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STATUS OF SOIL FERTILITY IN A COMMUNITY FOREST OF NEPAL

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Abstract

Soil is a complex mixture of mineral nutrients, organic matter, water, air and living organisms. The primary nutrients for plant growth are organic matter, nitrogen, phosphorus and potassium. In order to find the status of pH, organic matter (C), total nitrogen (N), available phosphorus (P) and available potassium (K) in forest soil, the study was conducted in Ghwangkhola Sapaude Babiyabhir Community Forest in Putali Bazaar Municipality-8, Syangja, Nepal. Soil parameters are analyzed through different standard methods followed worldwide by many soil scientists. Soil pH of sample in all three strata was slightly acidic and varies from 5.7 to 7.18. The carbon percentage was high and varies from 0.65% to 2.39%. The total nitrogen in soil was medium and varies from 0.09% to 0.12%. The concentration of available phosphorus in soil was high and varies from 73.71 kg/ha-93.23 kg/ha. The concentration of available potassium on soil was quiet low and varies from 2.54 kg/ha-4.23 kg/ha. Higher organic matter in the forest land indicate low activities of nitrogen losing process, which is due to the closed nutrient cycling and minimal disturbance in the natural forest system. So, addition of fertilizer rich in potassium and increasing pH is recommended to maintain potassium fertility and neutral pH in the forest soil.

Key Words: Soil fertility, NPKC, Community forest, western mid hill, Nepal

Introduction

Soil is a complex mixture of mineral nutrients, organic matter, water, air and living organisms. It is the thin layer covering the entire earth's surface, except for open water surfaces and rock outcrops (Kang & Tripathi, 1992). The properties of soil are determined by various environmental factors such as climate, parent materials, relief, organisms and time factor. There are a large number of different soils, reflecting different kinds and degrees of soil forming factors and their combinations (Kang & Tripathi, 1992). Soil in the forest ecosystem plays an important role by performing key ecological functions. Any conservation activities when implemented in the forests will have some impact on the forest soil (Kiran & Kaur, 2011). Physio-chemical characteristics of forest soils vary in space and time because of variation in topography, climate, weathering processes, vegetation cover, microbial activities and other biotic and abiotic factors (Reddy et al., 2012; Paudel & Jha, 2003).

Soil fertility is one of the key factors in determining agricultural output. Soil fertility depletion is seen as the most important process in the land degradation and a primary constraint to improve food security in developing countries (Drechsel et al., 2004). Physiography and the water resources also help to make the soil fertile to some extent. Total nutrient content varies from soil to soil depending upon the nature of parent material and other soil forming processes. Only the plant available form of the nutrient in the soil is relevant for the crops and is chemically determined through appropriate testing methods (Reddy et al., 2012). The primary nutrients for plant growth are nitrogen, phosphorus and potassium (known collectively as NPK). When they are insufficient, they will be responsible for limiting crop growth (Gruhn et al., 2000). Soil fertility includes the study of organic carbon, total nitrogen, total sulphur, cation exchange capacity, exchangeable potassium and soil pH (Tiwari et al., 2009).

Poor soil fertility, low level of mineral nutrients in soil, improper nutrient management, lack of plant genotypes are major constraints contributing to food insecurity, malnutrition and ecosystem degradation in developing countries (Cakmak, 2002). Soil fertility is poor in most of the field sites monitored in the Special Programme in Nepal (SPIN) (Ghani & W., 1997). Data from many long-term experiments in upland soils shows that yield had declined due to decrease in SOC, soil acidification and a decrease of nutrient use efficiency (Bado et al., 2010; Batino, 2008). Gregory, (1995) highlighted the need for research to address the issues of soil fertility management in Nepal. There is need to quantify current nutrient balances in farming systems and derive management strategies to enhance the effectiveness of inputs and reduce losses (Gregory, 1995). It is generally claimed by researchers, extensionists and farmers of Nepal that the soil fertility of both pakhobari land (upland) and khet land (lowland) of the hills of Nepal is deteriorating resulting in a food deficit in the hills of Nepal (Regmi & Zoebisch,2004; Mathema et al., 1999).

Physical factors that limit the yields are difficult to quantify so chemical parameters are mostly taken for this study. Micronutrient deficiencies are not only due to low contents of the elements in the soil but more due to their unavailability to growing plants (Adhikari et al., 2010). The micronutrient cations are most soluble and available under acidic conditions. Soil pH is an important property which is used to measure acidity and alkalinity of soil solution. It can affect the availability of plant nutrients, toxins and activity of many essential micro-organisms. It may influence the choice of crops grown and the type of soil organism that are present in the soil (Walworth, 2011). A neutral soil has pH 7. A soil is acidic if the pH is less than 7 and basic if pH is greater than 7. The majority of agricultural species prefer approximately neutral pH level. Acidic or alkaline nature of soil has low productivity. The availability of B is related to soil pH and is most available in acid soils. Soil pH is most important factor influencing the availability of plant uptake of Molybdenum (Mo) (Adhikari, et al., 2010).

Crops residue is a vital natural resource for conserving and sustaining soil productivity. It is a primary substrate for replacement of soil organic matter. Organic matter has a beneficial influence on soil fertility and physical properties of the soil, thereby contributing to efficient crop production and soil conservation (Campbell, 1978). Soil organic matter not only plays a major role in soil fertility by affecting physical and chemical properties, but also controls soil microbial activity by serving as a source of mineralized carbon and nitrogen (Tilahun, 2007). Organic matter can be transported downward by soil animals. Earthworms, for example, can completely mix soil to depths of a meter or so, transferring organic matter downward in the process (Paudel & Jha, 2003). Using the Walkley and Black (1934) scale, the ideal soil organic matter level from the nutrient cycling and fertility standpoint is generally considered to be 5-8%. If organic matter level falls below 2-3%, the nutrient and water holding capacity of the soil becomes very limited and may not be sufficient to support normal plant growth during some growing seasons (Hoskins, 1997).

Nitrogen, the most intensively used element, is available in virtually unlimited quantities in the atmosphere and is continually recycled among plants, soil, water and air. However, it is often unavailable in the correct form for proper absorption and synthesis by the plant (Gruhn et al., 2000). Cereals always require supplemental nitrogen fertilizer for adequate growth (Hirschfelt, 2000). Nitrogen makes plant dark green and more succulent. Plants absorb nitrogen from the soil solution in the form of ammonium (NH_4^+) or nitrate (NO_3^-) ions. Nitrogen in soil is present in different forms such as organic, ammonium, nitrates and nitrites. Most of the nitrogen in soil is present in organic form. Relatively small amount of nitrogen ordinarily occur in ammonium and nitrate form. Nitrogen is considered as the king among all nutrient elements (Mengel & Kirby., 1987). It is a substrate needed for the synthesis of amino acids and proteins which are constituents of protoplasm and chloroplast (Singh, 1996).

Most soil P is tightly bound to soil particles or contained in relatively insoluble complexes. The P-containing complexes in alkaline soils are different than those in neutral or acidic soils (Hoskins, 1997). The phosphorus nutrition is critical to plants. Phosphorus occupies a key position in metabolism. Carbohydrate metabolism proceeds when the organic compounds are esterifies with phosphoric acids. It also participates in fat and protein metabolism. It is an essential constituent of many vital compounds like nucleotides and most enzymes. It highly affects the plant growth. It is essential for root development, seed formation and diseases resistance to the plants. Plants absorb phosphorus from the soil solution mostly in the form of orthophosphate ($H_2PO_4^-$) ions (Pattanayak & Mishra, 1989).

Potassium is one of the primary nutrients of plant. It encourages normal cell division in young meristematic tissues. Plants absorb potassium in the form of K^+ ions. The plant requirement for available K is quite high. The plant roots take up potassium ion actively from soil solution. It is not coordinated with biomolecules in the plant (Brady, 1990).

The physio-chemical properties including pH, organic matter, total nitrogen, available phosphorus and potassium play the key role in determining the soil fertility. The main objective of the study is to assess the physicochemical parameters like pH, Organic Matter (C), Nitrogen (N), Phosphorus (P) and Potassium (K) of the soil. It is necessary to conduct soil nutrient analysis based on NPKC in Ghwangkhola Sapaude Babiyabhir community forest, Putalibazar Municipality-8, Syangja, Nepal because local people were unknown about the quality of soil. By knowing the soil quality of the community forest, user group would be able to find the appropriate productive cash crop in the given forest. It will help in improving the living standard of community forest user group (CFUG).

Methodology

At the beginning, a general visual field survey of the area was carried out to have a general view of the variations in the study area. Forty soil samples were collected by using stratified random sampling method. Out of them, 19 sample plots were taken in Ghwangkhola block which has moderately dense forest, 10 sample plots were taken in Sapaude block which has dense forest and 11 sample plots were taken in Babiyabhir block which has very sparse trees with pastureland. Soil samples were collected at three depths namely 10, 20 and 30 cm separately and mixed thoroughly to make a composite sample (IPCC, 2006). Before collecting soil samples, all the vegetation and litter from the soil surface was cleared. Soil samples were collected using a core sampler (Paudel & Jha, 2003). The soil samples were then air-dried, mixed well and passed through a 2 mm sieve for the analysis of selected soil chemical properties (Cicek et al., 2010). Global Positioning System (GPS) was used to identify the geographical locations of the sampling sites as shown in figure-1. Out of the 40 samples, 9 sub-samples (3 from each stratum were sampled for physiochemical analysis (Walworth, 2011).

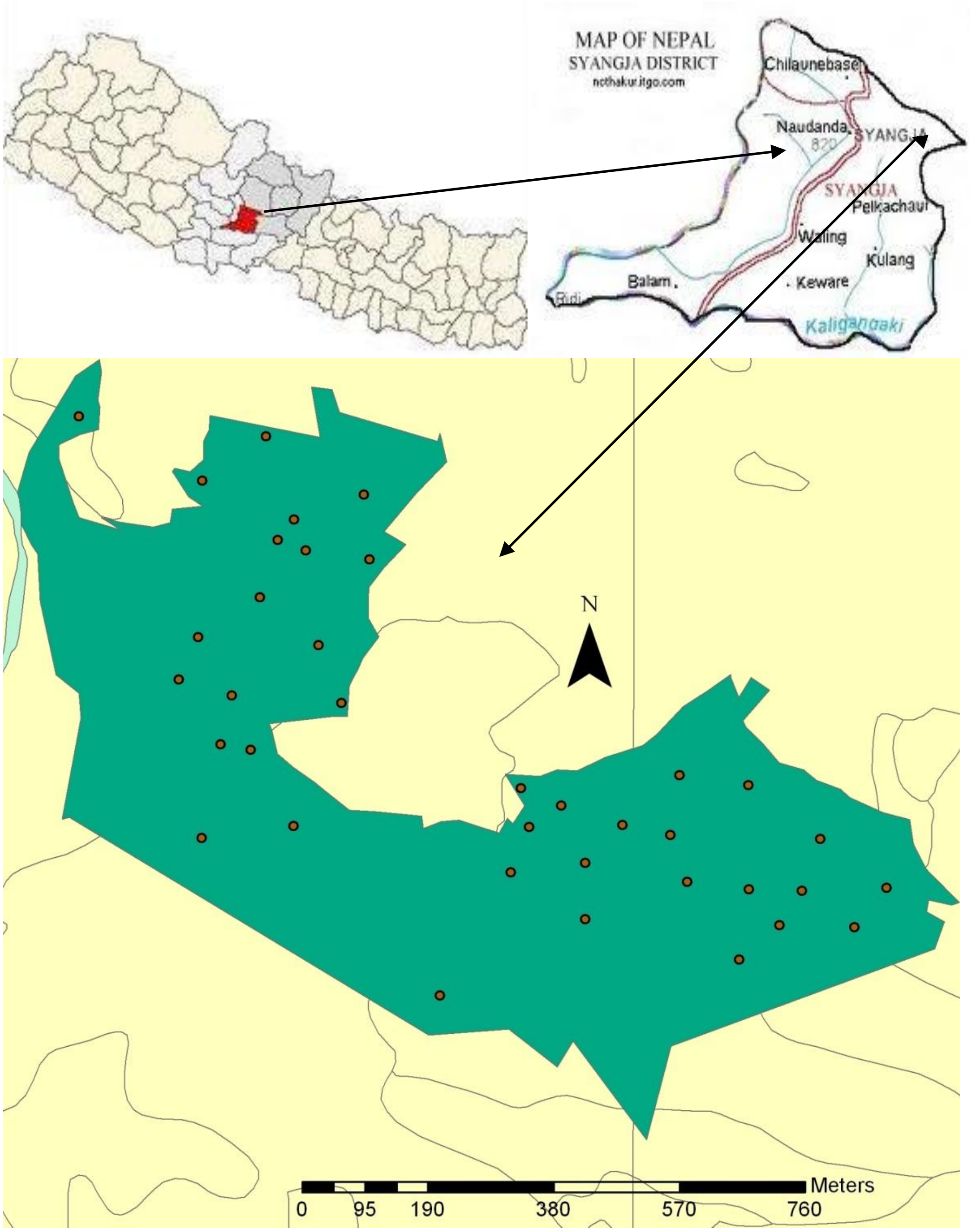

Figure 1: Map of Study Site (K C et al., 2013)

Soil parameters under the consideration are analyzed through different standard methods followed from Trivedy & Goel, (1984) which are briefly explained on below table:

Table 1: Brief summary of soil quality parameters

S.No.	Parameters	Method applied	Summary
1.	pH	pH Meter	The method determines the pH of soil using saturated part (1:1) extract.
2.	Organic matter	Modified Walkley and Black (1934) Titration Method	It determines the organic carbon by wet oxidation method, the soil sample treated with potassium dichromate in acidic condition is heated to 150˚C for 30 min and measured amount of unreacted dichromate gives amount of organic carbon titrating with standard ferrous ammonium sulphate.
3.	Total Nitrogen	Kjeldhal Distillaton Method (Sarah et al., 2010)	Organic nitrogen that is converted into ammonium sulphate by digestion with conc. H_2SO_4 is facilitated by using Na_2SO_4 or K_2SO_4. The digested solution liberates the ammonia on treating with alkali which is collected in boric acid solution and titrated with standardized dilute acid using mixed indicator.
4.	Available Potassium	Ammonium Acetate Extraction Method	Cations present in the exchange complex of the soil can be extracted by leaching the soil with ammonium acetate solution. Different exchangeable cations are then estimated separately in this ammonium acetate leachate.
5.	Available Phosphorus	Modified Olsen method (Olsen & Sommers, 1982)	It is determined as available phosphorus which can be extracted from soil with 0.002N H_2SO_4. The extracting solution removes adsorbed phosphates. In an acid molybddate solution, soluble orthophosphates combine with molybdates forming heteropoly molybdophosphoric acid which upon reduction with stannous chloride from a blue colored soluble complex molybdenum blue.

Results and Discussion

The physiochemical properties of the soil tested in the laboratory of Central Department of Environmental Sciences, Tribhuvan University, Kirtipur are expressed below.

Table 1: Physiochemical parameter of soil

Strata	pH	Organic Carbon (C) (%)	Total Nitrogen (N) (%)	Available Phosphorus (P) (kg/hectare)	Available Potassium (K) (kg/hectare)
Dense	6.52	1.45	0.11	88.46	2.54
Dense	6.01	2.39	0.12	91.39	3.45
Dense	6.55	2.26	0.09	81.85	4.23
Moderately Dense	5.7	1.94	0.09	87.36	3.14
Moderately Dense	6.06	1.77	0.09	73.71	2.78
Moderately Dense	6.65	0.97	0.10	84.79	2.66
Pastureland	5.68	1.94	0.11	84.42	2.96
Pastureland	7.18	0.65	0.12	93.23	3.02
Pastureland	5.59	1.77	0.11	84.79	3.51

Soil pH of sample in all three strata varies from 5.7 to 7.18 as shown in table-1. It shows that the soil is acidic in nature compared to soil of forest in Terai belt of Central Himalaya in India by (Lodhiyal & Lodhiyal, 1997) (6.5), Halol range in Gujarat by (Kiran & Kaur, 2011) (6.3), Girsel village in Dera Ismail Khan, Pakistan by (Khan et al., 2007) (7.9). The acidic soil may be due to the acids released by the decomposition of organic residues obtained from forest vegetation. In acidic soil, availability of P and Ca decreases whereas Fe and Mn increase (Marschner, 1995). The nutrients availability of the soil was closely related to soil pH (Gaire, 2003). Pine needles are acidic and the soil under pine trees is often more acidic than in other areas.

Organic matter content was measured as percentage of organic carbon. The carbon percentage varies from 0.65% to 2.39%, which was higher than the study in India by (DoAC, 2011) (>0.75%), in Karnataka, India by (Gunaga et al., 2011).(0.72%-1.44%), in Girsel village, Pakistan by (Khan et al., 2007) (0.43%) and in Dera Ismail Khan District in Pakistan by (Baber et al., 2006) (0.38% -1.10%). The carbon percentage was higher in dense strata of the forest and low in pastureland with very sparse trees. Soil organic matter may be due to high litter composition. Soil organic matter is inversely related to total nitrogen (Campbell, 1978). The higher organic matter values in the forest lands indicate low activities of nitrogen losing processes, which is due to the closed nutrient cycling and minimal disturbance in the natural forest system (Walworth 2011).

Nitrogen is an essential constituent of protein which is necessary for plant growth. The total nitrogen in soil varies from 0.09% to 0.12% which was less than in the forest in Terai belt of Central Himalaya in India by (Lodhiyal & Lodhiyal, 1997) (0.14%), farm yield manure of Nepal by (Chapagain & Gurung, 2010) (0.6%-1.1%) but more than in Girsel village in Dera Ismail Khan, Pakistan by (Khan et al., 2007) (0.02%). Measurement of the total nitrogen is difficult in soils and is difficult to interpret because levels of N are susceptible to change with storage of time, temperature and moisture content. Total nitrogen decreases as compared to initial status in spite of continuous application of nitrogenous fertilizer. As NARC, (2012) considers total nitrogen value to be medium when the value ranges from 0.07% – 0.15%, so the soil in the forest can be taken as medium fertile soil by taking account of total nitrogen.

The concentration of phosphorus in soil varies from 73.71 kg/ha-93.23 kg/ha which was more than in Asia by (Dobermann & Cassman, 2002) (11 kg/ha -25 kg/ha), Central Amazon by (Steiner et al., 2007) (0.2 kg/ha -1.5 kg/ha) but less than in Halol range in Gujarat by (Kiran & Kaur, 2011) (113.92 kg/ha). The observed values clearly mentioned the high availability of phosphorus as all the values lies above 30 (kg/ha) in Nepal (NARC, 2012) and (>24.6 kg/ha) in India (DoAC, 2011). Phosphorus content of the soil may change due to intensive cropping, but the observed soil was from the forest soil, so cropping factor rarely affects the phosphorus content.

The concentration of Potassium on soil varies from 2.54 kg/ha-4.23 kg/ha which was lower than in India by (DoAC, 2011) (<108 kg/ha), in Asia by (Dobermann & Cassman, 2002) (0 kg/ha -50 kg/ha), in Halol range of Gujarat by (Kiran & Kaur, 2011) (546.03 kg/ha) but more than that in central Amazon by (Steiner et al., 2007) (0.3 kg/ha -2.8 kg/ha).

Conclusion

From the above findings, it can be concluded that the soil of forest was considered as a fertile soil in case of organic matter, nitrogen and phosphorus but less fertile in case of pH and potassium. The higher organic matter values in the forest lands indicate low activities of nitrogen losing processes. So, addition of fertilizer rich in potassium and increasing pH is recommended to maintain potassium fertility and neutral pH.

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References

Adhikari, B. H., Shrestha, J., & Baral, B. R. (2010). Effects of Micronutrietns on Growth and Productivity of Maize in Acidic Soil *International Research Journal of Applied and Basic Sciences, 1*(1), 8.

Baber, S., Ahmad, M. F., & Bhatti, A. (2006). The Effect of Eucalypts Camaldulensis on Soil Properties and Fertility *Journal of Agricultural and Biological Science, 1*(3).

Bado, B. V., Aw, A., & Ndiaye, M. (2010). *Long-Term Effect of Continuous Cropping of Irrigated Rice on Soil and Yield Trends in the Sahel of West Africa*, Saint-Louis: Africa Rice Center (AfricaRice), Sahel Regional Station, B.P. 96.

Batino, A. (2008). *Organic Amendments for Sustainable Agricultural Production in Sudano-Sahelian West Africa*. Nairobi.

Brady, N. C. (1990). *The Nature and Property of Soil* (10 th edition ed.): Prentice Hall of India (P) Ltd. New Delhi India.

Cakmak, I. (2002). Plant Nutrition Research: Priorities to Meet Human Needs for Food in Sustainable Ways. *Plant and Soil 247*, 22.

Campbell, C. A. (1978). *Soil Organic Carbon, Nitrogen and Fertility*.

Chapagain, T., & Gurung, G. B. (2010). Effects of Integrated Plant Nutrient Management (IPNM) Practices on the Sustainability of Maize-Based Hill Farming Systems in Nepal Vancouver, Canada: Faculty of Land and Food Systems, The University of British Columbia.

Cicek, E., Yilmaz, F., & Yilmaz, M. (2010). Effect of N and NPK Fertilizers on Early Field Performance of Narrow-Leaved Ash *Fraxinus angustifolia*. *Journal of Environmental Biology*, 5.

DoAC. (2011). Soil Testing in India New Delhi: Department of Agriculture & Cooperation (DoAC), Ministry of Agriculture, Government of India.

Dobermann, A., & Cassman, K. G. (2002). Plant Nutrient Management for Enhanced Productivity in Intensive Grain Production Systems of the United States and Asia. *Plant and Soil, 247*, 23.

Drechsel, P., Giordano, M., & Gyiele, L. (2004). *Valuing Nutrients in Soil and Water: Concepts and Techniques with Examples from IWMI Studies in the Developing World*. Colombo, Sri Lanka: International Water Management Institute.

Gaire, J. (2003). *Soil Fertility and Productivity Status on Different Zones Of Chitwan Valley.* Master's Degree, Tribhuwan University.

Ghani, A., & W., B. M. (1997). *Improvement of Soil Fertility in Nepal through Balanced Application of Fertiliser*.

Gregory, P. J. (1995). *Soil Fertility Management for Sustainable Hillside Farming Systems in Nepal,* Project Draft Report. U.K.: ODA and Soil Science Department, The University of Reading.

Gruhn, P., Goletti, F., & Yudelman, M. (2000). *Integrated Nutrient Management, Soil Fertility, and Sustainable Agriculture: Current Issues and Future Challenges.* 2033 K Street, N.W. Washington, D.C. 20006, U.S.A.: International Food Policy Research Institute.

Gunaga, R. P., Kanfade, A. H., & R., V. (2011). Soil Fertility Status of 20 Seed Production Areas of Tectona Grandis Linn. f. in Karnataka, India. *Journal of Forest Science, 57, 2011 (11): 483–490 57*(11), 8.

Hirschfelt, D. J. (2000). *Soil Fertility and Vine Nutrition* (pp. 61-68).

Hoskins, B. R. (1997). *Soil Testing Handbook for Professionals in Agriculture, Horticulture, Nutrient and Residuals Management*,Third edition, Formerly "Soil Testing Handbook for Professional Agriculturalists". Orono, Maine: Maine Soil Testing Service/Analytical Lab, Maine Forestry & Agricultural Experiment Station, University of Maine.

IPCC. (2006). *Guidelines for National Greenhouse Gas Inventories,* Volume 4: Agricultural, Forestry and Other Land Use. UK: Intergovernmental Panel on Climate Change, Cambridge.

K C, A., Bhandari, G., Joshi, G. R., & Aryal, S. (2013). Climate Change Mitigation Potential from Carbon Sequestration of Community Forest in Mid Hill Region of Nepal *International Journal of Environmental Protection, 3*(7), 8.

Kang, B. T., & Tripathi, B. (1992). Technical Paper 1: *Soil Classification and Characterization*. The AFNETA Alley Farming Training Manual-Volume 2: Source Book for Alley Farming Research.

Khan, M. U., Qasim, M., & Khan, S. U. (2007). Effect of Integrated Nutrient Management on Crop Yields in Rice-Wheat Cropping System *Sarhad J. Agric. , 23*(4).

Kiran, G. S., & Kaur, M. R. (2011). Economic Valuation of Forest Soils *Current Science, 100*(3).

Lodhiyal, L. S., & Lodhiyal, N. (1997). Aspects of Productivity and Nutrient Cycling of Poplar (*Populus Deltoid Marsh*) Plantation in the Moist Plane Area of Central Himalaya. *Oecologia Montana, 6*, 7.

Marschner, H. (1995). *Mineral Nutrition of Higher Plants*. London: Academic Publishers.

Mathema, S. B., Shakya, P. B., & Pilbeam, C. J. (1999). *Socio-Economic Research on Management of Soil Fertility in Mid Hills of Nepal*, Main Report (Volume I) U.K.: Soil Science Department, The University of Reading.

Mengel, K., & Kirby E.A. (1987). *Principles of Plant Nutrition*. New Delhi, India: Panima Publishing Corpration.

NARC, (2012), *Annual Report of Soil Division*, National Agriculture and Research Centre, Khumaltar, Kathmandu, Nepal.

Olsen SR, Sommers LE, (1982) *Phosphorus.* In: Page AL, Miller RH, Keeney DR (eds) Methods of Soil Analyses: Part 2 Chemical and Microbiological Properties. Am.Soc. Agron, Wisconsin, pp 403–430.

Pattanayak, S. K., & Mishra, V. K. (1989). Transformation of Phosphorus in Some Acid Soils of Orissa. *Journal of Indian Society of Soil Science, 37*(3).

Paudel, S., & Jha, J. P. (2003). Physiochemical Characteristics of Soil in Tropical Sal (Shorea robusta) Forests in Eastern Nepal Himalayan *Journal of Sciences, 1*(2), 5.

Reddy, E.N. V., Devakumar, A. S., Charan Kumar, M. E., & Madhusudana, M. K. (2012). Assessment of Nutrient Turnover and Soil Fertility of Natural Forests of Central Western Ghats. *International Journal of Science and Nature, 3*(1), 5

Regmi, B. D., & Zoebisch, M. A. (2004). *Soil Fertility Status of Bari and Khet Land in a Small Watershed of Middle Hill Region of Nepal.*

Sarah, K., Otlogetswe, T., Jeremy, P., & Olusegun, A. (2010). Analysis of Persistence Soil Nutrient Status in Abandoned Cattle Kraals in a Semi Arid Area in Botswana. *Scientific Research and Essays, 5*(23), 10.

Singh, S. S. (1996). *Soil Fertility and Nutrient Management*. New Delhi, India: Kalyani Publisher.

Steiner, C., Teixeira, W. G., Lehmann, J., Nehls, T., Vasconcelos de Macêdo, J. L., Blum, W. E. H., & Zech, W. (2007). Long Term Effects of Manure, Charcoal and Mineral Fertilization on Crop Production and Fertility on a Highly Weathered Central Amazonian upland soil. *Plant Soil*.

Tilahun, G. (2007). *Soil Fertility Status As Influenced By Different Land Uses In Maybar Areas Of South Wello Zone.* Master, Harmaya University, North Ethiopia.

Tiwari, K. R., Sitaula, B. K., & Bajracharya, R. M. (2009). Effects of Soil and Crop Management Practices on Yields, Income and Nutrients Losses from Upland Farming Systems in the Middle Mountains Region of Nepal. *Springer Science+Business Media*.

Trivedy, R. K., & Goel, P. K. (1984). *Chemical and Biological Methods for Water Pollution Studies*. Karda, India: Environmetnal Publications.

Walkley, A. E. & Black, J.A (1934). "An Examination of the Degtjareff Method for Determining Soil Organic Matter, and Proposed Modification of the Chronic Acid Titration Method", *Soil Science,* 37:29-38.

Walworth, J. L. (2011). *Soil Sampling and Analysis.* Tucson, Arizona: College of Agriculture and Life Sciences, Arizona Cooperative Extension.