Responses Of Soil Parameters In The Terrestrial Ecosystem Due To Nitrogen (N) Enrichment: A Mini Review

Om Shiwani[1]*, Dr. Akbare Azam[2], Najm Ul Rafi[3] Dr. Awanish Kumar Singh[4], Dr. Awanish Kumar Pandey[5]

Abstract

In the existing age, Human-induced reactive Nitrogen (Nr) deposition is the major source of N in the terrestrial ecosystem. Reactive N plays an important role in global climate change through altered ecosystem processes, including acidification, mineralization, leaching of base cations, metal toxicity, microbial properties, altered species composition and diversity. These modifications impose a great threat to plants, microbes, human health and other living organisms. Current understanding on Nr deposition and its impact on natural ecosystem processes and properties basically depends on the simulated and observational N deposition studies. However, our understanding of the mechanisms, which regulate the response of soil parameters under N enrichment are still limited. Interaction among various parameters could play significant role in regulation of ecosystem properties and processes under N deposition. However, most of the studies have focused on the separate responses of soil pH, mineral-N availability and base cations under N-enrichment, which do not provide mechanistic understanding regarding change in soil parameters. Till date very few studies have been performed the simultaneous responses of soil pH, mineral-N availability and base cations under N-enrichment. In this review we have summarized the effect of N-input on soil pH, mineral-N and base cations, with other interactive parameters. The study also emphasizes on interactive study of soil parameters under N-input for better apprehension of mechanism responsible for the change in soil properties and processes.

Keywords: Nitrogen deposition; soil acidification; base cation; mineralization, terrestrial ecosystem

[1]*Assistant Professor, Department of Botany Govt. Girls' P. G. College Ghazipur U. P.
E-mail id: omshiwani@gmail.com
[2]Assistant Professor, Department of Chemistry Govt. Girls' P. G. College Ghazipur U. P. Mob. No. 9044464242
[3]Assistant Professor, Department of Chemistry Govt. P. G. College Jalesar Etah, U. P.
[4]Assistant Professor, Department of Physics S. S. Govt. Degree College Yusufpur Ghazipur, U. P.
[5]Assistant Professor, Department of Chemistry S. M. M. Town P. G. College Ballia , U. P.
Assistant Professor Department of Home Science Govt. Degree College Sahjanwa, Gorakhpur, U. P.
Assistant Professor Department of Chemistry Govt. Girls' Degree College Saiyadraja Chandauli, U. P.

***Corresponding Author:** Om Shiwani
*Assistant Professor, Department of Botany Govt. Girls' P. G. College Ghazipur U. P.
E-mail id: omshiwani@gmail.com

Introduction

Nitrogen (N) significantly participate in the growth, metabolism and reproduction of organisms. It exist in different forms in the cell such as nucleic acids, proteins, chlorophyll, amino sugars, vitamins, which are undoubtedly important for life (Coleman et al., 2004). It constitutes approximately 78% of gases present in the atmosphere, but it is also a limiting nutrient in the terrestrial ecosystem (Elser et al., 2007; Lebauer & Treseder, 2008). As it could not be taken directly in N_2 (inert) form, so it has to be fixed first in reactive form. Only a few microbes can break high energy triple bond of N_2 and fix atmospheric nitrogen into the available forms. Share of microorganism in nitrogen fixation is 100-300 Tg of per annum (Galloway et al., 2003), share of lightning is 3-10Tg of nitrogen fixation per annum (Prather et al., 2001), and anthropogenic activity (food demand and energy consumption) contributes 156Tg yr^{-1} in 1995 to 187tg yr^{-1}in 2005 (Galloway et al., 2008) of nitrogen fixation per annum.

In preindustrial time, biological nitrogen fixation was predicted up to (90-130) $\times 10^6$ metric tonnes yearly (Galloway, 1995). N deposition was reported more than 50 kg/ha during 2000–2010 worldwide (Penuelas et al., 2013), relatively high N deposition was recorded in many tropical regions in comparison to Europe and North America since the 1980s (Galloway et al., 2004; Duanet al., 2016). (Lamarque et al.,2005) speculated that N deposition by 21st century is projected to lie between 60 and 100Tg-N-yr^{-1} over global landmass on the basis of A2 scenario. N deposition has profound impacts on the soil and vegetation via altering soil pH (Carey et al., 2015; Ye et al., 2018), mineral N availability (Ye et al., 2018) base cation leaching (Lucas et al., 2011; Cai et al., 2017), microbial diversity, enzyme activity (Song et al., 2017; Penget al.,2017), plant diversity, community structure and productivity (Tang et al., 2017).

Effect of N treatment may vary according to the background N deposition level, N treatment level, time of N treatment, the form of N treatment, environmental factors, soil properties, etc. (Liu et al., 2015). Besides these, a wide range of climatic factors such as moisture and temperature, along with N fertilization also regulate the soil acidification, availability of mineral-N and buffering capacity of the soil (Xu et al., 2016; Cai et al., 2017). Temporal variation is also important in the regulation of soil processes i.e., acidification, N-transformations and buffering capacity. Temporal variations comprise the change in precipitation and temperature, which are generally associated with seasonal patterns (Zhang et al., 2008).

Mineral N is the chief nutrient that govern the quality and fertility of the soil. Continuous excess increase of N deposition may lead to N saturation where availability of inorganic N exceed the biological demand (Lohse et al., 2005) via altered mineralization, even reduce plant productivity and diversity (Wat mough & Dillon, 2003; Magill et al., 2004; Han et al., 2013). Variation in soil mineralization due to N enrichment responsible for altered environmental pH (Niu et al., 2017; Ma et al., 2016; Tian & Niu, 2015). Alteration in Soil pH is responsible for the change in the structure and composition of the soil bacterial assemblage (Fierer & Jackson, 2006; Rousk et al., 2010) as well as cation exchange capacity of the soil (Messiga et al., 2013; Cai et al., 2017; Mao et al., 2017). Long-term N-enrichment mediated reduction in pH leads to reduced nitrification (Bobbink et al., 2010). Soil acidification cause leaching of base cation (Bowman et al., 2008; Tian & Niu, 2015; Lucas et al., 2011) which affects the nutrient quality of soil and change the SOC content (Chapin et al., 2011).

As per our observation, there is diverse results have been found regarding responses of soil parameters due to N enrichment, which causes are still not clearly understood. Simultaneous studies of these soil parameters are still very limited. There is a lack of interactive study on the interdependency of soil N-mineralization, acidification and base cations in the terrestrial ecosystem. Therefore, this review is focused on how and to what extent N deposition influences the soil acidification, N-mineralization and buffering capacity of the soil.

Consequences of N-input on Soil pH

The N-induced soil acidification has been identified as a significant threat to the terrestrial ecosystem functioning, mostly grasslands, as grasslands are more prone to acidification due to N-enrichment. Various Studies on N stimulating effect on soil properties have shown more or less similar outcomes, which advocate the decrease in pH due to the addition of N. However, some studies have shown that the N addition rate increased, the soil pH decreased continuously (Zhang et al., 2012; Ma et al., 2016; Raza et al., 2020) while, Chen et al. (2015) reported decrease in soil pH in a 2 year of N-treatment in comparison to control, pH increased in each treatment level in the next year in comparison to the previous year. Significant reduction in the pH of topsoil was reported at high level of N-input (Widdig et al., 2020). It might be possible due to seasonal fluctuations, inter-annual variability in precipitation and temperature or by alteration in the uptake of inorganic nitrogen forms by the plants. A study conducted in tropical broadleaf forest showed no significant change in pH after 7 years of simulated N input (Huang et al., 2021). Tian and Niu (2015) in a meta-analysis found that the fertilization of urea and NH_4NO_3 added more to soil acidification than NH_4^+-form fertilizer, due to the volatilization of NH_4^+. After 20 years of N-enrichment, effect on soil pH declined (Tian & Niu, 2015). Vulnerability for acidification under N enrichment was found higher in grasslands than forests and among forests acidification was found least in boreal forest. Tian and Niu (2015) also reported that soil pH did not alter significantly in the boreal forest because the boreal forest is dominated by conifer species which prefer NH_4^+ as N source rather than NO_3^- (Hangs et al., 2003). Preference of NH_4^+ over NO_3^- decreases the substrate for nitrification (which cause release of H^+), so they are less susceptible to acidification due to N-deposition, whereas pH in the tropical and temperate forest were found to be significantly declined.

Different ecosystems respond differently as they differ in their edaphic properties and background environment (Table 1). Like, the pH values were found to increase along with increasing rates of N addition (Luo et al., 2017) in coastal mangrove sediments, which is contrasting to most of the studies that found a decrease in soil pH due to N addition.

$NaNO_3$ was used as a source of N by Luo et al. (2017) and they urged that due to an increase in phenolics as a result of N treatment, pH increased. Moisture content along with N addition has potential effects on soil pH via affecting the leaching process (Lucas et al., 2011) as well as the rate of mineralization. (Cai et al., 2017) conducted a study in a semi-dry grassland and reported that the soil pH declined due to N-input under both ambient and supplementary water treatments, but the effect was significant when N was applied without water, whereas with water the effect was not significant. They advised that N stimulated decrease in soil buffering capacity was prevented due to water addition and decreased soil available N via leaching of NO_3^-, resulting in improved pH status (Cai et al., 2017). However, Lieb et al. (2011) reported that increased NO_3^- leaching under water treatment caused increased leaching of base cation too and thus resulted in enhanced soil acidity. This contradiction might be possible due to the discrepancy in the various properties of the soil (Li et al., 2020)

Table 1. Impact of various form and doses of N-input on soil pH, base cations and available-N in various studies. (NA= Not Available)

Location (Latitude and longitude)	Form of N	Dose of N (Kg-N/ha/yr)	Duration of N treatment	pH	Base cations	Available-N	Reference
$41^0 49'$-$42^0 27'$N, $115^0 56'$-$116^0 51'$E	Urea	0, 20, 40, 80 and 160	2005-2006	Significantly reduced in 160 N treatment	NA	Increased significantly, highest in HN treatment	Zhang et al., 2012

$43^0$38´-N-$116^0$42´E	NH_4NO_3	0, 17.5, 52.5, 105, 175 and 280	1999-2011	Significantly reduced in both year treatment-wise, however year-wise pH increased	Ca^{2+}, Mg^{2+},Na^{+} concentration decreased with N-input, while yearly Ca^{2+} and Mg^{2+} increased and Na+ decreased	Increased with increase in N-treatment, while year-wise decreased	Chen et al., 2015
$43^0$26´-$44^0$9´N, $115^0$2´-$117^0$2´E	Urea	0, 25 and 50	2005-2012	With natural water supply pH decreased in N- treated plot, while with simulated water supply pH increased in both control and N-treated plots	NA	NA	Ma et al., 2016
$42^0$02N´-$116^0$17´E	Urea	0,50,100,150	Not confirmed	pH reduced significantly in both ambient and simulated water treatment under N-deposition	Ca^{2+}, Na^{+} significantly reduced in both water treatment under N-input, while Mg^{2+} increased in ambient water treatment under N-input	Increased in both ambient and simulated water treatment under N-addition, but was more profound in ambient condition	Cai et al., 2017
$43^0$26´-$44^0$08´N, $116^0$04´-$117^0$05´E	NH_4NO_3	0, 17.5, 52.5, 105, 175 and 280	2000-2006	Decreased with increasing N-deposition	NA	Increased with increase in N-input	Zhang and Han 2012
$43^0$38′ N, $116^0$42′ N and 1250 m.a.s.l.	NH_4NO_3	0, 17.5, 52.5, 105, 175 and 280	1999-2014	Reduced significantly	Na^{+}, K^{+}, Mg^{2+}, Ca^{2+} and Mn^{2+} decreased significantly and increased Al and Fe significantly	Increased	Ye et al., 2018
	NH_4NO_3	0, 10, 20, 30, 50, 100, 150, 200, and 500 with two frequency (2 and 12 times per year)	2008-2014	Reduced significantly	Mowing differently alter the response of N-input, while Mg^{2+}, Ca^{2+} decreased in very high N doses, but in low doses it increased. Fe and Mn increased in both known and unknown condition under N-input	NA	Wang et al., 2018
	NH_4NO_3	0 and 40	1998-2010	NA	NA	Increased significantly	Mueller et al., 2013
$38^0$32′45.52″N,$121^0$47′05.37″W	NH_4NO_3	0 and 45	2008-2013	Slightly reduced	NA	NO_3^- increased and NH_4^+ decreased	Carey et al., 2015

	NH_4CL $NaNO_3$ NH_4NO_3	0 and 70	2007-2009	In Threfore no effect, In Leognan slightly increased, In Revne significantly decreased	NA	In Trefor and Leognan no effect was found, while in Revne NO3- increased significantly	Dorland et al., 2013
$46^0$47′N, $71^0$07′ W,	[5Ca(NO_3)$_2$.NH_4NO_3.10 H2O]	0, 60, 120 and 180	1999-2006	Declined significantly	K^+ reduced significantly, Al increased, while Ca^{2+}, Mg^{2+} and Na^+ remain unaffected	NA	Messiga et al., 2013

Responses of base cation due to N enrichment

Base cations play important role in soil buffering capacity, which in-turn regulates soil pH. Base cations also play significant role in vital activity and helps in the maintenance of ecosystem structure and function. As different concentration and the ratio of base cations require by different plant species, variation in concentration and ratio of these cation cause change in species composition and diversity. Different studies on responses of base cation under N-enrichment have shown in Table 1. In a study, decrease in Ca^{2+}, Mg^{2+} and Na^+ and increase in Al^{3+} was reported in response to increasing concentration of N, while year-wise concentration of these base cations increased (Chen et al., 2015), however, no significant change in the concentration of base cations and acids cations were observed under 7 years of simulated N-input (Huang et al., 2021). (Cai et al., 2017) demonstrated that total exchangeable cations of the soil significantly decreased with rising N level under ambient and supplementary water treatments. Concentrations of soil exchangeable Ca^{2+} and Na^+ significantly reduced due to N treatment under both ambient and additional water conditions. Concentration of exchangeable Mg^{2+}increased under N treatment with ambient water condition. Concentration of the soil Ca^{2+} and Mg^{2+}significantly enhanced under water addition in the control (N_0) treatment (Cai et al., 2017). A meta-analysis performed by Lucas et al. (2011), it was reported that exchangeable Ca^{2+}, Mg^{2+} and K^+ reduced by 26%, 25% and 22% in temperate forest, grasslands and boreal forest, while Ca^{2+} concentration enhanced significantly in tropical forest due to N enrichment. Response of soil base cations also vary according to the fertilizer type. A substantial reduction of exchangeable Ca^{2+}, Mg^{2+}, and K^+ from the soils under ammonium nitrate (NH_4NO_3) fertilizer application was found, whereas under ammonium sulfate ($(NH_4)_2SO_4$) application only Ca^{2+} showed a significant reduction (Lucas et al.,2011). Tian and Niu (2015) reported a significant decline in concentration of Ca^{2+}, Mg^{2+} and K^+ in both grasslands and forests in response to increased N-input. However, they found that the concentration of Na^+ was significantly declined and Mn^{2+} was increased in grassland but not in the forest. So according to Tian and Niu (2015) grasslands are proceeding towards Mn^{2+} buffering phase.

A decline in base cations might be possible due to coupled leaching of base cation along with NO_3^- (Lieb et al., 2011). Vulnerability of grassland towards other stresses enhanced due to the reduction in base cations concentration (Bowman & Cleveland 2008). In an experimental study, reduction in soil-exchangeable base cations by 46%, 37% and 38% for Ca^{2+}, Mg^{2+} and K^+ respectively under the uppermost level of N treatment was reported (Bowman & Cleveland 2008). Base cations concentration is also influenced by a change in soil organic carbon (SOC) content in response to accelerated N-input (Chapin et al., 2011; Fang et al., 2017). SOC concentration in response to N-input either increased (Zhang & Han 2012), decrease (Liu & Greaver, 2010)or remain unchanged (Han et al., 2013) depending on the ecosystem type, fertilizer type and dose of fertilizer used as well as duration of N-deposition. Altered SOC concentration caused change in anion concentration of humus and thus affected the binding of base cations with humus, which results in the altered availability of soil base cations (Fang et al., 2017). So, ecosystem in which SOC declined as a result of N deposition will face extreme acidification due to promoted base cation leaching (due to reduced anion in humus because of reduced SOC) and increased H^+ concentration (Fang et al., 2017).

Effect of N-input on Soil mineral-N

Nutrient quality of soil is mainly governed by the decomposition and mineralization potential of soil, as plants nutrients uptake occurs mainly in the form of minerals. However, in recent studies, it has been revealed that a few plants can directly take up organic N compounds (Raab et al., 1996). Inorganic N largely derived from atmospheric deposition, fertilization, mineralization and biological N fixation. It affects the soil properties through altered litter quality, rate of mineralization, C:N ratio, microbial communities etc. Hypothetically, the total organic pool present in the soil is mineralizable, but the dynamic fraction of organic-N which mineralized each year is only 1-3% (Bremner, 1965). N enrichment causes the change in mineral-N concentration (Table 1) on account of alteration in the rate of mineralization and other soil processes (Han et al., 2013). Tropical studies have shown that in the high level of N-input significantly increase the concentration of soil $NO_3^-$and NH_4^+ (Chen et al., 2015; Han et al., 2013), however concentration in each level of N-input was lower in the next year than previous year (Chen et al., 2015), which might be due to altered annual precipitation pattern, temperature (Schaeffer et al., 2013) or shift in preference of inorganic N uptake (Ashton et al., 2010; Zhou et al., 2019). N enrichment studies have found a significant increase in mineral-N (NH_4^+ and NO_3^-) concentration in response to increased N treatment with a decreased rate of mineralization in high N treated plot (Han et al., 2013). Zhang et al., 2012 reported that rate of mineralization and mineral-N concentration increased simultaneously. An increase in mineral-N may be significant (Jing et al., 2016) or non-significant (Knoblauch et al., 2017). Response of different form of mineral-N vary under N-input, i.e. a study conducted in the temperate steppe showed that the concentration of ammonia significantly decreased and nitrate concentration increased under N (urea) addition (Zhang et al., 2018).

Availability of water also impact the responses of mineral-N under N-input. Cai et al., 2017 reported that N treatment significantly increased the concentration of soil mineral-N under ambient and simulated water addition. A significant reduction in the concentration of soil NO_3^- at high N dose with water treatment was reported, which may be possible due to leaching losses. Moreover, interaction between water and N showed significant effect on the concentrations of soil NO_3^- and NH_4^+ (Cai et al., 2017).

A study conducted in semi-arid grassland of inner magnolia (Liu et al., 2015) showed that in the 1st year of experiment soil ammonium concentration enhanced but not significantly under the high level of N treatments ($(NH_4)_2SO_4$, NH_4Cl and KNO_3), however nitrate concentration was not affected significantly. In the second year, soil NO_3^- concentrations increased under high level of $(NH_4)_2SO_4$ treatment, however decreased under high level of NH_4Cl and KNO_3 treatments. NH_4^+ concentrations declined under all three high level of N treatments in the second year of experiment. Depth of soil also influences the consequence of N-input on mineral-N, as reported in some studies that N input potentially affected the surface zone of soil, but sub-surface strata was not much affected. (Zeng et al., 2015) demonstrated that the concentration of soil mineral-N increased significantly with increasing the N level. While, inorganic N in sub-surface zone showed small increase with a minor change in soil pH.

Conclusion

From above study it can be inferred that N-Enrichment results in the diverse effect on the soil parameters under different conditions. Soil pH showed generalized response under N- treatment in different condition, but the spatial and temporal response of the mineral-

N was not consistent under different N treatment. Responses of base cations were also inconsistent under different form of N-input in space and time. Our knowledge about interactive response of soil acidity, N availability and base cation due to N-input is still limited; only a few studies have introduced the simultaneous role played by soil pH, base cations and inorganic-N in the ecosystem. Since soil pH, available-N, and base cations play important role in biochemical processes of the soil, therefore the mechanism which is responsible for these changes under N-enrichment needs to be investigated in order to mitigate the negative effect of N-enrichment on ecosystem structure and function.

Acknowledgement
Authors are grateful to the Council of Scientific and Industrial Research (CSIR) New Delhi, India for financial support.

Conflicts of interest Authors declares that they have no known conflicts of interest associated with this study

References:
Ashton, I. W., Miller, A. E., Bowman, W. D., & Suding, K. N. (2010). Niche complementarity due to plasticity in resource use: plant partitioning of chemical N forms. Ecology, 91(11), 3252-3260.

Bobbink, R., Hicks, K., Galloway, J., Spranger, T., Alkemade, R., Ashmore, M., ... & De Vries, W. (2010). Global assessment of nitrogen deposition effects on terrestrial plant diversity: a synthesis. Ecological applications, 20(1), 30-59.

Bowman, W. D., Cleveland, C. C., Halada, Ĺ., Hreško, J., & Baron, J. S. (2008). Negative impact of nitrogen deposition on soil buffering capacity. Nature Geoscience, 1(11), 767-770.

Bremner, J. M. (1965). Total nitrogen. Methods of soil analysis: part 2 chemical and microbiological properties, 9, 1149-1178.

Cai, J., Luo, W., Liu, H., Feng, X., Zhang, Y., Wang, R.,... & Jiang, Y. (2017). Precipitation -mediated responses of soil acid buffering capacity to long-term nitrogen addition in a semi-arid grassland. Atmospheric Environment, 170, 312-318.

Carey, C. J., Beman, J. M., Eviner, V. T., Malmstrom, C. M., & Hart, S. C. (2015). Soil microbial community structure is unaltered by plant invasion, vegetation clipping, and nitrogen fertilization in experimental semi-arid grasslands. Frontiers in microbiology, 466.

Chapin, F. S., Matson, P. A., Vitousek, P. M., Chapin, F. S., Matson, P. A., & Vitousek, P. M. (2011). The ecosystem concept. Principles of terrestrial ecosystem ecology, 3-22.

Chen, D., Lan, Z., Hu, S., & Bai, Y. (2015). Effects of nitrogen enrichment on belowground communities in grassland: Relative role of soil nitrogen availability vs. soil acidification. Soil Biology and Biochemistry, 89, 99-108.

Coleman, D. C., Callaham, M., & Crossley Jr, D. A. (2017). Fundamentals of soil ecology. Academic press.

Dorland, E., Stevens, C. J., Gaudnik, C., Corcket, E., Rotthier, S., Wotherspoon, K.,... & Bobbink, R.(2013). Differential effects of oxidised and reduced nitrogen on vegetation and soil chemistry of species-rich acidic grasslands. Water, Air, & Soil Pollution, 224, 1-13.

Duan, L., Yu, Q., Zhang, Q., Wang, Z., Pan, Y., Larssen, T., ... & Mulder, J. (2016). Acid deposition in Asia: Emissions, deposition, and ecosystem effects. Atmospheric Environment, 146, 55-69.

Elser, J. J., Bracken, M. E., Cleland, E. E., Gruner, D. S., Harpole, W. S., Hillebrand, H., ... & Smith, J. E. (2007). Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine and terrestrial ecosystems. Ecology letters, 10 (12), 1135-1142.

Fang, K., Kou, D., Wang, G., Chen, L., Ding, J., Li, F., ... & Yang, Y. (2017). Decreased soil cation exchange capacity across northern China's grasslands over the last three decades. Journal of

Geophysical Research: Biogeo sciences, 122 (11), 3088-3097.

Fierer, N., & Jackson, R. B. (2006). The diversity and biogeography of soil bacterial communities. Proceedings of the National Academy of Sciences, 103(3), 626-631.

Galloway, J. N., Dentener, F. J., Capone, D. G., Boyer, E. W., Howarth, R. W., Seitzinger, S. P., ... & Vöosmarty, C. J. (2004). Nitrogen cycles: past, present, and future. Biogeochemistry, 70, 153 226.

Galloway, J. N., Schlesinger, W. H., Levy, H., Michaels, A., & Schnoor, J. L. (1995). Nitrogen fixation: Anthropogenic enhancement-environmental response. Global biogeochemical cycles, 9(2), 235 -252.

Galloway, J. N., Townsend, A. R., Erisman, J. W., Bekunda, M., Cai, Z., Freney, J. R., ... & Sutton, M. A. (2008). Transformation of the nitrogen cycle: recent trends, questions, and potential solutions. Science, 320 (5878), 889-892.

Galloway, J.N., Aber, J.D., Erisman, J.W., Seitzinger, S.P., Howarth, R.W., Cowling, E.B. and Cosby, B.J. (2003). The nitrogen cascade. AIBS Bulletin, 53 (4), 341-356.

Han, X., Tsunekawa, A., Tsubo, M., & Shao, H. (2013). Responses of plant–soil properties to increasing N deposition and implications for large-scale eco-restoration in the semiarid grassland of the northern Loess Plateau, China. Ecological engineering, 60, 1-9.

Huang, J., Zhang, W., Li, Y., Wang, S., Mao, J., Mo, J., & Zheng, M. (2021). Long-term nitrogen deposition does not exacerbate soil acidification in tropical broadleaf plantations. Environmental Research Letters, 16(11), 114042.

Jing, X., Yang, X., Ren, F., Zhou, H., Zhu, B., & He, J. S. (2016). Neutral effect of nitrogen addition and negative effect of phosphorus addition on topsoil extracellular enzymatic activities in an alpine grassland ecosystem. Applied Soil Ecology, 107, 205-213.

Knoblauch, C., Watson, C., Becker, R., Berendonk, C., & Wichern, F. (2017). Change of ergosterol content after inorganic N fertilizer application does not affect short-term C and N mineralization patterns in a grassland soil. Applied Soil Ecology, 111, 57-64.

Lamarque, J. F., Kiehl, J. T., Brasseur, G. P., Butler, T., Cameron-Smith, P., Collins, W. D., ... & Thornton, P. (2005). Assessing future nitrogen deposition and carbon cycle feedback using a multimodel approach: Analysis of nitrogen deposition. Journal of Geo physical Research: Atmospheres, 110 (D19).

LeBauer, D. S., & Treseder, K. K. (2008). Nitrogen limitation of net primary productivity in terrestrial ecosystems is globally distributed. Ecology, 89(2), 371-379.

Li, Z., Zeng, Z., Tian, D., Wang, J., Wang, B., Chen, H. Y., ... & Niu, S. (2020). Global variations and controlling factors of soil nitrogen turnover rate. Earth-science reviews, 207, 103250.

Lieb, A. M., Darrouzet-Nardi, A., & Bowman, W. D. (2011). Nitrogen deposition decreases acid buffering capacity of alpine soils in the southern Rocky Mountains. Geoderma, 164(3-4), 220-224.

Liu, L., & Greaver, T. L. (2010). A global perspective on belowground carbon dynamics under nitrogen enrichment. Ecology letters, 13(7), 819-828.

Liu, X. R., Ren, J. Q., Li, S. G., & Zhang, Q. W. (2015). Effects of simulated nitrogen deposition on soil net nitrogen mineralization in the meadow steppe of Inner Mongolia, China. PloS one, 10(7), e0134039.

Lohse, K. A., & Matson, P. (2005). Consequences of nitrogen additions for soil losses from wet tropical forests. Ecological Applications, 15(5), 1629-1648.

Lucas, R. W., Klaminder, J., Futter, M. N., Bishop, K. H., Egnell, G., Laudon, H., & Högberg, P. (2011). A meta-analysis of the effects of nitrogen additions on base cations: implications for plants, soils, and streams. Forest Ecology and Management, 262(2), 95-104.

Luo, L., Meng, H., Wu, R. N., & Gu, J. D. (2017). Impact of nitrogen pollution/ deposition on extracellular enzyme activity, microbial abundance and carbon storage in coastal mangrove sediment. Chemosphere, 177, 275-283.

Ma, H. K., Bai, G. Y., Sun, Y., Kostenko, O., Zhu, X., Lin, S., ... & Bezemer, T. M. (2016). Opposing effects of nitrogen and water addition on soil bacterial and fungal communities in the Inner Mongolia steppe: a field experiment. Applied Soil Ecology, 108, 128-135.

Magill, A. H., Aber, J. D., Currie, W. S., Nadelhoffer, K. J., Martin, M. E., McDowell, W. H., ... & Steudler, P. (2004). Ecosystem response to 15 years of chronic nitrogen additions at the Harvard Forest LTER, Massachusetts, USA. Forest ecology and management, 196(1), 7-28.

Messiga, A. J., Ziadi, N., Bélanger, G., & Morel, C. (2013). Soil nutrients and other major properties in grassland fertilized with nitrogen and phosphorus. Soil Science Society of America Journal, 77 (2), 643-652.

Mueller, K. E., Hobbie, S. E., Tilman, D., & Reich, P. B. (2013). Effects of plant diversity, N fertilization, and elevated carbon dioxide on grassland soil N cycling in a long-term experiment. Global Change Biology, 19(4), 1249-1261.

Niu, D., Yuan, X., Cease, A. J., Wen, H., Zhang, C., Fu, H., & Elser, J. J. (2018). The impact of nitrogen enrichment on grassland ecosystem stability depends on nitrogen addition level. Science of the Total Environment, 618, 1529-1538.

Nohrstedt, H. Ö. (2002). Effects of liming and fertilization (N, PK) on chemistry and nitrogen turnover in acidic forest soils in SW Sweden. Water, Air, and Soil Pollution, 139, 343-354.

Peng, Y., Chen, G., Chen, G., Li, S., Peng, T., Qiu, X., ... & Tu, L. (2017). Soil biochemical responses to nitrogen addition in a secondary evergreen broad-leaved forest ecosystem. Scientific Reports, 7(1), 1-11.

Peñuelas, J., Poulter, B., Sardans, J., Ciais, P., Van Der Velde, M., Bopp, L., ... & Janssens, I. A. (2013). Human-induced nitrogen–phosphorus imbalances alter natural and managed ecosystems across the globe. Nature communications, 4(1), 2934.

Prather, M., Ehhalt, D., Dentener, F., Derwent, R. and Grubler, A. (2001). Atmospheric chemistry and greenhouse gases.(No. PNNL-SA-39647). Pacific Northwest National Lab. (PNNL), Richland, WA (United States).

Raab, T. K., Lipson, D. A., & Monson, R. K. (1996). Non-mycorrhizal uptake of amino acids by roots of the alpine sedge Kobresia myosuroides: implications for the alpine nitrogen cycle. Oecologia, 108, 488-494.

Raza, S., Miao, N., Wang, P., Ju, X., Chen, Z., Zhou, J., & Kuzyakov, Y. (2020). Dramatic loss of inorganic carbon by nitrogen-induced soil acidification in Chinese croplands. Global change bio logy, 26 (6), 3738-3751.

Rousk, J., Bååth, E., Brookes, P. C., Lauber, C. L., Lozupone, C., Caporaso, J. G., ... & Fierer, N. (2010). Soil bacterial and fungal communities across a pH gradient in an arable soil. The ISME journal, 4(10), 1340-1351.

Schaeffer, S. M., Sharp, E., Schimel, J. P., & Welker, J. M. (2013). Soil–plant N processes in a High Arctic ecosystem, NW Greenland are altered by long-term experimental warming and higher rainfall. Global change biology, 19(11), 3529-3539.

Song, Y., Song, C., Meng, H., Swarzenski, C. M., Wang, X., & Tan, W. (2017). Nitrogen additions affect litter quality and soil biochemical properties in a peatland of Northeast China. Ecological Engineering, 100, 175-185.

Soon, Y. K., & Malhi, S. S. (2005). Soil nitrogen dynamics as affected by landscape position and nitrogen fertilizer. Canadian Journal of Soil Science, 85(5), 579-587.

Tang, Z., Deng, L., An, H., Yan, W., & Shangguan, Z. (2017). The effect of nitrogen addition on community structure and productivity in grasslands: a meta-analysis. Ecological Engineering, 99, 31-38.

Tian, D., & Niu, S. (2015). A global analysis of soil acidification caused by nitrogen addition. Environmental Research Letters, 10(2), 024019.

Watmough, S. A., & Dillon, P. J. (2003). Base cation and nitrogen budgets for a mixed hardwood catchment in south-central Ontario. Ecosystems, 6, 675-693.

Widdig, M., Heintz-Buschart, A., Schleuss, P. M., Guhr, A., Borer, E. T., Seabloom, E. W., & Spohn, M. (2020). Effects of nitrogen and phosphorus addition on microbial community composition and element cycling in a grassland soil. Soil Biology and Biochemistry, 151, 108041.

Xu, X., Yin, L., Duan, C., & Jing, Y. (2016). Effect of N addition, moisture, and temperature on soil microbial respiration and microbial biomass in forest soil at different stages of litter decom-position. Journal of soils and sediments, 16, 1421-1439.

Zeng, J., Liu, X., Song, L., Lin, X., Zhang, H., Shen, C., & Chu, H. (2016). Nitrogen fertilization directly affects soil bacterial diversity and indirectly affects bacterial community composition. Soil Biology and Biochemistry, 92, 41-49.

Zhang, C. J., Yang, Z. L., Shen, J. P., Sun, Y. F., Wang, J. T., Han, H. Y., ... & He, J. Z. (2018). Impacts of long-term nitrogen addition, watering and mowing on ammonia oxidizers, denitrifiers and plant communities in a temperate steppe. Applied Soil Ecology, 130, 241-250.

Zhang, X., & Han, X. (2012). Nitrogen deposition alters soil chemical properties and bacterial communities in the Inner Mongolia grassland. Journal of Environ mental Sciences, 24(8), 1483-1491.

Zhang, X., Wang, Q., Li, L., & Han, X. (2008). Seasonal variations in nitrogen mineralization under three land use types in a grassland landscape. acta oecologica, 34(3), 322-330.

Zhou, M., Yan, G., Xing, Y., Chen, F., Zhang, X., Wang, J., ... & Liu, T. (2019). Nitrogen deposition and decreased precipitation does not change total nitrogen uptake in a temperate forest. Science of the Total Environment, 651, 32-41.