Journal of Soil Science
ISSN: 2231–6833 & E-ISSN: 2231–6841, Volume 1, Issue 1, 2011, PP-16-24
Available online at http://www.bioinfo.in/contents.php?id=81

EFFECTS OF N-APPLICATION ON THE PHYSICAL AND CHEMICAL PROPERTIES OF SOIL UNDER DIFFERENT MOISTURE REGIMES IN THE EXPERIMENTAL PLOTS OF BANARAS HINDU UNIVERSITY

PUNITA VERMA[1] AND SAGAR R.[1*]
[1]Department of Botany, Banaras Hindu University, Varanasi-221 005, India
*Corresponding author. E-mail: sagar@bhu.ac.in

Received: January 30, 2011; Accepted: May 06, 2011

Abstract-Study intends to investigate the effects of N application on the soil physical and chemical properties, under different moisture regimes from the experimental plots located in the campus of Banaras Hindu University, India. For this, a total of 27, 1×1 m plots distributed in three moisture regimes, treated with three N-levels (0, 60, and 120 kg ha^{-1} yr^{-1}) were used. The plots were treated with N for two years. After two years of N treatment soils were sampled from each of the 1×1 m plots for the analysis of physical and chemical properties and these parameters were analyzed following standard methods. Study revealed that different N-treatments and moisture regimes caused significant differences in studied soil properties, except C:N ratio and among these soil variables water holding capacity (WHC), bulk density (BD), porosity, NO_3^--N and NH_4^+-N were significantly different due to coupling of N treatment and soil moisture. Soil WHC and porosity increased due to increase in N dose and soil moisture, while, BD and pH decreased due to increase in these treatments. Soil N, C, NO_3^--N and NH_4^+-N exhibited their maximum values at moderate levels of N dose as well as soil moisture. Principal Component Analysis (PCA) revealed three distinct clusters, each with three N-levels in the ordination diagram. Further, segregation of soil properties of control and N treated plots in the PCA diagram also suggested that long term N deposition into the soil is responsible for the alteration in soil physical and chemical properties. Thus, the present work invites in-depth study on the physical and chemical properties of the soil under elevated N depositions, so that the hidden challenges can be managed because soil is the back bone of the terrestrial ecosystem that supports the huge diversity.
Key words- PCA ordination, Nitrogen treatment, Soil moisture, Soil pH, Soil physical and chemical properties

Introduction

To meet the global food requirements, human has increased many fold use of chemical fertilizers which causes, increase in atmospheric CO_2 and N concentrations [1]. N being most abundant element in the atmosphere even then its trace amount cannot be directly taken by the plants from the atmosphere until it is chemically fixed into NH_4^+-N and NO_3^--N which are the essential components of the soil inorganic N. Only certain groups of algae and bacteria have such potential to fix atmospheric N in little amount [1-2]. In many ecosystems, increased N-depositions have been reported to limit the growth, survival and activities of microbial flora and fauna present in the soil system and these microbial flora and fauna change the soil structure and chemistry [3] by altering the soil respiration, soil pH, soil enzymes [4], soil nutrients [5], litter decomposition and ultimately soil fertility [6] and cause imbalances in soil properties [7] due to its feedback inhibition when the system is N-saturated [8]. The N saturation (the availability of NH_4^+-N and NO_3^--N in excess of total combined plant and microbial nutritional demand) model assumes that in N limited ecosystems; initially the deposited N is quickly consumed by the microbes and plants for their growth and development and accumulates in plant biomass and soil organic matter. At same point, entry of additional N into the system exceeds the biotic N demands in the system and the system is predicted to be lost its N retention capacity, further N addition in the system is predicted to be vanished from the system either through NO_3^- leaching or gaseous (N_2O) emissions [9] because there is a limit to the amount of N that natural ecosystems can occupy; beyond this threshold the ecosystem may loss its identity. Excess N depositions in the systems cause tremendous sick effects on soil (*viz*; reduction in soil fertility), water (*viz*; eutrophication), air (increase in concentrations of nitric and nitrous oxide, respectively, cause acid rain and green house effect) which alters the soil health, community composition, species diversity and productivity [2, 9-10].

Long-term N deposition retards litter decomposition by inhibiting enzyme production [11], and results in increased litter accumulation in terrestrial ecosystems [12]. The accumulated litter negatively affects the seed germination and recruitment of many species [13] because substrate setting is a key determinant for the regeneration niche or seedling habitat [14]. Further, many plant species need gap for victorious recruitment of new seedlings and emergence of seedlings under litter could be inhibited by low light availability, high early mortality due to mechanical obstruction and fungal infection in the dark, moist conditions, chemical embarrassment resulting from some substance produced by the litter [15], thus causing species diversity to decline [2, 9, 10-11,14-16]. N motivated depletions in plant diversity are frequently cited in several studies [17]. Gilliam [18] advocated for decline in species richness due to loss of many N-efficient species, reduction in species equitability due to increasing dominance of few high N-demanding species, and finally decline in species diversity as a result of decrease in both species richness and evenness [19]. N induced depletions in plant diversity are serious to nature conservation and ecosystem function [17].

An understanding on the impact of N-deposition on natural terrestrial ecosystems is becoming decisively essential for tropical countries like India. Still there is a paucity of knowledge regarding the impact of N-deposition on the soil properties of Indian soils, although it has been acknowledged that deposited N amounts can be quite high in these regions due to huge human population [5, 7, 20]. Annual N-deposition rates in China and India has increased dramatically and India ranked third in the N-deposition rate among the countries [21-22]. A study from Indian dry tropical forest ecosystems reported the range of wet N- from 9.1-27.1 kg N $ha^{-1}yr^{-1}$[23]. The detailed N-deposition rate for India is not available and there is no single study on the chronic low–level N-deposition in India [7, 20]. Such ignored study is important for well being of the soil system that supports huge species diversity for proper functioning of the ecosystems. Similar to nitrogen, soil moisture is also a key limiting factor for the growth and survival of the plants. Within the terrestrial ecosystem, soil moisture availability substantially determines the physical and chemical properties of the soil [24-25] that sustain species diversity [26]. Further, soil moisture and concentrations of organic matter also play substantial role in the organic matter decomposition and nutrient cycling through the activities of soil microbes. In dry soils; microbial activity is poor, conversely in moisture rich or in moisture saturated soils, anaerobic conditions occur which also affects microbial activity. In general, N addition to soil in form of fertilization increases in the organic component of soils which improves the soil porosity and allows the plant roots to have easier access to water [2].

To understand the effects of elevated N-deposition on the soil properties under different moisture regimes is a genuine necessity in managing the soil fertility, through which loss in species diversity can be minimized. Therefore, the objective of the present study was to see the effects of N treatment on the physical and chemical properties of soil under different moisture regimes in an experimental plot established within the campus of Banaras Hindu University.

Materials and Methods

2.1. Study sites

The study was conducted at three locations within the campus of Banaras Hindu University (24˚ 18' N and 83˚ 03' E, and 129 m msl altitude), Varanasi, India, during February-Marchl 2007. The area is a part of middle Gangetic Plains. The mean minimum and maximum sunlight throughout the year for location-1, 2 and 3, respectively, varied from 15-40%, 30-60% and 60-85%. Similarly, at same time for each month of a year, gravimetric soil moisture of each plot was recorded. Location-1, 2 and 3, respectively, had 13.24-15.25%, 4.92-9.10% and 2.70-3.50% mean minimum and maximum soil moisture throughout the year. Hereafter, Location-1, 2 and 3 are labeled as high moistened, medium moistened and less moistened sites, respectively.

The area experiences a seasonally dry tropical monsoon climate. The year is divisible in to three seasons *viz:* a hot summer (April-June), a warm rainy season (July -September), and a cold winter (November to February). The month of March and October constitute transition periods, between winter and summer, and between rainy and winter seasons, respectively. Mean monthly minimum and maximum temperature varied from 7.3-25.4^{0}C and 25.6-35.6^{0}C, respectively, and the mean annual rainfall was 932 mm [25]. The soil of the Banaras Hindu University campus has been characterized as Banaras Type III [27]. The soil is pale brown, silty loam, inseptisol with neutral reaction. In general, the soil is alluvial, well drained and moderately fertile being low in available nitrogen and medium in available phosphorus and potassium [28].

2.2. Study design

A 10×10 m^2 area was demarcated in the centre of each location to avoid the edge effect. Within each 10×10 m^2 area, nine, 1×1m experimental plots, arranged in three parallel rows (three 1×1m^2 plots in each row) were established. A 1.5m distance between two 1×1m^2 plots was kept as buffer zone to protect against boundary effects due to migration of N out of the sampling areas. Within each moisture level three treatments of nitrogen, each replicated three times, were considered: control (without N), low N (60 kg N ha^{-1} yr^{-1}) and high N (120 kg N ha^{-1} yr^{-1}). Thus, a total of 27, 1×1m^2 plot (3 moisture levels × 3 treatments × 3 replicates) were used in the present experiment. All the plots and treatments were laid out randomly.

2.3. N-treatment

Commercial urea fertilizer as source of nitrogen was applied to the plots in evening, at one month interval in form of split dose, starting from year 2007 to 2010. In evening time, temperature is low and at this low temperature; activation energy of the urease enzyme is low that decreases the N loss by the volatilization process [4]. Urea was used as a source of dry N due to its relatively high N content, easy handling, and price, while; it has greater potential for N loss through ammonium volatilization [29]. Published estimates of atmospheric N deposition are not available for the sites as well for the region considered in this study. We used 60 and 120 kg N $ha^{-1}yr^{-1}$which is probably a relatively high dose to ensure the measurable response on the soil processes and also on species diversity because in our past study we applied 30 and 60 kg N $ha^{-1}yr^{-1}$ in the soil, at these levels, N did not saturated in the system. The plots were treated with N for two years.

2.4. Soil sampling and Analysis

After two years of N treatment, three soil samples (0-10 cm depth) were collected from each 1×1 m^2 plot, using a 100 cm^3 volume corer. The three soil cores were combined to form a composite soil sample for each plot. These composite samples were gently homogenized. Large roots, woods, litters and all fine roots were removed from the composite soil samples carefully. One part of soil sample was air dried, sieved through 2 mm mesh screen, and were analyzed for bulk density, porosity, water holding capacity and soil nutrients.

Soil bulk density (g/cm^3) was measured by using corer method (stainless steel cylinders with a volume of 100 cm^3) [30] and was determined as the dry soil weight divided by the soil volume. Soil porosity was determined by subtracting the ratio of soil bulk density to particle density (*ca.* 2.65) from its maximum value of 1. The constant 2.65, is the assumed particle density of the soil [31]. Soil pH was determined by using a glass electrode (1:2; soil: water ratio). Soil organic carbon was analyzed by using dichromate oxidation and titration with ferrous ammonium sulphate [32]. Ammonium nitrogen (NH^{+}_{4}-N) was extracted by 2M KCl and analysed by using the phenate method [33]. Nitrate nitrogen (NO^{-}_{3}-N) was analysed by the phenol disulphonic acid method after extraction by $CaSO_4$ [34].

The plots were ordinated by Principal component Analysis (PCA) option in Biodiversity pro software. Two-way ANOVA (Analysis of variance) procedure of SPSS package [35] was used to see the effect of moisture regimes and nitrogen treatment on the physical and chemical properties of the soil A Tukey's HSD test was used to determine the significance of differences in mean values of soil physical and chemical properties between different moisture regimes and also in between different N-treatments. All the statistical analyses were performed by SPSS software [35].

Results

3.1. Soil physical characteristics

The summary of soil properties across the moisture and N gradient is presented in Table 1. The percent values of water holding capacity and soil porosity in the study area varied from 39-50 and 46- 53, respectively. The values were minimum in less moistened plots and maximum in high moistened plots (Table 2). Across the moisture and N-application the soil bulk density ranged from 1.25 to 1.43 g cm^{-3} of the soil (Table 1). The values were being maximum in less moisture containing plots and minimum in high moisture containing plots, indicating drying effect (Table 2). As in case of soil moisture, WHC and soil porosity also consistently increased due to increase in N dose, while soil bulk density decreased due to increase in N dose (Table 2). Analysis of variance revealed that WHC, soil bulk density and porosity varied significantly due to soil moisture and N-treatments and the interaction of N with soil moisture also caused significant differences in these soil properties (Table 3). Tukey's test indicated significant differences in mean values of WHC, bulk density and porosity between less and high moisture containing plots while those in between less and medium and medium and high moisture containing plots were insignificant. Analogous responses were also observed in relation to N treatment for WHC and bulk density, whereas differences in soil porosity among the N treatments were statistically insignificant (Table 2).

3.2. Soil chemical characteristics

In present study, soil pH ranged from 7.45 to 7.92 indicating alkaline nature of soil (Table 1). In contrast to WHC and porosity, soil pH decreased due to increase in moisture content and N levels, suggesting that soil moisture and N application are beneficial in reduction of soil alkalinity in alkaline soils. ANOVA exhibited significant differences in soil pH due to soil moisture and N treatments; however, the effect of their coupling was insignificant on the soil pH (Table 3). Tukey's test suggested significant differences in their mean values among different moisture regimes. The mean values of soil pH between 0 kg N ha^{-1} yr^{-1} and of 60 kg N ha^{-1} yr^{-1} treated plots and between 60 kg N ha^{-1} yr^{-1} and of 120 kg N ha^{-1} yr^{-1} treated plots were significantly different nonetheless, those in between 0 kg N ha^{-1} yr^{-1} and of 120 kg N ha^{-1} yr^{-1} treated plots were insignificant (Table 2).

Among the chemical properties, soil N, C, NH^{+}_{4}-N and NO^{-}_{3}-N are summarized in Table 1. Percent soil N and C varied from 0.07 to 0.22 and 0.77 to 1.44, respectively. NH^{+}_{4}-N and NO^{-}_{3}-N µg g^{-1} of soil were in between 1.16-4.10 and 3.18-8.12, respectively (Table 1). In both situations the values of these soil variables were greater in moderate levels of soil moisture and N levels (Table 2). These soil variables were statistically significant due to soil moisture and N levels, but only NH_4^+-N and NO_3^--N varied significantly due to interaction of soil moisture and N treatment (Table 3). Tukey's test showed that soil N and C differed only between the less and high moisture containing plots. On the other hand, mean values of NH_4^+-N and NO_3^--N were significantly different between less and medium and between medium and high moistened plots and the mean values of these did not differ significantly between less and high moisture containing plots. In relation to N treatment, the mean value of soil N was significantly different between 0 and 60 kg N ha^{-1} yr^{-1} treated plots and the mean value of soil C significantly different between 0 and 60 kg N ha^{-1} yr^{-1} and between 60 and 120 kg N ha^{-1} yr^{-1} treated plots. Similar to Soil C, the mean values of NH_4^+-N and NO_3^--N were significantly different between 0 and 60 kg N ha^{-1} yr^{-1} treated plots and between 60 and 120 kg N ha^{-1} yr^{-1} treated plots (Table 2).

The PCA ordination, a multivariate analysis, exhibited three distinct clusters one each for the three moisture regimes and each regime harboured three N-levels "Fig." (**1**). The PCA ordination of fertilized and unfertilized plots on the basis of their physical and chemical properties are presented in Figure (**2**); where, physical and chemical parameters of N treated plots occupied different position from the control plots in the ordination diagram, indicating the effect of N treatment on these soil properties.

Discussion

In present study, greater soil water holding capacity in highly moistened location could be argued due to greater soil porosity. The better soil porosity at the location experiencing adequate soil moisture could be probably due to activity of soil fauna; especially microarthropods [36], isopods [37], and earth worms [38], that quickly decompose the woody litters through fragmentation. A maximum litter decomposition had been argued when the process was carried on by joint activity of macro-and microorganisms, which had been advocated due to a positive coupling between the population of these organisms and decomposition rate of organic material [39], thus, these organisms help in the reduction of soil compactness by increasing the percentage of macro-pores [37-38]. Similar to present study, in our past study, soil porosity, soil moisture and water holding capacity were positively interrelated [31]. Further, such correlations could be expected since soil water is governed by the size and arrangement of soil particles and pore spaces of the soil [40]. These soil pore spaces determine the soil porosity and bulk density. Higher amounts of pores present in the soil environment increase the availability of soil moisture and soil porosity [31].

In this study, the in highly moistened plots had less soil pH compared to the less moistened or dry plots, because availability of soil moisture facilitates the decomposition of leaf as well as wood litters and the organic acids released trough this mechanism lower the soil pH. Nevertheless, the effects of nature and quality of litter fall as well as rooting influences could not be ignored. Further, reduction in soil pH due to N application may also occur by addition of H^+ through decomposition of organic matter and break down of urea fertilizers in presence of soil moisture and exchange of basic cations for H^+ by the roots of woody plants. Rao et al [16] observed increasing trend of soil pH with increase in soil bulk density / decrease in soil porosity and former and latter exhibited negative trend with increase in atmospheric N deposition. Similarly, we also observed negative pattern of soil pH with soil porosity, which is in agreement of several studies [see ref. 16 for greater details], additionally, the declining pattern of soil pH and increasing tendency of soil porosity to the increasing dose of N application are also in agreement with the several studies [6, 16, 41]. Moreover, depletion in soil pH with increase in N dose could be due to the augmentation of available soil nitrogen [42], and increased quantity of NH_4^+-N, taken by plants, and converted into NO_3^--N by nitrobacteria, which enhanced the H^+ concentration in the soil system. Ammonium ions acidify the soil since the H^+ released during nitrification of the ammonium ions are the major cause of acidity in soils [9].

Soil moisture and pH are regarded as an essential regulator of microbial community composition and their activities [43-45]. Reduced soil moisture and increased pH has been argued to inhibit the activity of soil microorganisms by lowering intracellular water potential and reducing the hydration and enzymatic activity by restricting the substrate supply. A pH range around 6.3 - 6.8 is optimum range preferred by most soil microbes [44] because higher soil pH (>6.0) make advantage to dissolution of organic matter that provide a lot of C and N substrate for microbes, and speed up the course of N mineralization [46]. In our study, mean value of soil pH varied from 7.52 to 7.83, thus, under current soil moisture and N-application, the soil pH may limit the activities of soil microorganisms.

The NH_4^+-N and NO_3^--N are produced in the soil through the process of ammonification and nitrification, respectively which are the components of N mineralization [9, 46-48]. A small number of reports showed that the rate of N-mineralization increased with increasing moisture in the early phase, then decreased quickly with rising moisture from certain value [47-48]. Chen et al [48] reported that soil moisture significantly affected the rates of ammonification, nitrification and net N mineralization and the values of nitrification and net N mineralization were greater at half moisture saturated soil than the current and full water saturated soil. In our study, soil-C, N, NH_4^+-N and NO_3^--N yielded a typical humped-back curve in relation to N-application. This conveys that these soil variables are low at low N level, increase to climax at moderate level and decrease gradually at high N level. This tendency can be analysed as; at low level of N-application soil-N is not enough for the activities of microorganisms to release them in form of NH_4^+-N and NO_3^--N. As N increases, more actively participating microorganisms are invited to release the NH_4^+-N and NO_3^--N through the process of ammonification and nitrification, respectively and thus net N mineralization, at sufficiently high N level, the system become N saturated. This N saturation can turn down the microbial population as well as their activities due N deficit in the system because excessive N addition in the system beyond a saturation threshold depletes the soil N from the system either through NO_3^- leaching or gaseous (N_2O) emissions [9]. Keeping NO_3^- leaching and gaseous (N_2O) emissions a side, excessive N application in the system beyond the N saturation threshold, can also damage the natural flora and fauna of soil which depletes soil fertility [39]. Due to greater available NH_4^+-N and NO_3^--N, in 60 kg N $ha^{-1}yr^{-1}$ treated plots in this study we could assume that rates of ammonification and nitrification would be maximum at moderate level of N availability compared to low as well as high N levels.

In this study, greater, NH_4^+-N and NO_3^--N, ammonification, nitrification and N-mineralization at moderate moisture level, might be due to availability of optimum soil spaces for the better growth and activity of soil microorganisms that are excited under favourable moisture conditions. It has been argued that in dry systems microbial activity is frequently limited by moisture [49], followed by available C and N [50]. Rate of nitrification may increase at a certain threshold of soils moisture [45], because limited soil moisture directly governs nitrification by affecting the biochemical processes [51] and, indirectly, by affecting oxygen utilization by the microbes and the aerobic capacity of the soil [52]. Greater amount of organic-C and N improve soil structure, water retention capacity and increase infiltration rates [53]. The soil porosity buildup could promote WHC, soil moisture, aeration and habitat for microbial community [54]. The microbial community togetherwith adequate soil moisture is largely responsible for the transformation of organic matter and facilitates N-mineralization potential of the soil [54-55]. According to Deenik [56], in dry soils due to poor water availability, microbial activity is inhibited which in turn reduces the rate of soil N-mineralization.

The trend of increasing total N mineralization with increasing C and N contents has been widely observed [6, 16, 54, 57]. Under ample moisture condition, rich quality of organic matter (C:N ratio) determines the magnitude and speed of N mineralization such that organic matter rich in N content has greater N mineralization than organic matter poor in N content [16]. Vourlitis et al [58] also reported that the N mineralization of semiarid shrubland soil increased monotonically with relative N deposition due to augmentation of soil organic matter (low C: N ratio). Rao et al [16] observed converse relationship between the C: N ratio and total N mineralized, organic C and N both have a positive relationship with mineralization. Plants that exist in nutrient rich habitats generally generate high quality tissues that are having high N content [13]. The quantity of N in litter affects both decomposition rates and soil N mineralization. High quality litter (low C: N ratio) is more quickly decomposed than low quality litter, resulting in more speedy nutrient cycling [13, 59]. On the basis of N application into the soil, the present study suggests that N depositions and soil moisture conditions produced significant differences in the physical and chemical properties of the soil. In general, moderate soil moisture and N application invited favourable physical and chemical conditions of the soil for the better growth and perpetuation of the microbial flora and fauna that may support large species diversity for the sustainable development of the system. It has been advocated that the soil poor in organic matter content, moisture, O_2, porosity, WHC, nutrients, unfavorable pH and high soil acidity and erosion are not favorable for both plant and microbial growth, because these two components are the backbone that can sustain the ecosystem for the human well beings [60]. Therefore, the study warrants in depth study on the diversity and activity of microbial populations and processes of litter decomposition under the elevated N deposition in different moisture conditions, so that complete and meaningful logic can be achieved to deal with such a global problem.

Acknowledgements
PV is thankful to the Banaras Hindu University for providing the fellowship.

References

[1] Vitousek P.M., Howarth R.W. Likens G.E. Matson P.A. Schindler D. Schlessinger W.H. and Tilman D. (1997) *Issues in Ecology*, (1), 1-17.
[2] WRI (1998) *Nutrient overload:unbalancing the global nitrogen cycle. Earth trends 2001. Earth Resource Institute.*
[3] Pandey A.N., Purohit R.C. and Rokad M.V. (1995) *Environmental Conservation*, (22), 69–71.
[4] Makoi J.H.J.R. and Ndakidemi P.A. (2008) *African Journal of Biotechnology*, (7), 181-191.
[5] Xiankai L. Jiangming M. and Shaofeng D. (2008) *Acta Ecologia Sinica*, (28), 5532-5548.
[6] Wang H., Mo J. Xiankai L. Jinghua X.U.E. Jiong L. and Yunting F. (2009) *Frontiers of Forestry in China*, (4), 21-27.

[7] Singh K.P. and Tripathi S.K. (2000) *Current Science*, (79), 316-323.
[8] Boxman A.W., Blanck K. and Brandrud T.E. (1998) *Forest Ecology and Management*, (101), 65–79.
[9] Matson P.A., McDowell W. D. Townsend A. and Vitousek P. (199) *Biogeochemistry*, (46), 67-83.
[10] Zavalet E.S., Shaw M.R. Chiariello N.R. Mooney H.A. and Field C.B. (2003) *PNAS*, (100), 7650-7654.
[11] Fog K. (1988) *Biological Review*, (63), 433-462.
[12] Phoenix G.K., Hicks W.K. Cinderby S. Kuylenstierna J.C.I. Stock W.D. Dentener F.J. Giller K.E. Austin A.T. Lefroy R.D.B. Gimeno B.S. Ashmoress M.R. and Ineson P. (2006) *Global Change Biology*, (12), 470-476.
[13] Pan J.J., Widner B. Ammerman D. and Drenovsky R.E. (2010) *Plant Ecology*, (206), 139-150.
[14] Grubb P. J. (1977) *Biological Review*, (52),107-145.
[15] Deborah E.G. and Werner P.A. (1983) *Oecologia*, (60), 149 155.
[16] Rao M.R., Nair P.K.K. and Ong C.K. (1998) *Agroforestry Systems*, (38), 3-50.
[17] Raghubanshi A.S. (2008) *Current Science*, (94), 1404-1412.
[18] Townsend A.R., Braswell B.H., Holland E.A. and Penner J.E. (1996) *Ecological Applications*, (6), 804– 814.
[19] Galloway J.N. and Cowling E.B. (2002) *Ambio*, (31), 64-71.
[20] Singh K. P. and Misra R. (1979) *Structure and functioning of natural, modified and silvicultural ecosystems in eastern Uttar Pradesh. Final Technical Report, Banaras Hindu University, Varanasi*.
[21] Weltzin J.F. and Coughenour M.B. (1990) *Journal of Vegetation Science*, (1), 325-334.
[22] Sagar R., Singh A. and Singh J.S. (2008) *Tropical Ecology*, (49), 189-197.
[23] Andrews N.R. (2008) *Bioscience Horizones*, (1), 148-156.
[24] Agrawal R.R. and Mehrotra C.L. (1952) *Soil Work in Uttar Pradesh. Vol. II. Department of Agriculture, U.P, India.*
[25] Singh H. and Singh K.P. (1994) *Soil Biology and Biochemistry*, (26), 695-702.
[26] Jones C.A., Koenig R.T., Ellsworth J.W., Brown B.D. and Jackson G.D. (2007) *Management of Urea Fertilizer to Minimize Volatilization. EB 173. Montana State University Extension and Washington State University Extention.*
[27] Piper C.S. (1944) *Soil and Plant Analysis. Interscience Publishers Inc., New York*.
[28] Sagar R. and Verma P. (2010) *Environmentalist*, (30), 289-298.
[29] Walkley A. (1947) *Soil Science*, (63), 251-264.
[30] APHA (American Public Health Association) (1985) *Standard methods for the examination of water and wastewater. American Public Health Association, Washington.*
[31] Jackson M.L. (1958) *Soil Chemical analysis. Prentice Hall, Englewood, Cliffs.*
[32] SPSS (1997) *SPSS Base 7.5 Application Guide. SPSS, Chicago*.
[33] Seastedt T.R. (1984) *Annual Review of Entomology*, (29), 25-46.
[34] Ayres E., Dromph K.M. and Bardgett R.D. (2006) *Soil Biology and Biochemistry*, (38), 183-186.
[35] Bottinelli N., Henry-des-Tureaux T., Hallaire V., Mathieu J., Benard Y., Duc Tran T. and Jouquet (2010) *Geoderma*, (156), 43-47.
[36] Mishra K.C. (1989) *Mannual of Plant Ecology. Oxford and IBH Publishing Co. Pvt. Ltd. New Delhi*.
[37] Oades J.M. (1984) *Plant Soil*, (76), 3 19-337.
[38] Stevens C. (2009) *The Impact of Atmospheric Nitrogen Depositition on Grasslands. Vdm Verlog*.
[39] Fang Y.T., Zhu W.X., Mo J.M., Zhou G.Y. and Gundersen P. (2006) *Journal of Entomological Science*, (18), 756–763.
[40] Cassman K.G. and Munns D.N. (1980) *Soil Science Society of American Journal*, (44), 1233-1237.
[41] Stark J.M. and Firestone M.K. (1995) *Applied and Environmental Microbiology*, (61), 218-221.
[42] Sierra J. (1997) *Soil Biology and Biochemistry*, (29), 1557-1563.
[43] Curtin D., Campbell C.A. and Jalil A. (1998) *Soil Biology and Biochemistry*, (30), 57-64.
[44] Bernhard-Reversat E. (1988) *Forest Ecology and Management*, (23), 233-244.
[45] Chen F., Zeng D. Singh A.N. and Chen G. (2005) *Journal of Forest Research*, (16), 101-104.
[46] Austin A.T., Yahdjian L., Stark J.M., Belnap J., Porporato A., Norton U., Ravetta, D.A. and Schaeffer S.M. (2004) *Oecologia*, (141), 221-235.
[47] Schaeffer S.M., Billings S.A. and Evans R.D. (2993) *Oecologia,* (134), 547-553.
[48] Grundmann G.L., Renault P., Rosso L. and Bardin R. (1995) *Soil Science Society of America Journal*, (59), 1342-1349.
[49] Renault P. and Sierra J. (1994) *Soil Science Society of America Journal*, (58), 1023-1030.
[50] Bhagat R.M. and Verma T.S. (1991) *Soil Science*, (152), 108–115.

[51] Mlambo D., Mwenje E. and Nyathi P. (2007) *Journal of Tropical Ecology*, (23), 437–448.
[52] Mbah C.N. and Onweremadu E.U. (2009) *Amer-Eurasian Journal of Agronomy*, (2), 07-12.
[53] Deenik J. (2006) *Soil and Crop Management*, (15), 1-5.
[54] Barret J.E. and Bruke I.C. (2000) *Soil Biology and Biochemistry*, (32), 1707-1716.
[55] Viourlitis G.L., Zorba G. Pasquini S.C. and Mustard R. (2007) *Soil Science Society of American Journal*, (71), 836-842.
[56] Melillo J.M., Aber J.D. and Muratore J.F. (1982) *Ecology*, (63), 621-626.
[57] Jha A.K. and Singh J.S. (1991) *Vegetatio*, (97), 63-76.

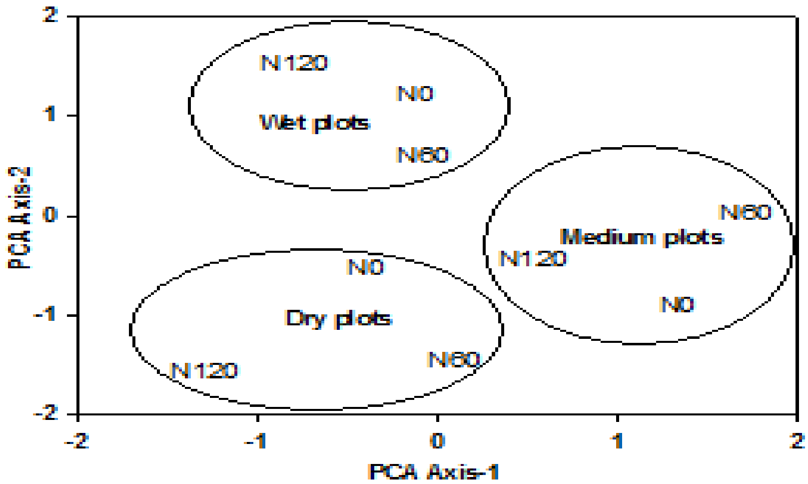

Fig. 1- PCA ordination of the moisture regimes, each having three N-levels based on their soil properties.

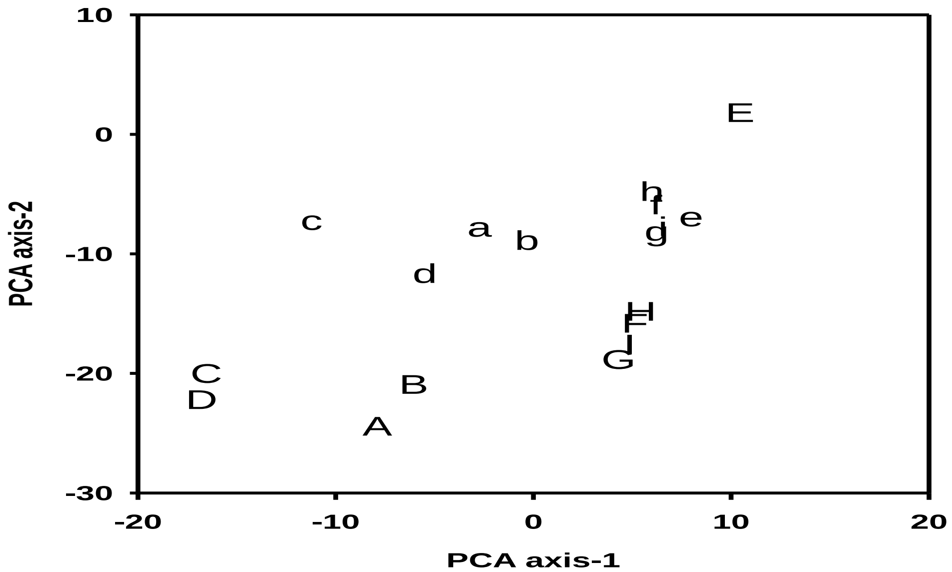

Fig. 2- PCA ordination of N treated (small letters) and without N treated or control (capital letters) plots on the basis of their soil properties. In the ordination diagram A = nitrogen, B = carbon, C = nitrate-N, D = ammonium-N, E = C:N ratio, F = pH, G = water holding capacity, H = bulk density and I = porosity.

Table 1- Mean soil physical and chemical characteristics under different nitrogen treatment at different moisture regimes from the experimental plots located in the campus of Banaras Hindu University. Values in parentheses are ± SE. 1, 2 and 3 represent, 0 kg N $ha^{-1}yr^{-1}$, 60 kg N $ha^{-1}yr^{-1}$ and 120 kg N $ha^{-1}yr^{-1}$, respectively. The value of NO_3^--N and NH_4^+-N are in µg/g of soil and bulk density is in g/cm^3 of the soil and others are in percent.

Soil parameters	Less			Medium			High		
	1	2	3	1	2	3	1	2	3
Water holding capacity	39.0 (2.04)	41.0 (3.12)	42.0 (1.20)	44.0 (1.25)	45.0 (1.17)	47.0 (3.46)	48.0 (3.00)	49.0 (2.28)	50.0 (3.8)
Bulk density	1.43 (0.03)	1.40 (0.01)	1.39 (0.05)	1.40 (0.03)	1.39 (0.04)	1.30 (0.08)	1.30 (0.07)	1.27 (0.06)	1.25 (0.04)
Porosity	46.0 (1.13)	47.0 (0.51)	48.0 (2.00)	47.0 (2.00)	48.0 (1.41)	51.0 (2.92)	51.0 (2.70)	52.0 (2.36)	53.0 (1.64)
pH	7.92 (0.01)	7.86 (0.02)	7.70 (0.01)	7.80 (0.03)	7.76 (0.02)	7.65 (0.02)	7.64 (0.02)	7.56 (0.03)	7.45 (0.08)
Soil-N	0.07 (0.01)	0.11 (0.02)	0.08 (0.01)	0.10 (0.01)	0.22 (0.04)	0.16 (0.03)	0.08 (0.01)	0.12 (0.02)	0.09 (0.01)
Soil-C	0.77 (0.3)	1.14 (0.3)	0.84 (0.04)	0.90 (0.12)	1.44 (0.23)	0.99 (0.12)	0.81 (0.11)	1.20 (0.18)	0.83 (0.11)
C:N ratio	11.0 (2.34)	10.36 (2.12)	10.50 (2.10)	9.0 (1.12)	6.55 (0.64)	6.19 (0.54)	10.13 (1.98)	10.0 (1.18)	9.22 (1.11)
NO_3^--N	1.36 (0.15)	2.29 (0.19)	1.42 (0.14)	3.30 (0.49)	4.10 (1.12)	3.21 (0.98)	1.16 (0.10)	2.19 (1.65)	1.48 (0.43)
NH_4^+-N	3.22 (0.38)	5.60 (0.80)	3.18 (0.57)	5.41 (1.12)	8.12 (1.57)	6.11 (1.26)	4.36 (1.20)	6.84 (1.29)	4.45 (1.66)

Table 2- Summary of mean soil physical and chemical properties under different nitrogen treatment in different moisture regimes Values in parentheses are ±SE. The means within a column superscripted with different letters were significantly different from each other at P = < 0.05. Values of NO_3^--N and NH_4^+-N are in µg/g of soil. Bulk density is in g/cm^{3}of the soil and others are in percent. 1 = Water holding capacity, 2 = Bulk density, 3 = Porosity, 4= pH, 5 = Soil-N, 6 = Soil-C, 7 = C:N ratio, 8 = NO_3^--N, and 9 = NH_4^+-N.

Conditions	1	2	3	4	5	6	7	8	9
Less	40.67^a	1.41^a	47.00^a	7.83^a	0.09^a	0.92^a	10.62^a	1.69^a	4.00^a
	(0.88)	(0.01)	(0.58)	(0.07)	(0.01)	(0.11)	(0.19)	(0.30)	(0.80)
Medium	45.33^{ba}	1.36^{ab}	48.67^{ab}	7.74^b	0.16^b	1.11^b	7.25^b	3.54^b	6.55^b
	(0.88)	(0.03)	(1.20)	(0.04)	(0.03)	(0.17)	(0.88)	(0.28)	(0.81)
High	49.00^b	1.27^b	52.00^b	7.55^c	0.10^a	0.95^a	9.78^a	1.61^a	5.22^a
	(0.58)	(0.01)	(0.58)	(0.06)	(0.01)	(0.13)	(0.28)	(0.30)	(0.81)
0 kg N ha^{-1}yr^{-1}	43.67^a	1.38^a	48.00^a	7.79^a	0.08^a	0.83^a	10.04^a	1.94^a	4.33^a
	(2.60)	(0.04)	(1.53)	(0.08)	(0.01)	(0.04)	(0.58)	(0.68)	(0.63)
60 kg N ha^{-1}yr^{-1}	45.00^{ab}	1.35^{ab}	49.00^{ab}	7.73^{ab}	0.15^b	1.26^b	8.97^{ab}	2.86^b	6.85^b
	(2.31)	(0.04)	(1.53)	(0.09)	(0.04)	(0.09)	(1.21)	(0.62)	(0.73)
120 kg N ha^{-1}yr^{-1}	46.33^b	1.31^b	50.67^b	7.60^b	0.11^a	0.89^a	8.64^b	2.04^a	4.58^a
	(2.33)	(0.04)	(1.45)	(0.08)	(0.03)	(0.05)	(1.28)	(0.59)	(0.85)

*Table 3- Analysis of variance indicating the effects of soil moisture and N-treatments on the physio-chemical characteristics of soil. * <0.05, **<0.01,***<0.001, ^{NS} Not significant.*

Dependent variables	Independent variables			
	Soil moisture (A)	N-treatment (B)	A×B	Error
df	2	2	4	18
Water holding capacity	300***	45***	3.46*	
Bulk density	266***	26***	4.06*	
Porosity	281***	28***	4.62*	
pH	59***	28***	0.17^{NS}	
Nitrogen	89***	11**	2.26^{NS}	
Carbon	262***	41***	0.74^{NS}	
C:N ratio	1.28^{NS}	1.18^{NS}	0.97^{NS}	
NO_3^--N	89***	16***	7.30**	
NH_4^+-N	272***	27***	3.96*	