutrient load from plastic greenhouse cultivation, although few studies have examined nutrient leaching and accumulation in the soil layers. In this study, soil, soil water, irrigation water, and weather conditions were monitored in the twice-a-year cultivation of cucumber and tomato in a plastic greenhouse for 2 years. Soil and soil water samples were analyzed every two weeks to investigate the level of nutrient accumulation and the nutrient leaching characteristics. Excessive fertilization caused nutrient accumulation in the root zone and the leaching of nutrients into the lower soil profile. The amount of phosphorus that accumulated on the soil particles of the root zone, however, did not significantly leach out with soil water movement. The electrical conductivity (EC) and NO_3–N of the soil water gradually increased from the root zone to the lower zone and the NO_3–N average concentration in the 150 cm soil layer was nearly equal to the maximum concentration of the fertigation water. The amount of percolation was 476.3 mm (56% of the irrigation water) in the cropping period for first cucumber cultivation (CP-C#1), 241.8 mm (53% of the irrigation water) in the cropping period for second cucumber cultivation (CP-C#2), 346.6 mm (42% of the irrigation water) in the cropping period for first tomato cultivation (CP-T#1), and 348.1 mm (51% of the irrigation water) which in the cropping period for second tomato cultivation (CP-T#2). The total NO_3–N losses through leaching from the lower zone (60 to 150 cm soil layer) to deeper soil were 137.4 kg N ha^{-1} in the CP-C#1, 195.9 kg N ha^{-1} in the CP-C#2, 758.6 kg N ha^{-1} in the CP-T#1, and 54.7 N ha^{-1} in the CP-T#2. A significant amount of nutrients were not utilized for crop growth but instead leached in accordance with the movement of the soil water. The results of this study can serve as a baseline for the long-term monitoring of greenhouse nutrient loads and can be used in the design of new guidelines to reduce nutrient loads from plastic greenhouse cultivation.

1. Introduction

Greenhouse cultivation has expanded due to the increasing demand for value-added agricultural products and the decreasing area of available agricultural land in Korea. According to the Agriculture, Forestry and Fisheries survey, the number of households with greenhouse farms was 10.2% of the total number of rural households in 2010 (KOSTAT, 2011). Approximately 60% of the new plastic greenhouses in Korea have been installed in paddy fields, where water for crop is typically obtained from irrigation or precipitation (Lee et al., 1998). Unlike in paddy field cultivation, precipitation is blocked in plastic greenhouse cultivation and water for crops can only be obtained through irrigation systems. Nutrients required for plant growth in plastic greenhouse systems are supplied by fertigation, which is a fertilization method that involves supplying nutrients in irrigation water because it is known to increase nutrient uptake by plants (Singandhupe et al., 2003; Mahajan and Singh, 2006; Liang et al., 2013).

Plastic greenhouse farming occurs year-round, with more than two crop rotations per year. Because of the misconception that

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the application of large amounts of nutrient fertilizer results in high crop yields, it is general practice to apply a standard dose of fertilizer to a single crop once a year. For this reason, excess nutrients have been applied in greenhouses without consideration for the impact on the physical and chemical characteristics of the soil. If the amount of nutrients applied to the soil exceeds the amount needed by the crops, it can lead to soil pollution (Thompson et al., 2007; Min et al., 2012). During crop cultivation in plastic greenhouse, excess nutrients that are a potential source of nonpoint pollution accumulate in the soil. In long-term greenhouse cultivation, nutrient accumulation leads to higher soil salinity (Shi et al., 2009). Some nutrients that accumulate in the root zone may leach downward with the application of irrigation water, possibly causing soil and groundwater contamination (Kim et al., 2008). In a study by Ha et al. (1997), because of yearly increases in greenhouse cultivation, nitrate–nitrogen (NO_3–N) concentrations in the shallow groundwater near the greenhouse area had increased and in some cases the concentrations exceeded the groundwater quality standard for agricultural water (20 mg L^{-1}). In addition, it was found that in Korea, 82.8% of the irrigation water in greenhouses was supplied by shallow groundwater (Lee et al., 1998). If contaminated or salinized groundwater is used for irrigation water, it can cause a cycle in which nutrients reaccumulate in the soil (Lee et al., 2008).

A nutrient management plan is needed to reduce pollution loads from greenhouse cultivation. To minimize nutrient accumulation in the upper soil layer and the leaching of nutrients into lower soil layers and shallow groundwater, it is necessary to investigate soil nutrient concentrations and the processes of nutrient accumulation and leaching in the soil layers. In particular, nitrogen and phosphate are important nutrients not only for plant growth but also for soil and water pollution management in agricultural areas. Nitrogen is a mobile nutrient that is rapidly leached. When there is no supply of irrigation water, nitrogen leaching may be slow or nonexistent (Li et al., 2003; Shen et al., 2003; Ajdary et al., 2007; Yu et al., 2008). However, a combination of irrigation and high nitrogen use in plastic greenhouse cultivation results in the substantial loss of nitrogen through leaching and the consequent contamination of the groundwater by nitrogen, especially, NO_3–N (Li et al., 2003; Thompson et al., 2007; Wan et al., 2010). Phosphate on the other hand, is not easily leached with the movement of water from soil layers. Phosphate is strongly fixed to soil particles and is reactive with iron, calcium, and several other elements, so most phosphate forms tight bonds with soil and tends to accumulate rather than leach (Yang et al., 2011; Hu et al., 2012). Because there is little surface runoff in plastic greenhouses, phosphate accumulation in the soil can cause problems for soil management. In addition, an excessive concentration of phosphate in the soil particles interferes with the absorption of other ions in crops and can even leach into the lower soil layers along with the soil water (Peng et al., 2011). There are several studies that examine the status of soils in plastic greenhouses in Korea. These research projects (Kang and Hong, 2004; Lee et al., 2005; Lee et al., 2005; Lee et al., 2008, RDA, 2006) were all conducted in an area with a large proportion of plastic greenhouses, monitored the nutrients via the EC, and monitored the level of phosphorus pentoxide (P_2O_5), NO_3–N, and total-nitrogen (T-N) in the surface only. The EC of the soil exceeded the levels suitable for crop production of the RDA (Rural Development Administration) (2.0 dS m^{-1}) and sometimes even exceeded the standard of the U.S. Soil Salinity Laboratory Staff (4.0 dS m^{-1}) (U.S. Salinity Laboratory Staff, 1954; Ha et al., 1997; RDA, 2006; Lee et al., 2008; Kim et al., 2008). Kang and Hong (2004) found a significant correlation between soil EC and NO_3–N. Lee et al. (2005) found that the ratio of the greenhouse area that could maintain the proper status of soil nutrients was 26.1% in EC and only 4.3% in P_2O_5. Castellanos et al. (2013) observed that greenhouse soil had sufficient quantities of nutrients even after crop harvesting and that this phenomenon was particularly serious in plastic greenhouse systems in Korea.

Unlike rice paddy or upland agriculture, in which pollutants leave the system through surface flow, pollutants in a greenhouse infiltrate into the soil and leach downward by water movement through soil pores. Therefore, it is important to understand the movement of contaminants not only along the surface of the soil but also from the surface to the subsoil. However, most studies have only focused on surface soil concentrations and the relationship between nutrient concentration in the surface soil layers and crop yield or groundwater quality in areas near plastic greenhouses (Lim et al., 2007; Kang and Hong, 2004). Nutrient monitoring studies of soil and soil water that include an analysis of soil depth, nutrient accumulation, and the process of nutrient leaching are lacking. Further plastic greenhouse studies are needed to understand the interactions among fertigation, water movement, nutrient cycling and the leaching process.

This study aims to investigate soil nutrient concentrations and movement, especially phosphate accumulation and nitrogen leaching, under plastic greenhouse conditions. Nutrient leaching is related to soil moisture content, soil physical characteristics and the concentrations of available nutrients in soil and soil water (He et al., 2011; Castellanos et al., 2013). Therefore, in this study, to investigate the characteristics of nutrient accumulation and leaching in soil under plastic greenhouse cultivation, soil moisture content, irrigation, and climate conditions were monitored and fertigation water was collected at each fertigation event. Soil samples were collected before, during, and after cropping periods and soil water samples were collected to determine the fluctuations in soil nutrient concentrations as well as nutrient accumulation and leaching. Using the monitoring data and the results of the nutrient analyses, the volume of the percolated water in the root zone and the amount of nutrient loss in the soil layers were determined.

2. Materials and methods

2.1. Experimental site

The field experiments were conducted in plastic greenhouses located in Namsa-Myeon, Cheoin-Gu, Yongin-Si, and Gyeonggi-Do, South Korea (E 37°06′04″, N 127°08′08″). Fig. 1 shows a location map of the experimental sites. Although the study area was a rural area that has traditionally cultivated crops in rice paddies, the area has recently experienced an expansion in the greenhouse cultivation of vegetables and flowers. The 30-year average annual temperature in the study area is 11.4 °C. The monthly high average air temperature is 25.6 °C (August) and the low is −2.9 °C (January). The 30-year average annual solar radiation is 18.7 MJ m^{-2}. The 30-year average annual precipitation is approximately 1312.2 mm and rainfall is mainly concentrated in the summer season from June to September. The soil type in the study area (RDA SIS, http://soil.rda.go.kr) is classified as the Seogcheon (SE) series (*coarse loamy, mixed, nonacid, mesic Fluvaquentic Endoaquept*).

2.2. Crop management

At the experimental site (100 × 30 m), cucumber was cultivated two times during first year (2011) and tomato was cultivated two times during the second year (2012). Table 1 shows the cucumber and tomato crop management schedules for both years. In 2011, during the fallow period prior to planting (FP-C#1: fallowing period before first cucumber cultivation) from December 2 to December 23, 2010, the field was ploughed, the soil was bedded, and basal fertilizers were applied. In the second fallow period (FP-C#2: fallowing period before second cucumber cultivation) from June 20 to