Factors Affecting Nitrogen Mineralization in Soils under Waterlogged Conditions

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Introduction

Many farmlands around the world, including the very productive farms in central United States, often are waterlogged for times ranging from weeks to months during the spring and summer months. Such conditions result in changes in the soil chemical and biochemical properties (Ponnamperuma, 1972; Bartlett and Ross, 2005). A number of studies have been done on the chemistry of waterlogged soils (Waring and Bremner, 1964; Ponnamperuma, 1972; Sahrawat, 1981), but little information is available on the biochemical processes affecting soil N mineralization under those conditions. The production of NH_4-N (ammonification) in soils is controlled by enzyme-catalyzed reactions. These enzymes belong to different classes and are highly specific, and the organic N compounds in soils are derived from many sources, belonging to different chemical classes, and present in different microenvironments (Ladd and Jackson, 1982).

Materials and Methods

- **Soils and their properties**

Table 1. Selected chemical and physical properties of the soils used.

Soil	Taxonomic class	pH $CaCl_2$	pH H_2O	Org. C g kg^{-1} soil	Org. N g kg^{-1} soil	C/N ratio	Clay g kg^{-1}	Sand g kg^{-1}
Sparta	Entic Hapludolls	6.59	6.74	10.3	0.88	11.7	62	851
Clarion	Typic Hapludolls	6.97	7.16	21.2	1.85	11.5	201	476
Kenyon	Typic Hapludolls	6.55	6.66	30.3	2.56	11.8	213	398
Readlyn	Aquic Hapludolls	5.86	6.08	34.1	2.93	11.6	214	359
Floyd	Aquic Pachic Hapludolls	6.20	6.32	35.4	2.98	11.9	227	331
Harps	Typic Calciaquolls	6.99	7.23	49.1	4.77	10.3	251	311
Webster	Typic Endoaquolls	6.62	6.80	51.7	3.85	13.4	303	251
Nicollet	Aquic Hapludolls	6.55	6.60	52.1	3.88	13.4	236	406
Canisteo	Typic Endoaquolls	6.98	7.23	52.3	4.95	10.6	383	140
Clyde	Typic Endoaquolls	7.01	7.18	58.3	5.55	10.5	288	208
Okoboji	Cumulic Vertic Endoaquolls	6.58	6.90	58.3	5.39	10.8	402	51

- **NH_4-N released was determined by steam distillation (Waring and Bremner, 1964).**
- **Determination of the hydrolysis of enzyme substrates**

1. Formamide hydrolysis in soils was determined as described by Frankenberger and Tabatabai (1980) for amidase activity but without buffer or toluene.
2. The same procedure used for formamide hydrolysis was used for arginine, asparagine, and glutamine hydrolysis, but 50 mmol L^{-1} of L-arginine, L-asparagine, or L-glutamine, respectively, was used as a substrate for arginase, asparaginase, or glutaminase activities (Frankenberger and Tabatabai, 1991a, b).
3. Hydrolysis of *p*-nitrophenyl-β-D-glucopyranoside and hydrolysis of *p*-nitrophenyl-N-acetyl-β-D-glucosaminide was determined as described by (Tabatabai, 1994).

- **The effects of heavy metals on NH_4-N released were studied by comparing the amounts of NH_4-N released in heavy metals-amended and unamended soils.**
- **Temperature coefficient of ammonium release (Q_{10}).**

The Q_{10} values were calculated by dividing the rate of NH_4-N released from soil incubated under waterlogged conditions for times ranging from 3 to15 days at 30°C by the rate of the NH_4-N released at 20°C.

- **Heavy metals used**

Fisher certified reagent-grade chemicals. Of those, Cd^{2+}, Co^{2+}, and Cu^{2+} were added as sulfate; Ni^{2+} and Cr^{3+} as chloride; Pb^{2+} as acetate.

Results

- **Amount of NH_4-N released**

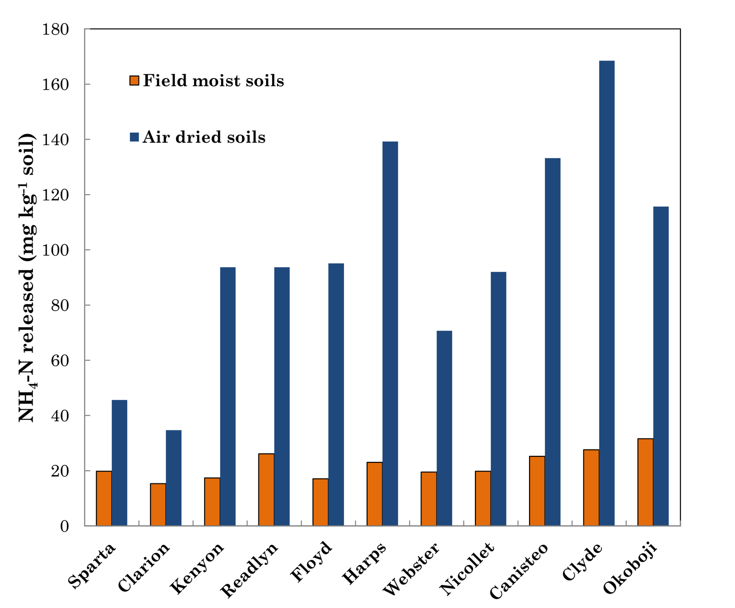

Fig.1. Amounts of NH_4-N released in field-moist and air-dried soils incubated at 30°C under waterlogged conditions for 15 days.

Table 2. Rates of NH_4-N released in field-moist and air-dried soils at 30°C.

Soil	Field-moist soils mg kg^{-1}day^{-1}	Field-moist soils kg ha^{-1}day^{-1}	Air-dried soils mg kg^{-1}day^{-1}	Air-dried soils kg ha^{-1}day^{-1}
Sparta	1.4	3.1	3.2	7.2
Clarion	0.97	2.2	2.3	5.2
Kenyon	1.1	2.5	6.4	14.3
Readlyn	1.7	3.8	6.4	14.3
Floyd	1.1	2.5	6.7	15.0
Harps	1.6	3.6	10.1	22.6
Webster	1.2	2.7	4.5	10.1
Nicollet	1.4	3.1	6.6	14.8
Canisteo	1.7	3.8	9.4	21.1
Clyde	1.8	4.0	11.7	26.2
Okoboji	2.2	4.9	8.7	19.5
Avg.	1.5	3.3	6.9	15.5

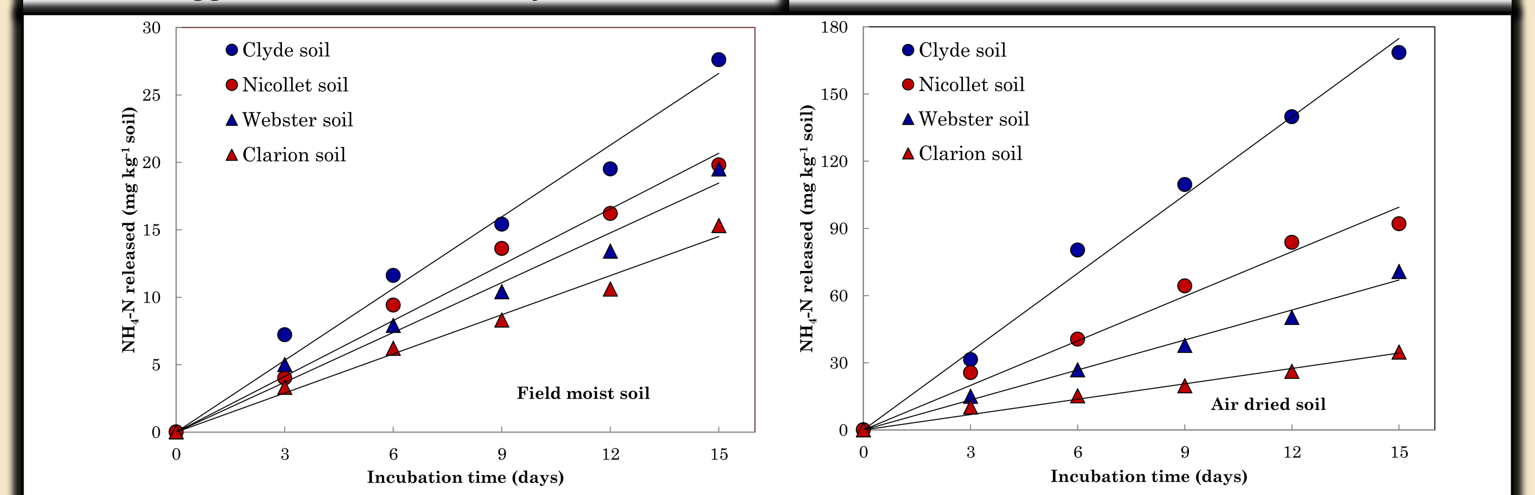

Fig. 2. Relationships between the amounts of NH_4-N released in field-moist and air-dried soils incubated at 30°C under waterlogged conditions and the time of incubation (days). The *r* values for all the relationships were ≥ 0.98***. At all data points, the differences among the duplicate values were smaller than the point size.

- **Relationships among rates of NH_4-N released and rates of hydrolysis of enzyme substrates.**

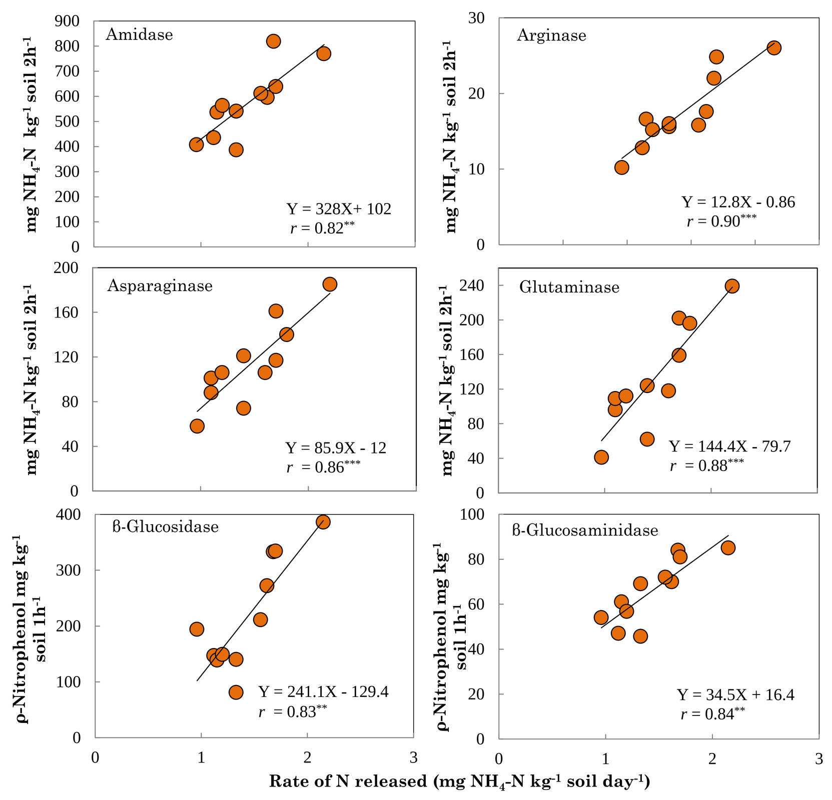

Fig. 3. Relationships between rates of NH_4-N released under waterlogged conditions at 30°C and selected enzyme substrates hydrolyzed in field-moist soils. At all data points, the differences among the duplicate values were smaller than the point size.

- **Effect of temperature (Q_{10}) .**

Table 3. Effect of temperature (Q_{10}) on the rates of NH_4-N released in soils.

Soils	Field-moist 30°C	Field-moist 20°C	Air-dried 30°C	Air-dried 20°C
Clarion	0.97 (1.3)	0.73	2.3 (1.0)	2.2
Harps	1.6 (1.2)	1.3	10.1 (1.1)	8.9
Webster	1.2 (1.3)	0.95	4.5 (1.2)	3.8
Clyde	1.8 (1.2)	1.5	11.7 (1.3)	9.3
Okoboji	2.2 (1.4)	1.6	8.7 (1.1)	8.2
Avg.	1.6 (1.3)	1.2	7.5 (1.1)	6.5

Rate of NH_4-N released (mg kg^{-1} soil day^{-1}) †

† Figures in parentheses are Q_{10} values calculated from rate of NH_4-N released at 30°C/rate of NH_4-N released at 20°C.

- **Effects of heavy metals.**

Table 4. Effects of selected heavy metals on NH_4–N released in soils under waterlogged conditions.

Metal	Total concentration (µmol kg^{-1} soil)† Clarion	Harps	Okoboji	Inhibition of NH_4-N released (%)‡ Clarion	Harps	Okoboji
Cd	3(0)§	0(0)	0(0)	66	71	9
Co	161(0.3)	126(0.2)	17(0.2)	31	69	22
Cr	804(1.0)	529(0.2)	703(0.4)	50	63	32
Cu	298(0.6)	395(0.5)	411(0.2)	43	12	14
Ni	188(0)	215(0)	201(0)	71	43	21
Pb	111(3)	133(1)	143(3)	85	55	34

† Figures in parentheses are the soluble heavy metals in soils (µmol kg^{-1} soil).

‡ At 10 mmol kg^{-1} soil.

§ Not detectable.

Conclusions

The rates of NH_4-N released from soils under waterlogged conditions at 30°C or 20°C during 15 days incubation were linear and were greater in air-dried than in field-moist soils; the rates differed among the 11 soils studied. The rates were affected by organic C and N, microbial biomass C and N, and with the rates of hydrolyses of six specific enzyme substrates. Six heavy metals added to soils inhibited the amounts of NH_4-N released under waterlogged conditions. The degree of inhibition varied among the soils and the metals studied.

References

Bartlett, R.J., Ross, D.S., 2005. Chemistry of redox processes in soils. In: Tabatabai, M.A., Sparks, D.L. (eds.). Chemical Processes in Soils. SSSA Book Series No. 8. SSSA, Madison, WI. pp. 461-487.

Frankenberger, W.T., Tabatabai, M.A., 1980. Amidase activity in soils. I. Method of assay. Soil Sci. Soc. Am. 44, 282–287.

Frankenberger, W.T., Tabatabai, M.A., 1991a. Factors affecting L-asparaginase activity in soils. Biol. Fertil. Soils. 11, 1-5.

Frankenberger, W.T., Tabatabai, M.A., 1991b. Factors affecting L-glutaminase activity in soils. Soil Biol. Biochem. 23, 875-879.

Ladd, J.N., Jackson, R.B., 1982. Biochemistry of ammonification. In: Stevenson, F.J., Bremner, J.M., Hauck, R.D., Keeney, D.R (Eds.), Nitrogen in Agricultural Soils. Agronomy No. 22. ASA-CSSA-SSSA, Madison, WI. pp. 173-228.

Ponnamperuma, F.N., 1972. Chemistry of submerged soils. Adv. Agron. 24, 24-96.

Sahrawat, K.L. 1981. Ammonification in air-dried tropical lowland Histosols. Soil. Biol. Biochem. 13, 323-324.

Tabatabai, M.A., 1994. Soil enzymes. In: Weaver, R.W., Angle, J.S., Bottomley, P.S. (Eds.), Methods of Soil Analysis. Part II: Microbiological and Biochemical Properties. Soil Science Society of America, Madison, pp. 775-833.

Waring, S.A., Bremner, J.M., 1964. Ammonium production in soil under waterlogged conditions as an index of nitrogen availability. Nature 201, 951-952.

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