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Organic amendment accelerates nitrification in soil

Shagufta Gill, M. Abid, Zulfiqar Ahmad and Farooqe Azam*
Nuclear Institute for Agriculture and Biology, P.O. Box 128, Jhang Road, Faisalabad, Pakistan

Abstract

A laboratory incubation experiment was conducted to study the effect of low and normal levels of CO_2 in the incubation vessels on the process of nitrification. The soil samples were incubated for 5 days under conditions of i) 0, 0.1 and 0.2% wheat straw added to the soil and ii) without or with the arrangements to trap headspace CO_2 in sodium hydroxide solution. Soil samples analyzed for NH_4 and NO_3+NO_2-N after 1, 3 and 5 days of incubation showed a significant reduction in the rate of nitrification at decreased level of CO_2 in the soil and headspace atmosphere. Organic matter amendment in the form of wheat straw significantly enhanced the rate of nitrification especially when CO_2 was trapped in sodium hydroxide solution. Implications of organic matter content of soil and its decomposition to nitrification and subsequent denitrification are discussed.

Key words: ammonium N, denitrification, elevated CO_2, Nitrate N, organic matter

Introduction

Organic matter amendment has multifarious beneficial effects on soil fertility and productivity. Nutrient dynamics and availability, water economy of the crops and overall soil health depends to a considerable extent on the quality and quantity of organic matter reaching the soil. A close relationship between organic matter content and fertility/productivity of soil is well established. However, organic matter additions have implications to plant availability of nutrients, especially of nitrogen (N) that undergoes internal cycling through microbial processes of immobilization and remineralization and nitrification/denitrification. In general, the process of N immobilization is governed by the chemical complexity of the organic matter reaching the soil. The process is more rapid when simple carbonaceous materials like sugars are present and decreases with the increased complexity (Ahmed *et al*., 1973, Azam *et al*., 1985). Likewise, denitrification is dependent to a significant extent on the availability of carbonaceous materials particularly those that can be easily oxidized by the soil microorganisms (Burford and Bremner, 1975). Thus organic matter can stimulate denitrification not only by serving as energy source for the denitrifiers but also through consuming oxygen and the development of microsite anaerobiosis (Ottow and Fabig, 1985; Arah, 1997).

The significance of organic matter in enhancing denitrification is quite well recognized. It is known, however, that the process of denitrification is generally substrate-limited i.e., availability of NO_3 will determine the pace of denitrification. Hence, nitrification has a direct relevance to denitrification not only in terms of making NO_3 available but also because of the fact that substantial quantities of oxides of nitrogen are released during the process of nitrification itself (Bouwman, 1990; Williams *et al*., 1998; Abbasi and Adams, 2000, Azam *et al*., 2002). It will appear therefore that amongst different N cycle processes, the process of nitrification stands out to be the most important process vis-à-vis ecosystem functioning and environmental concerns. For nitrification to occur, availability of NH_4 is the necessary prerequisite. It is known, however, that the predominant nitrifiers i.e., *Nitrosomonas* and *Nitrobacter* use CO_2 as a sole source of C (Aleem, 1965). Hence, any agricultural management practice (including organic matter amendment) that leads to enhanced availability of CO_2 is expected to favour the process of nitrification and consequently the denitrification. Previously, we have reported a decrease in the rate of nitrification under conditions of reduced CO_2 partial pressure in the incubation vessels (Azam *et al*., 2005). Objective of the present study was to determine the influence of organic matter amendment on the pace of nitrification in soil.

Materials and methods

Soil used in the study was collected from an experimental field at the Nuclear Institute for

* E.mail: asim6006@fsd.comsats.net.pk

Agriculture and Biology (NIAB), Faisalabad, Pakistan. Air-dried and sieved (<2-mm) soil had the following characteristics: pH (1:1, soil:water suspension), 7.8; electrical conductivity, 1.5 dS m^{-1}; organic C, 0.62%; total N, 0.06%; NH_4^+-N, 5 mg kg^{-1}; NO_3^- + NO_2^- -N, 11 mg kg^{-1}; clay, 35%; slit, 29%; sand, 36%. The analytical methods have been described elsewhere (Lodhi *et al*., 2006).

Portions of soil (50 g) were placed in 54 plastic jars (250-ml capacity, 7.5 cm diameter, and 10 cm height). Three sets of 18 jars each received powdered wheat straw at 0%, 0.1%, or 0.2% that was thoroughly worked out with the soil. Soil in all the jars was moistened to 15% (w/w) with a solution of $(NH_4)_2SO_4$ to achieve NH_4-N level in soil of 200 mg kg^{-1}. Nine jars from each set of 18 were provided with a setup to trap CO_2. The setup consisted of a plastic cups (3 cm diameter) containing 10 ml 10% NaOH solution and a rolled piece of filter paper (2 cm diameter, 5 cm height) to enhance the surface area for more efficient absorption of CO_2 in NaOH. The absorbing surface was 3 times higher with than without the rolled filter paper (data not shown) thereby ensuring almost complete absorption of CO_2. In some other related studies dealing with denitrification (unpublished), it was possible to maintain almost CO_2-free conditions in the headspace of 250-ml serum bottles using NaOH traps. However, no attempt was made to ascertain the level of CO_2 in the present study. The jars were closed with a perforated lid to allow for gaseous exchange and incubated for 20 days at 30±2°C. The loss of moisture during incubation was made up with distilled water.

Triplicate jars were removed at 1, 3, and 5 days of incubation from each set (i.e., those with or without the arrangements for trapping CO_2) for the determination of NH_4- and NO_3+ NO_2-N content of the soil [a maximum of 5 days incubation was considered sufficient in light of the previous experiences showing almost complete nitrification during this time]. The cups were removed from the jars, the soil thoroughly mixed and 20-g portions extracted with 50 ml 1N KCl solution by shaking for 1 h on a reciprocating shaker. The suspension was suction-filtered through Whatman no. 4 filter paper followed by two washings of residual soil with 20-ml aliquots of water. The combined filtrate was analyzed for NH_4- and NO_3 + NO_2-N (referred to as NO_3-N hereafter) by the micro-Kjeldahl method (Keeney and Nelson, 1982). The data obtained were analyzed for the determination of standard error of means using MICROSOFT EXCEL software.

Results and discussion

Figure 1 presents the data on NH_4-N, NO_3-N and NH_4+NO_3-N content of soil samples incubated for 5 days without or with wheat straw. Incubation period of 5 days was selected in view of the fact that the process of nitrification is fairly rapid and completed within this time. There was a rapid decrease in the content of NH_4-N (Figure 1a), the pace of decrease being much faster after days of incubation. Even after day 1, substantial decrease in the NH_4-N content of soil was observed. This could be attributed to an initial immobilization of NH_4-N which is assimilated in preference to NO_3 (Jansson, 1958). The pace of immobilization is generally more in the presence of easily oxidizable C sources (Ahmad *et al*., 1973, Azam *et al*., 1985, 1993). Since, the soil samples were air-dried and remoistened, release of substantial quantities of decomposable C was not unexpected. The freshly released organic C would have resulted in initial immobilization of NH_4-N.

The decrease in NH_4-N was quick in soil samples amended with wheat straw; the extent of decrease being more at 0.2 than at 0.1% wheat straw. Negligible quantities of NH_4-N were observed after 5 days of incubation suggesting. This decrease could partially be attributed to immobilization of N. Substantial immobilization of N during the decomposition of wheat straw has been reported (Azam *et al*., 1985). However, data presented in Figure 1c suggests that immobilization was not the main reason of decrease in NH_4-N as the quantities of NH_4+NO_3-N were fairly stable during 5 days of incubation. Therefore, nitrification could have been the main reason for the decrease in NH_4-N content.

Figure 1b clearly suggests the occurrence of rapid nitrification. The amount of NO_3 increased rapidly after 3 days of incubation and the entire amount of NH_4-N appeared to have nitrified during 5 days of incubation. In soil samples incubated in the presence of CO_2 trapping system, nitrification was much slower and increased significantly with the amount of wheat straw. The difference in unamended and amended soil samples was

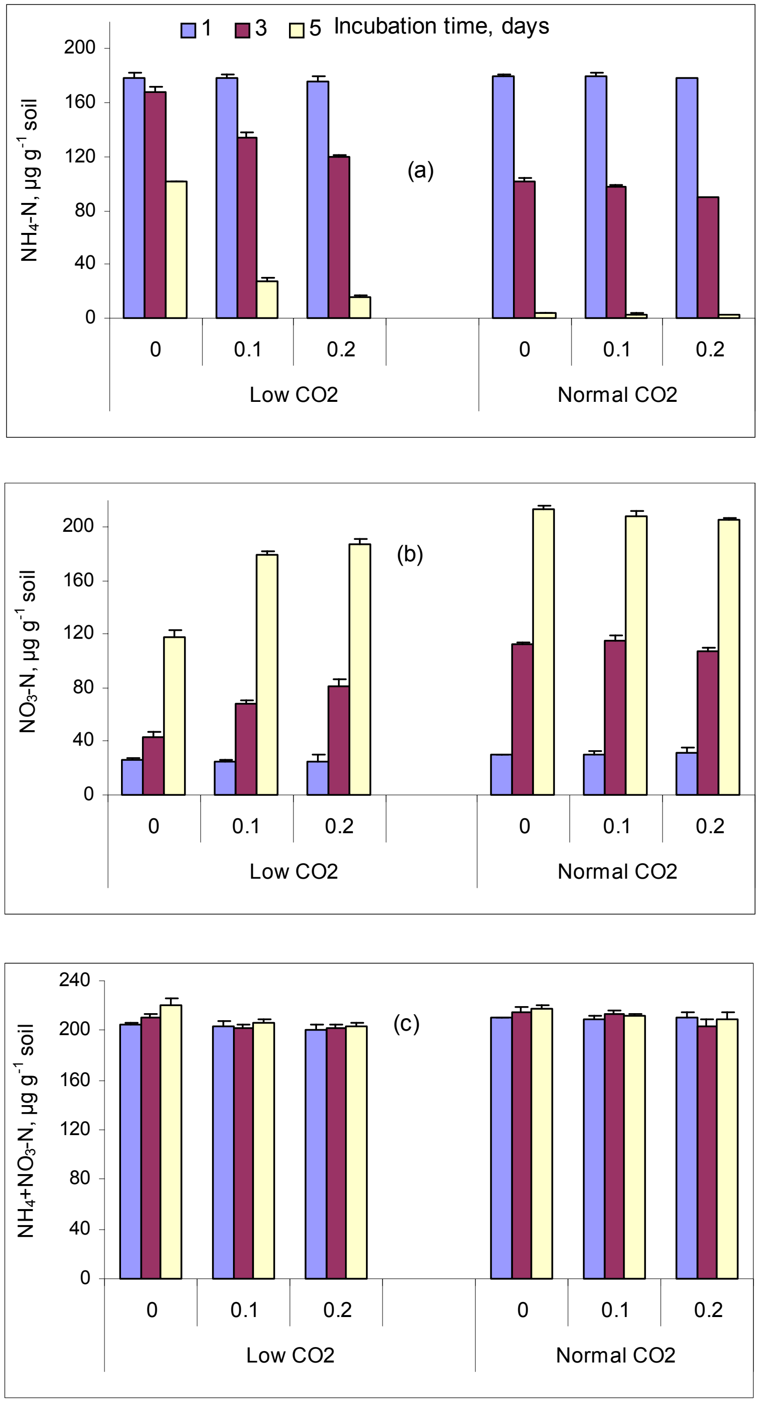

Figure 1. Changes in NH_4-N, NO_3-N and NH_4+NO_3- during 5 days of incubation of soil amended with 0, 0.1 and 0.2% wheat straw and with (low CO_2) or without (normal CO_2) the arrangements for trapping CO_2.

substantial and significant after 3 and 5 days of incubation. Under normal CO_2 conditions (CO_2 not being trapped in NaOH), the rate of nitrification was not affected by the level of wheat straw amendment. It would appear that the process of nitrification is fairly sensitive to lower availability of CO_2 while above certain limits the effect is not pronounced. Under normal conditions any CO_2 generated through microbial respiration will stay within the soil matrix and will be sufficient to meet the demands of autotrophic organisms responsible for nitrification. In this case, further additions to the decomposable C pool in the form of wheat straw would not affect the process of nitrification significantly. Under conditions of limited CO_2 availability (in incubation jars with arrangement for trapping CO_2), however, higher levels of CO_2 will be present at 0.1 and 0.2% wheat straw compared to 0 straw thereby leading to significant effects on the rate of nitrification as depicted in Figure 1b. These results suggested that organic amendment-mediated transient increase in soil CO_2 prior to its efflux from soil and absorption in alkali was sufficient to stimulate the process of nitrification.

Table 1 shows the ratio of NH_4 to NO_3 as a measure of the extent of nitrification; a higher ratio suggesting a more rapid nitrification. At day 1, the average ratio for different wheat straw amendment levels was 0.14 and 0.17 under low and normal CO_2 conditions, respectively. Thus from the outset, the rate of nitrification was significantly higher under normal conditions. The difference due to CO_2 became more obvious after 3 days when the ratio was 0.48 and 1.16 (average of 3 wheat straw treatments) under low and normal CO_2 conditions, respectively; ratios after 5 days were 6.43 and 70.9 when the process of nitrification was almost completed. The ratios also clearly depicted the significance of wheat straw amendment as these were significantly higher in amended soil and more so at 0.2% than at 0.1% straw.

Table 1. Efficiency of nitrification expressed as the ratio of NO_3 to NH_4 content of soil

CO_2 level	Amendment, %	Incubation time, days		
		1	3	5
Low	0	0.15	0.26	1.17
	0.1	0.14	0.51	6.49
	0.2	0.14	0.68	11.63
	Average	0.14	0.48	6.43
Normal	0	0.17	1.10	63.51
	0.1	0.17	1.18	72.61
	0.2	0.18	1.19	76.58
	Average	0.17	1.16	70.90

Nitrification rate depends on microbial activity, available C and CO_2 concentration in the soil atmosphere and is reported to increase substantially at elevated levels of CO_2 (Hungate *et al*., 1999, Azam *et al.*, 2005). Since the content of CO_2 in the soil atmosphere is several times greater (because of the respiratory activities of microorganisms) than that above the soil (Certini *et al*., 2002), nitrifiers are functioning at elevated levels of CO_2. However, most studies on nitrification have been reported under conditions of elevated CO_2 and seldom under CO_2-depleted conditions. As such, our is the first study of its kind that suggests that N dynamics will be very different in experiments employing closed systems with arrangements for trapping CO_2 in alkali solutions or in systems where CO_2-free air is passed over the incubated soil samples.

The results of the present study suggest the significance of organic matter in affecting nitrification. Under conditions of depleted organic matter or when the soil is exhausted of organic C, nitrification in soil will be curtailed. Hence, availability of NO_3 will be a limiting factor for leaching and denitrification. Thus readily decomposable organic matter will favour denitrification not only due to enhanced supplies of C to the denitrifiers but also by ensuring enhanced availability of NO_3 through elevated levels of CO_2 and higher activity of the nitrifiers.

References

Ahmed, Z., Y. Yahiro, H. Kai and T, Harada.1973. Transformation of the organic nitrogen becoming decomposable due to the drying of soil. *Soil Science and Plant Nutrition* 19: 287-298.

Aleem, M.I.H., G.E. Hoch and J.E. Varner. 1965. Water as the source of oxidizing and reducing power in bacterial chemosynthesis. *Proceeding National Academy of Science USA* 54: 869-873

Arah, J.R.M. 1997. Apportioning nitrous oxide fluxes between nitrification and denitrification using gas-phase mass spectrometry. *Soil Biology and Biochemistry* 29: 1295-1299.

Azam, F., S. Gill. and S. Farooq. 2005. Availability of CO_2 as a factor affecting the rate of nitrification in soil. *Soil Biology and Biochemistry* 37: 2141-2144.

Azam, F., K. Haider and K.A. Malik. 1985. Transformation of ^{14}C labelled plant components in soil in relation to immobilization-remineralization of N fertilizer. *Plant and Soil* 86: 15-25.

Azam, F., C. Mueller, A. Weiske, G. Benckiser and J.C.G. Ottow. 2002. Nitrification and denitrification as sources of atmospheric N_2O - role of oxidizable C and applied N. *Biology and Fertility of Soils* 35: 54-61.

Azam, F., F.W. Simmons and R.L. Mulvaney. 1993. Immobilization of ammonium and nitrate and their interaction with native N in three Illinois Mollisols. *Biology and Fertility of Soils* 15: 50-54.

Bouwman, A.F. 1990. Exchange of greenhouse gases between terrestrial ecosystems and the atmosphere. p. 100-120. In: Soils and the greenhouse effect. A.F. Bouwman (ed.) Wiley, Chichester.

Burford, J.R. and J.M. Bremner. 1975. Relationships between the denitrification capacities of soils and total, water-soluble and readily decomposable soil organic matter. *Soil Biology and Biochemistry* 7: 389-394.

Certini, G., G. Corti, A. Agnelli and G. Sanesi. 2002. Carbon dioxide efflux and concentrations in two soils under temperate forests. *Biology and Fertility of Soils* 37: 39-46

Hungate, B.A., P. Dijkstra, D.W. Johnson, C.R. Hinkle and B.G. Drake. 1999. Elevated CO_2 increases nitrogen fixation and decreases soil nitrogen mineralization in Florida scrub oak. *Global Change Biology* 5: 781-789

Jansson, S.L. 1958. Tracer studies on nitrogen transformations in soil with special attention to mineralization-immobilization relationships. *Annals of Royal Agriculture College, Sweden* 24: 101-361.

Keeney DR and DW Nelson. 1982. Nitrogen-inorganic forms. p. 594-624.In: Methods of soil analysis. A.L Page, R.H. Miller and D.R. Keeney (eds), American Society of Agronomy, Madison, Wisconsin.

Lodhi, A., M. Arshad, F. Azam, M.H. Sajjad and M. Ashraf. 2006. Changes in mineral and mineralizable N of soil incubated at varying salinity, moisture and temperature regimes. *Pakistan Journal of Botany* 38: 112-120.

Ottow, J.C.G. and W. Fabig. 1985. Influence of oxygen aeration on denitrification and redox level in different bacterial batch cultures. p 427–440. In: Planetary Ecology. D.E. Caldwell, J.A. Brierley and C.L. Brierley (eds). Van Nostrand Reinhold, New York.

Williams, P.H., S.C. Jarvis and E. Dixon. 1998. Emission of nitric oxide and nitrous oxide from soil under field and laboratory conditions. *Soil Biology and Biochemistry* 30:1885-1893.