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Glufosinate treatment of weeds results in ammonia emission by plants

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Abstract

The herbicide glufosinate, which is also called phosphinothricin (PPT), is known to inhibit glutamine synthetase and thus causes a blockage of ammonium (re)assimilation in plants. The objective of the present study was to test whether application of this herbicide results in an ammonia volatilization from the plants and to quantify nitrogen loss via ammonia emission. Four different weed species (*Chenopodium album*, *Echinocloa crus-galli*, *Solanum nigrum*, *Tripleurospermum inodorum*) were grown as monocultures in the greenhouse and treated with PPT when their canopies covered the soil. In the first experiment, whole shoot samples were taken during the following days and analysed for ammonium, pH and total nitrogen content. In the second experiment, apoplastic pH and ammonium concentration of the leaves were measured after herbicide application and used for the calculation of Γ-values (ratio between NH_4^+ and H^+ concentration), the stomatal NH_3 compensation point and the canopy net NH_3 flux with a soil vegetation atmosphere transport (SVAT) model.

Herbicide treatment caused a rapid increase in shoot ammonium concentration and the ammonium portion of the plant total nitrogen ranged from 0.6 to 0.9% and from 17 to 44% before and after PPT application, respectively. *S. nigrum* showed a strong increase in ammonium portion (35%) followed by a decrease (20%), which may have resulted from ammonia volatilization. The difference in total shoot nitrogen content per ground area at the start and 2 weeks after PPT application averaged for the three C_3 weed species to a nitrogen loss of ca. 0.4 g N m^{-2} or approximately 13% of the total nitrogen in the weed canopy. Analysis of the apoplastic fluid yielded an increase in ammonium concentration and a pH decrease after an initial increase on day 1 after the PPT treatment. In order to evaluate the potential for ammonia loss, the Γ-value was calculated for both apoplastic and tissue water. *S. nigrum* showed the most dramatic increases in both apoplastic and tissue–water Γ-values 4 days after PPT treatment. The calculated stomatal NH_3 compensation point was strongly elevated after PPT treatment. However, temporal changes of apoplastic pH and ammonium concentration varied between the species and the modelled ammonia emission ranged from 0.03 to 0.09 g N m^{-2}. It is concluded that PPT application results in an ammonia emission of ca. $<10\%$ of the canopy nitrogen

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content. This is negligible with respect to the nitrogen balance of an agroecosystem; however, the ammonia pollution of the atmosphere has to be taken into account.

Keywords: Ammonia compensation point; Ammonium concentration; Glufosinate; Ammonia emission; Weeds

1. Introduction

Glufosinate, which is also called phosphinothricin (PPT), has been isolated from microorganisms (Bayer et al., 1972) and synthesized as a chemical herbicide. PPT irreversibly inhibits glutamine synthetase (GS; E.C. 6.3.1.2; Manderscheid and Wild, 1986), which results in a blockage of the ammonium assimilation derived from nitrate reductase activity and the photorespiratory pathway. Consequently, the concentration of ammonium increases (Wild and Manderscheid, 1984) and there is a decrease in the content of some amino acids (Shelp et al., 1992; Wild and Wendler, 1993). The ammonium accumulation observed after PPT treatment was lower in C_4 plants than in C_3 plants (Wendler et al., 1990). This corresponds to the finding that the rate of photorespiratory ammonia formation is higher in C_3 plants than in C_4 plants (Devi and Raghavendra, 1993). The inhibition of photosynthesis after PPT application is not induced by the high concentrations of ammonium but by direct inhibition of the ribulose-1,5-bisphosphate carboxylase by the accumulation of glyoxylate and phosphoglycolate (Wild and Wendler, 1993).

Ammonia is exchanged between the plant canopy and the atmosphere, which depends on the ammonia concentration in both compartments and leaf stomatal conductance (Husted and Schjoerring, 1995). The ammonia concentration in the leaf gas phase, which is the stomatal NH_3 compensation point, is higher than zero and is determined by the apoplastic ammonium and proton concentrations and by the effect of temperature on NH_4^+ dissociation (Husted and Schjoerring, 1996). Glutamine synthetase, which has a high affinity for ammonium, keeps the cellular ammonium concentration low. Consequently, the gaseous ammonia concentration in the substomatal cavity of the leaf is in most cases lower than that in the atmosphere and the plant functions as an ammonia sink. The stomatal NH_3 compensation point has been shown to vary with nitrogen nutrition (Mattsson and Schjoerring, 1996, 2003) and leaf age (Hill et al., 2002). The importance of GS in controlling plant ammonium levels, and thereby ammonia emission, has been demonstrated by treating plants with the GS inhibitor methionine sulphoximine (MSO; Husted and Schjoerring, 1995; Mattsson and Schjoerring, 1996). MSO and ATP react to form MSO-phosphate, which then occupies the active site of the enzyme thereby preventing further catalytic activity (Ronzio et al., 1969). PPT inhibits GS in a similar manner, and it has been shown that PPT is a more effective inhibitor of higher plant GS than MSO (Manderscheid and Wild, 1986; Wild and Manderscheid, 1984). Thus, it can be expected that weeds treated with the herbicide PPT emit ammonia into the atmosphere. However, this has not yet been investigated.

The objectives of the present studies were to test whether PPT treatment of weeds causes ammonia emission and to quantify the nitrogen loss of different weed species. This was done by (i) measuring in the total plant ammonium accumulation and nitrogen loss and (ii) by analysing apoplastic ammonium and proton concentration, which are used for modelling the ammonia exchange of the weed canopy using a SVAT model.

2. Materials and methods

2.1. Plant material and growth conditions

Four different weed species were used: common lambsquarters (*Chenopodium album*), watergrass (*Echinocloa crus-galli*), which is a C_4 plant, black nightshade (*Solanum nigrum*) and scentless mayweed (*Tripleurospermum inodorum*). Plants were grown in trays (0.25 m × 0.15 m) consisting of 3 × 5 small pots, which were filled with a commercial standard prefertilized mix of peat and soil (ED73). The trays of each species were closely placed together to simulate a plant canopy. Each tray was considered as one