Letter to Editor

Toxic Effects of Ammonia Volatilizing from Sandy Soil Fertilized with Ammonium Salts and Urea on Barley Crop Decreases

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Abstract

We observed that ammonia volatilizing from sandy soil fertilized with ammonium sulphate, ammonium nitrate and urea reduced growth and development of barley, resulting in yield reduction.

Keywords: ammonia, ammonium salts, urea, sandy soil, spring barley

Introduction

Plants not only take up NO_3^- and NH_4^+ from the soil, but also absorb ammonia from the air [1-6]. The presence of ammonia in the air is the effect of chemical contamination of the atmosphere. Sources of ammonia in the atmosphere include industrial emissions and volatilization from manures and fertilizers [7-9].

Ammonia emissions in Poland were estimated at 300,000 tonnes of NH_3 a year [10]. This ammonia can serve as an additional nitrogen source for plants if the levels are not too high. However, if the concentration becomes too high, ammonia may become toxic to plants.

The average global concentration of atmospheric ammonia ranges from 1 to 10 μg $NH_3 \cdot m^{-3}$ of air. In some regions, where pollution is high, this concentration can be much higher and may reach levels as high as 220 μg $NH_3 \cdot m^{-3}$ of air. Following fresh manure application, the concentration of atmospheric ammonia above soil surface can reach 2,400 μg $NH_3 \cdot m^{-3}$ [11]. Toxicity of ammonia to plants has been reported at concentrations higher than 600 μg $NH_3 \cdot m^{-3}$ for 24 h and 10,000 μg mg $NH_3 \cdot m^{-3}$ for 1 h [12]. At a concentration of ammonia 11 μg·m-^{3} in the air, the rates of sorption are: 37.44 – 55.44 $m \cdot h^{-3}$ for grasses and 46.6 m h^{-1} for maize [13].

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The objective of this study was to determine if ammonia volatilization following surface application of various fertilizers could cause reduction of spring barley growth and development.

Materials and Methods

The experiment was conducted using spring barley (*Hordeum vulgare*). Plants were seeded into polyethylene pots, filled with 10 kg of coarse sand that contained 90% sand, 7% silt and 3% clay. Initial soil pH was 5.5, but it was corrected to 6.8 by adding 2 g of $CaCO_3$ per pot. Soil organic carbon content was 0.7%. Total cation exchange capacity (CEC) was 3 $cmol^+ kg^{-1}$ of soil. Concentrations of available P and K according to Egner-Rhiem were 41 and 11 mg kg^{-1} of soil, respectively. Volumetric water content at field (50 hPa of water tension) capacity was 15%.

Each pot was fertilized using the following amounts and types of materials: 2 g $CaCO_3$, 0.35 g K_2HPO_3, 0.25 g KH_2PO_4, 0.30 g $MgSO_4$ 0.80 g K_2SO_4, 10 mg $FeCl_3$, 8 mg H_3BO_3, 0.2 mg $CuSO_4$, 0.2 mg $ZnSO_4$ and 2 mg $MnSO_4$. The above nutrients were applied in solutions and were mixed thoroughly with the soil prior to potting. Nitrogen fertilizer treatments were applied as ammonium sulphate, ammonium nitrate calcium nitrate and urea at a rate of 700 mg N per pot. One-half of that dose, with an exception of urea, was applied before sowing and the other half at shooting phase (Feckes 5-6). Urea application was divided into four rates of 175 mg N per treatment in the following times: pre-sowing, tillering, shooting and heading. The pre-plant N application was added in solution followed by thorough mixing of soil. The in-crop application was added in solution injected into the soil by pipettes followed by watering. Eight plants at the stage of 2 leaves were re-planted into the pots through holes in pot covers (combinations A, B). The same planting procedure was used for uncovered pots (combination C). Soil moisture was kept at the tension of 50 hPa by daily addition of water. Pots were weighted to establish the amount of water needed to maintain the required moisture level. The experiment was a conducted in a greenhouse at ambient temperature and natural daylight. The experiment was conducted according to a completely randomized design with five replications. The three combinations with regard to exposure of above-ground parts to ammonia emissions are described below.

In the first combination (A) the above-ground part of the plants was separated from the underground part by the plastic cover limiting exposure of plants to ammonia being volatilized from soils. (Fig. 1). In this treatment the ammonia, released from decomposition of nitrogenous fertilizer, was being absorbed through diaphragm pumps and pumped through 0.001% solutions of H_2SO_4 in which the ammonia was absorbed and trapped. The absorbed ammonia was determined using the spectrophotometric method [14]. Nitrogen application rates were comparable to routine rates previously used in pot experiments with barley.

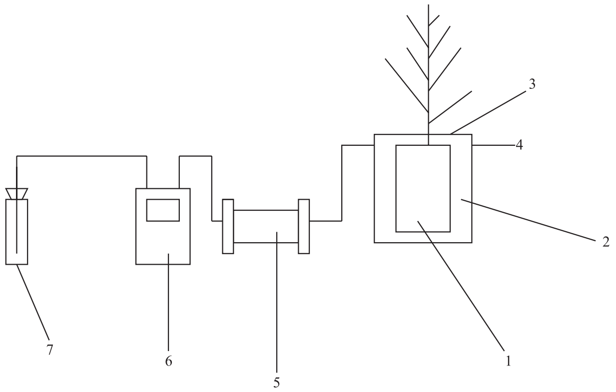

Fig. 1. The design of apparatus for investigating the emissions of ammonia from soils

1 – a pot with a plant, 2 – the external container of the pot, 3 – a hermetic cover of container separating the underground part of a plant from the aboveground part, 4 – the inlet of air to container, 5 – diaphragm pumps with efficiency (~0.2 $m^3 \cdot h^{-1}$, for recruiting the air flying out from container (2), 6 – the counter of quantity of the air taken through pump (5), 7 – the bottle containing 1 dm^3 of 0.001% H_2SO_4, absorber of ammonia from the air taken by the pump (5).

In the second combination (B) the aboveground part of a plant was separated from the underground part by the plastic cover and there was no an exchange of soil air (Fig. 1). In this case ammonia separated from the soil to the air had limited access to the aboveground parts of a plant.

In the third combination (C) the experiment was conducted using open pots. Ammonia volatilizing from the soil was accessible to the aboveground parts of a plant. Additionally, five pots with no fertilizers added were used as control. Statistical analysis was conducted using analysis of variance (ANOVA) and Tukey test at p=0.05 to estimate differences between treatment means.

Results and Discussion

The experiment with spring barley was established on the 2nd of April 2004 (seeding) and it was concluded on the 23rd of July 2004, when the crop reached full maturity.

In A and B treatments, an effect of ammonia volatilisation was limited by a plastic cover separating the aboveground part of plants from the soil (Photo. 1, 2). Growth and development of barley was best in the calcium nitrate treatments in all three combinations of the experiment – no toxic effects of ammonia were observed in plants (Photos 1, 2, 3)

Plants in open pots (treatment C) were adversely affected by the application of the N treatments, particularly those fertilized with ammonium sulphate and ammonium nitrate. The lower effects of urea compared with other fertilizer treatments were probably due to splitting the application into four sub-treatments, which reduced plant exposure to ammonia emissions.

The barley in combination (C) and fertilized with ammonium sulphate and ammonium nitrate resulted in a very slow growth throughout the study. The leaves were very small and light-green. The grain heads were short, often empty or filled with very few grains, which have been recorded previously as typical symptoms of ammonia poisoning in grain crops.

The barley grown in pots closed by a cover with continuous exchange of air in combination A and without air exchange in combination B was characterized by a better growth of plants relative to all treatments in combination C, which was exposed to ammonia released from soil. The leaves were dark-green, and grain heads and spikelets were filled with grains.

Grain yield (Table 1) was the smallest by fertilization with ammonium sulphate in treatment combination C and amounted 2.19 g per pot. In comparison, the yield in combination A amounted 3.84 g per pot and 3.46 g per pot in combination B. When barley was fertilized with ammonium nitrate, the yield per pot was: 2.65 g in combination C, 12.40 g in A and 16.55 g in B. When barley was fertilized with urea, grain yield was essentially the same among all treatments (A, B, C) (Table 1).

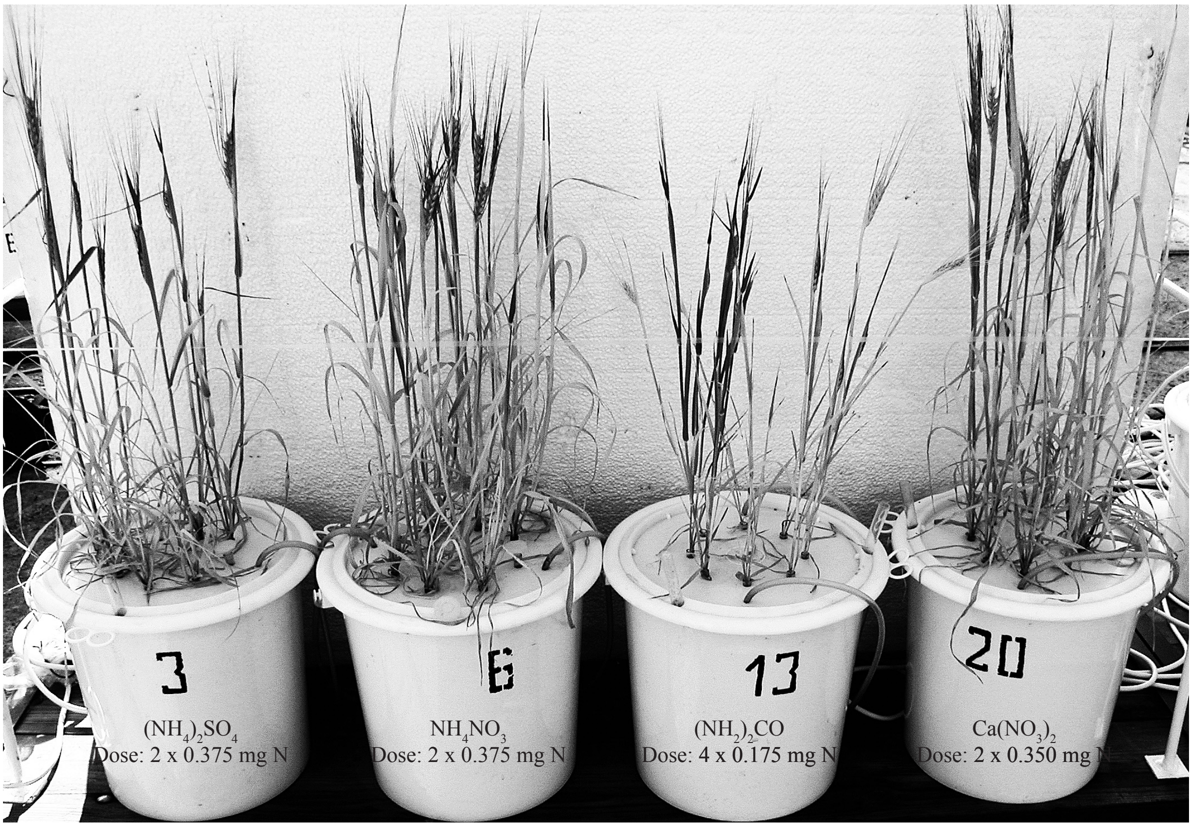

Photo 1. Spring barley in pot experiment on coarse sand – combination A.

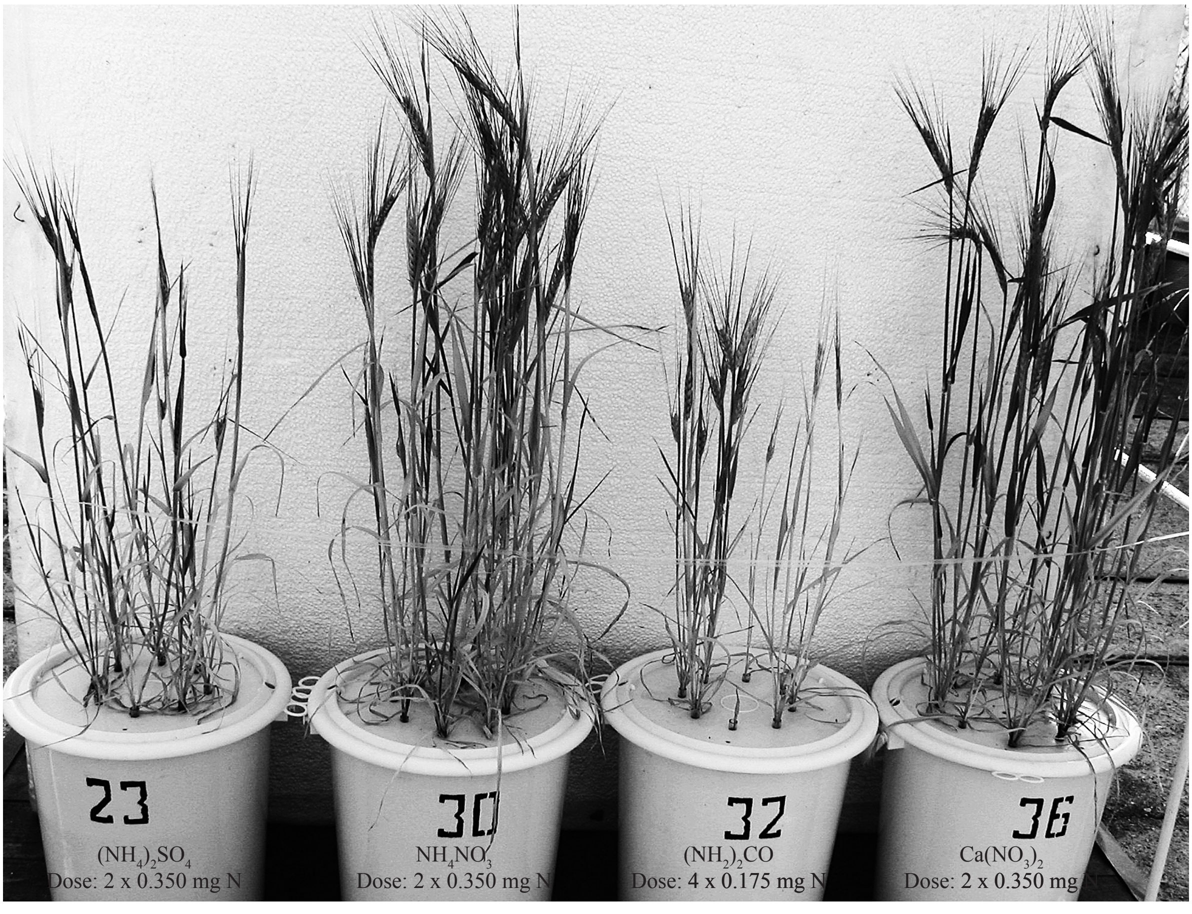

Photo 2. Spring barley in pot experiment on coarse sand – combination B.

Photo 3. Spring barley in pot experiment on loose sand – combination C.

Table 1. The yields of spring barley (mean value, n = 5).

Form of nitrogen	Combination	Grain g per pot	Straw g per pot
$(NH_4)_2SO_4$	A	3.84 a*	8.05 a
	B	3.46 a	6.61 a
	C	2.19 a	9.48 a
NH_4NO_3	A	12.40 b	16.81 b
	B	16.55 b	17.44 b
	C	2.65 b	5.92 c
$(NH_2)_2CO$	A	5.52 a	5.91 a
	B	4.32 a	5.81 a
	C	4.84 c	10.24 a
$Ca(NO_3)_2$	A	17.64 c	19.18 b
	B	19.32 b	20.11 b
	C	13.00 d	20.15 d
Control without fertilization	C	0.93 a	1.04 b

A – the pot closed with the cover with continuous exchange of air, B – pot closed with the cover without exchange of air, C – open pot.
* – values in column marked with the same letter do not differ significantly at $\alpha = 0.05$

Combinations A and B fertilized with ammonium nitrate yields were, respectively, over four and six times larger than in combination C. The reason for the large difference was that a substantial portion of N in ammonium nitrate is nitrate which is not subject to volatilization. It is well established that nitrites are also most effectively absorbed by the root system. In combination C the process of absorbing nitrates was limited by the toxic concentration of atmospheric ammonia absorbed by the above-ground part of a plant.

It is worth mentioning that the coarse texture sand of low organic carbon content used in this experiment had a limited nitrification potential, which was likely to prompt the release of ammonia.

The largest grain yields were observed in the calcium nitrate treatments in all combinations: A, B and C. This resulted from negligible ammonia emissions relative to other fertilizer treatment and therefore no toxic effects on plants were observed (Table 1).

The emission of ammonia from under barley (Table 2) was the highest in urea treatment at heading stage (21.64 mg N). The entire amount of N volatilized throughout the experiment was 34.49 mg N. The largest amount of ammonia volatility in the shooting phase was 11.19 mg N from ammonium sulphate, while only 4.58 mg N was volatilized during this period from ammonium nitrate.

The least amount of ammonia volatilized was with calcium nitrate. During the entire season, only 1.38 mg N was released in this treatment.

Table 2. The emission of ammonia from sandy soil under spring barley. Mean value (mg N per pot, n = 5).

Development stage	$(NH_4)_2SO_4$	NH_4NO_3	$(NH_2)_2CO$	$Ca(NO_3)_2$
Emergence	0.73 a*	0.56 a	0.6 a	0.01 b
Tillering	5.12 a	1.48 c	6.14 a	0.23 b
Shooting	11.19 c	4.58 b	2.12 a	0.79 a
Heading	4.47 a	3.99 a	21.64 c	0.14 b
Flowering	2.52 a	1.77 a	3.16 b	0.048 c
Full maturity	0.51 a	0.19 a	0.52 a	0.16 a
Stubble	0.34 b	0.11 a	0.32 b	0.09 a
Total	24.87 c	12.68 b	34.49 d	1.47 a

* – see Table1

Table 3. The emission of ammonia from sand, unsown soil. Mean value (mg N per pot, n = 5).

Weeks	$(NH_4)_2SO_4$	NH_4NO_3	$(NH_2)_2CO$	$Ca(NO_3)_2$
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0.10 a*	0.55 b	0.07 a	0.04 a
5	0.10 a	1.15 c	0.66 b	0.04 a
6	0.30 b	1.7 d	0.73 c	0.05 a
7	21.03 d	13.89 c	8.00 b	0.38 a
8	9.96 c	2.93 b	17.83 d	0.42 a
9	5.03 a	1.34 c	4.56 a	0.55 b
10	4.38 c	3.49 b	14.89 d	0.82 a
11	8.43 b	10.27 c	21.34 d	1.3 a
12	11.55 b	19.09 d	13.85 c	1.3 a
13	5.79 c	2.39 b	9.57 d	1.3 a
14	5.38 a	5.78 a	8.79 a	1.1 a
15	8.19 c	4.63 b	9.57 d	1.2 a
16	1.56 a	1.45 a	3.51 c	0.8 b
17	1.44 c	0.98 b	2.22 a	0.2 a
Total	83.24	69.64	115.59	9.50

*- see Table1

The emission of ammonia from sandy unsown soil (Table 3) was much higher for all mineral nitrogenous fertilizers than for the soil sown with barley. The largest amount of ammonia volatilized was with the urea applications (115 mg N per pot) and the least from under calcium nitrate at 9.5 mg N per pot. Even though the emissions from urea treatment were the largest, they did not cause the largest harm to plants. This was likely due to dividing urea application rates in combinations with plants into four doses over the vegetation season, whereas urea added to unsown soil was introduced as a single dose.

In the light of results presented in this study, it is evident that ammonia volatilization from ammonium sulphate, ammonium nitrate and urea can have toxic effects on barley growth. It seems that the mechanism of this toxicity is exposure of the above-ground parts to ammonia emissions. In contrast, calcium nitrate as the N source does not produce significant ammonia emissions and reduction of plant growth. Volatility of ammonia from fertilizers is not only an economic loss but can also contribute to reduction of plant yield in light soil of limited nitrification potential, which is a common feature of a substantial portion of the soil cover in Poland.

References

1. LANGFORD A.O., FEISSENFELD P.C. Natural vegetation as a source or sink for atmospheric ammonia: a case study. Science. **255**, 581, **1992**.
2. LOHAUS G., WINTER H.,RIENS B., HEID H.W. Further studies of the phloem loading process in leaves of barley and spinach. The comparison of metabolite concentrations in the apoplastic compartment with those in the cytosolic compartment and in the sieve tubes. Botanica Acta.**108**, 270, **1995**
3. LOHAUS G.,HELDT H. Assimilation of gaseous ammonia and the transport of its products in barley and spinach leaves. J.Exp Bot. **48**, 1779, **1997**.
4. ROGERS H.H.,ANEJA V.P. Uptake of atmospheric ammonia by selected plant species. Environmental and Experimental Botany.**20,** 251, **1980**.
5. SCJOERRING J.K.,KYLLINGSBAEK A.,MORTENSEN J.V., BYSKOV-NIELSEN S. Field investigations of ammonia exchange between barley plants and the atmosphere. I. Concentration profiles and flux densities of ammonia, Plant, Cell and Environment. **16**, 161, **1993.**

6. WOLLENWEHER B.,RAVEN J.A. Nitrogen acquisition from atmospheric NH_3 by Lolium perenne: utilization of NH_3 and implications for acid/base balance. Bot Acta. **106**, 42, **1993**.
7. BOBBINK R.,HEIL G.W., Raessen M.B.A.G. Atmospheric deposition and canopy exchange processes in the heatland ecosystems. Environ Pollut.**75**, 29, **1992**.
8. CHURCH B.M., LEECH P.K. Ministry of Agriculture, Fisheries Food Rep.No.SS/SAFC/39, **1980**
9. SCHULZE E.D., De VRIES W., HAUHS M.,ROSEN K., RASMUSSEN L., TAMM C.O., NISSON J. Critical loads for nitrogen deposition on forest ecosystems. Water Air Soil Pollution **48**, 451, **1989**.
10. SAPEK A. Emission of ammonia from agrcultural production.Post. Nauk Roln. 2/95, **1995**.(in Polish)
11. BEAUCHAMP E.G. Nitrogen loss from sewage sludges and manures applied to agricultural lands. In: FRENEY J.R. SIMPSON J.R.(eds) Gaseous loss of nitrogen from plant soil systems. M. Nijhoff. The Hague, pp 181-195, **1983**
12. VAN DER EERDEN L.J.M Toxicity of ammonia to plants. Agriculture and Environment. pp. 223-235.1**982**
13. COWLING D.W.LOCKYER D.R. Increased growth of ryegrass exposed to ammonia. Nature. **292**, 337, **1981**.
14. MROCZKOWSKI W., CYGAŃSKI A. Spectrofhotometric determination of nitrogen in plant materials. Chemia Analityczna. **28**, 319, **1983**.(in Polish)