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Research Article

Soil fertility status of agricultural land in Mid-hill of Gorkha District, Nepal

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Abstract

Soil fertility management in agricultural land is challenging in hilly areas of Nepal. The study assesses the soil fertility status of Bari (upland) and Khet (lowland) agriculture land in Mid-hill of Gorkha district. Altogether 30 samples were collected from soil surface (0 to 20 cm) by using hand shovel in January, 2017. The soil fertility parameters like pH, organic matter (OM), total nitrogen (TN), available phosphorus (P) and available potassium (K) were analyzed using standard methods in the laboratory of Central Department of Environmental Science, Tribhuvan University. Results revealed that an average pH in upland (6.62) was higher than the lowland (5.94). Similarly, OM (3.95%) and K (36.49 $kgha^{-1}$) were relatively high in upland. In addition, pH, OM and available K were significantly varied at $p<0.05$ in upland and lowland soils, however, there is no significant difference in TN and available P. In addition, soil nutrient index showed that status of available K in both types of land is low, while OM and TN are medium soil quality in upland and lowland soil. The use of organic fertilizer and improved farming system can maintain and sustain soil fertility for crop growth and yield. Understanding distribution of soil nutrients in the study area might be useful for planners to make effective soil fertilizer management strategies.

Keywords: Lowland, Nepal, Soil nutrient index, Upland agriculture

Introduction

Soil is a composition of minerals, nutrients, organic matter, water, air and living organisms in which a thin layer covering the entire earth surface, except in water body (KC et al., 2013). Several environmental factors that have changed the physical-chemical properties of soils such as climate, topography, vegetation cover, microbial activities and other biotic and abiotic factors (Paudel & Sah, 2003; Eshwara Reddy et al., 2012). Vegetation plays an important role in soil formation (Chapman & Reiss, 1992). The surface vegetation has yearly contribution to the soil in the form of needles, leaves, branches, cones, pollens and twigs. The gradual decomposition of these organic matter by the microbial activity returns it to the soil as nutrients. Thus, the main sources of soil organic matter are the plant tissues (both above and below ground litter) (Eshwara Reddy et al., 2012), which influence thephysicochemical properties of soil.

Soil nutrient is an essential factor in determining the sustainable food production in an agro-ecosystem (Khan et al., 2017). Soil fertility is soil capability to supply the essential nutrients in balanced way for the proper growth of plants. It is highly determined by both natural factor such as parent material, climate, erosion and soil age as well as anthropogenic activity such as application of fertilizer and pesticide (Issaka et al., 2014). Nutrients are removed from the agricultural soil through the crop production (food, fiber, wood). The nutrient level removal may results decline of soil fertility, if replenishment with inorganic or organic nutrient inputs is inadequate. Soil fertility may decline through other factors such as adverse weather condition, invasion of weeds, soil physical deterioration or a combination of many other factors. Therefore, it is major concern for most of the farmers and their adaption of improved techniques has been limited.

Agriculture in Nepal are still practicing subsistence farming and mostly dominated by smallholder farmers and mixed cropping system (Pandey et al., 2018). The study of Balla et al. (2014) and Rijal (2001) shows that declining the soil fertility status across the country is a key factor that constraints productivity of the most crops and farming system. Other factors like shifting

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cultivation, overgrazing and overuse of marginal land, climatic variability (Ghimire & Panday, 2016; Shrestha et al., 2014) and soil erosion (Novara et al., 2018) are also responsible for degrading soil nutrients status of the top soil. Due to lack of awareness among the farmers about soil nutrient management, the issues are becoming critical for the productivity of land, especially in Mid-hill of Nepal (Regmi & Zoebisch, 2004). The sustainability of land productivity in hilly region mostly depends on how farmers manage, protect and utilize their farm and forest resources.

The traditional fertilizing method is not scientifically suitable and efficient to apply fertilizer in places with different nature of soils (Desavathu et al., 2018) even they use organic and farm yard manure. Nowadays in Nepal, heavy use of chemical fertilizer and pollutant technologies results in degrading the most common farmland (Deshar, 2013). According to the World Bank Group, the national average use of chemical fertilizer has increased dramatically from 16.7 kg ha^{-1} in 2002 to 74.1 kg ha^{-1} in 2016. However, its uses in Nepal is relatively low as compared to the other south Asian countries. An overuse of fertilizer is the waste of fertilizer and it is also cause of serious environmental degradation (Yang & Zhang, 2008). Moreover, the fertilizers are discharged into the ecosystem by dripping, drifting and leaking into surrounding areas than the target area. Especially, the loss of soil nutrients is severe in hilly regions due to heavy soil erosion problem. According to MoEST (2006), 10 tons per hector of the soil are lost annually even from the well managed paddy terraces. Therefore, the regular monitoring of soil fertility status is important for sustainable land productivity. Soil fertility indicators can be grouped in broad ways such as physical, chemical and biological indicators and transforming them into single value known as soil quality or fertility index. Mostly soil fertility is determined by the availability of nutrients like N, P, K, soil organic matter (SOM), and pH.

Population growth has challenged to produce more food to meet the present and future needs; therefore people maximize the use of land and more chemical fertilizer and pesticides have been used for higher production. But, farmers are not aware about the slow declining of soil fertility status. Thus, soil fertility status of the soil needs to be monitored regularly. The aim of this study is to assess soil fertility status of agricultural land of Palungtar Municipality of Gorkha District, Nepal. About 200 ha of traditionally managed farm land were used for the production, in the study area. Agriculture production such as rice and maize are commonly practicing crops. Therefore, it will help local farmers and local government agencies to adapt better soil management practices and land-use planning for environmentally friendly productive agriculture system.

Materials and Methods

Study area

The study area lies in Palungtar Municipality, Gorkha District, Nepal (Fig. 1). It is southern part of the district and part of sub-watershed of Marsyangdi River. The subsistence farming system has been adopted by the farmers. The gravity flow irrigation system is common method for lowland agriculture system which is also known as irrigated land or lowland (Khet) and other monsoon dependent land, i.e. upland or non-irrigated land (Bari). The lowland and upland are randomly distributed inside the study area. There are at least two crops pattern practicing on both types of land for example; rice-wheat-maize, rice-fallow-rice, rice-potato-maize are common in lowland and maize-cereal-fallow, maize-groundnuts-fallow, rice-cereal-fallow in upland. Rice is the major crops during the monsoon season in lowland and maize is the major crops in upland.

Soil sample collection and analysis

Altogether, 30 samples, 15 from each land types, were collected in January, 2017 from the surface soil (0-20 cm depth) by using hand shovel. The soil samples were collected after harvesting of rice production in lowland and maize in upland agricultural land. A hand-held Gramin GPS device (precision 3 meter) was used to recognize the soil sampling location. The composite samples were taken using the W-shaped technique from each land and it was collected in plastic bag with proper codding. The samples were brought to laboratory and air dried. The air dried samples were ground and sieved through 2 mm sieve for analysis of soil organic matter (OM), pH, total nitrogen (TN), available phosphorus (P) and potassium (K). The soil quality parameters were analyzed in laboratory of Central Department of Environmental Science by using the standard methods (Table 1). During the soil sampling, 15 households, directly involved into agriculture practice, were selected for the questionnaire survey in both types of land. The questions related to the soil fertility management, crop farming practices, irrigation water management and fertilizer were asked.

Table 1: Methods used for analysing soil parameters

S.N.	Parameters	Units	Methods	Source
1	pH		Potentiometric 1:2	Jackson (1973)
2	Organic matter (OM)	%	Walkely and Black	Walkely & Black (1934)
3	Total nitrogen (N)	%	Kjeldhal	Bremner & Mulvaney (1982)
4	Available phosphorus (P)	kg ha^{-1}	Olsen's bicarbonate	Olsen & Cole (1954)
5	Available potassium (K)	kg ha^{-1}	Flame photometry	Toth & Prince (1949)

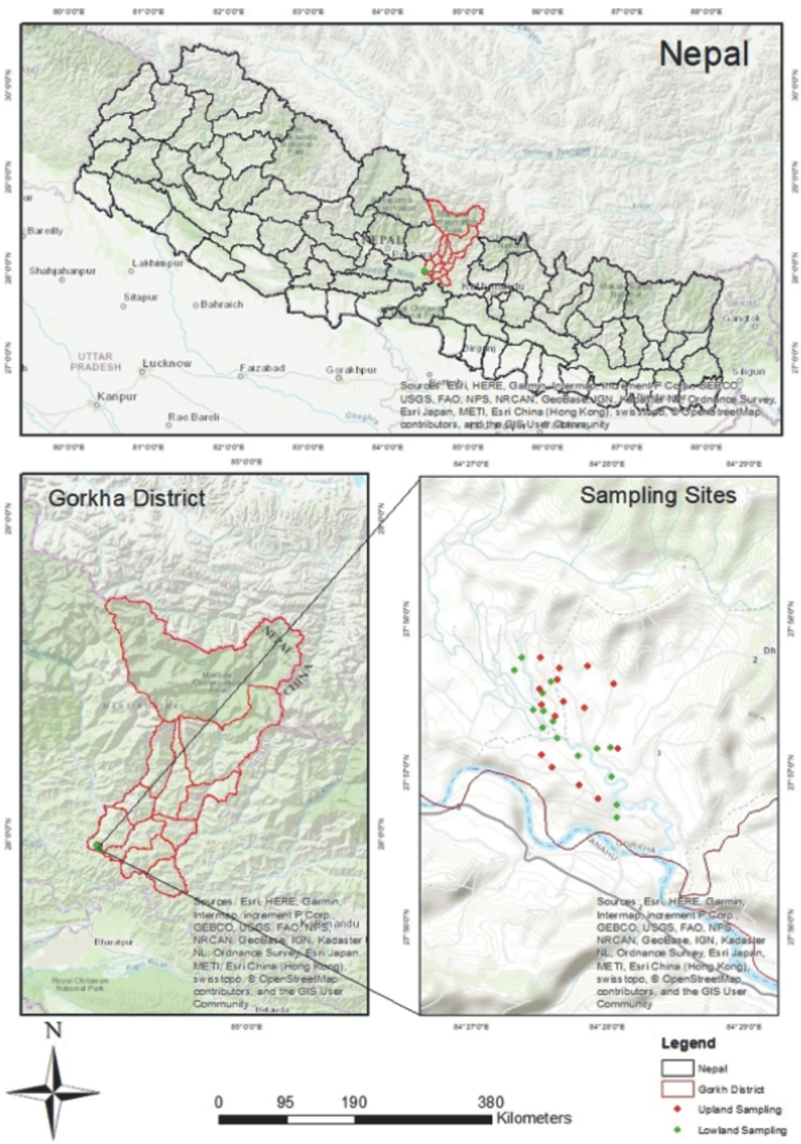

Figure 1: Location of soil sample collection in Palungtar municipality of Gorkha district, Nepal

Statistical analysis

The data of soil quality parameters were summarized using the descriptive analysis such as mean, minimum (Min.), maximum (Max.), and standard deviation (Sd). Due to the non-normal distribution data and small sample size, the non-parametric test Mann-Whitney U test was used to compare the significant difference of soil chemical parameters in between the lowland and upland soil fertility parameters. All the data were arranged in Microsoft excel (Version 2013) and statistical analyses were done by using the R-software (R-Studio, 2016). The soil pH and nutrient values (OM, N, P and K) were classified on the basis of Nepal Agricultural Research Council, NARC (2013) (Table 2). On the basis of soil classification, the soil nutrient index was calculated by using the given formula (Ramamoorthy & Bajaj, 1969).

$$Nutrient\ Index\ (NI) = \frac{(N_L \times 1)+(N_M \times 2)+(N_H \times 3)}{N_T}$$

Where;

N_L, N_M, and N_H are the number of sample fall in low (low and very low), medium and high (high and very high) classes of nutrient status, respectively

N_T is the total number of samples analyzed for the given area.

The resulting nutrient class is shown in Table 3.

Table 2: Classification of soil fertility parameters by National Agriculture Research Council (NARC)

Soil parameter	Very low	Low	Medium	High	Very high
OM (%)	<1	1-2.5	2.5-5	5-10	> 10
Total N (%)	<0.05	0.05-0.1	0.1-0.2	0.2-0.4	> 0.4
Available P	<10	10-30	30-55	55-110	> 110
AvailableK	<55	55-110	110-280	280-500	> 500
	Highly acidic	Acidic	Slightly acidic	Neutral	Alkaline
pH	<4.5	4.5-5.5	5.5-6.5	6.5-7.5	> 7.5

Table 3: Classification of soil nutrient index

SN.	Nutrient Index	Values
1	Low	<1.67
2	Medium	1.67-2.33
3	High	>2.33

Results and Discussion

Soil fertility management practices

The present results showed that all of the respondents use inorganic fertilizer at least two times in a year, in lowland, during the paddy plantation. In addition, few farmers use organic manure. For instance, 26.67% farmers use chicken manure and 40% farmer use goat, cow, ox, and buffalo dung. In inorganic fertilizers, DAP and Urea are the common fertilizers used in the lowland; but 33.33% farmers use potash during paddy plantation season. On the other hand, people are using more organic manure in upland than lowland. The intensive use of chemical fertilizers in farm land not only deteriorates the quality of soil, it also pollutes different environmental components. Due to soil pollution, the soil microorganism may loss from the soil which are important for the availability of soil nutrients for plants.

Soil pH

The soil pH is an important parameter for identification of chemical nature of soil (Kulshreshtha et al., 2003) as it measures hydrogen concentration to indicate acidic and alkaline nature of soil. The present results showed that an average pH of upland soil is lower than the lowland soil (Table 4). In upland, pH ranged from 5.7 to 7.6 with mean value 6.62, while in lowland soil, it ranged from 5.6 to 6.62 with mean value (5.94). This shows that the lowland soil is relatively acidic as compared to the upland agriculture soil. More than 90% of the total sample in lowland fall into the slightly acidic, but very few soil samples show neutral pH. Moreover, about 30% of the total samples fall into the slightly acidic category in upland and remaining samples fall into neutral to alkaline pH (Fig. 2). In addition, the soil pH shows no significant difference at $p<0.05$ level of significance in upland and lowland agricultural lands. The acidic nature of lowland soil may also affect other soil fertility parameters.

The normal range of pH for optimum availability element for most of the crops is 6.0-7.5 (Snach et al., 2003). The present results showed that about 90% of the total soil sample of lowland fall into slightly acidic pH. The relatively acidic pH in lowland soil might be the cause of leaching cation such as Ca and Mg, increase phototoxic elements such as Al and Mn, reducing microbial activity deteriorating soil structure making soil unhealthy (Nduwumuremyi, 2013). Moreover, farmers use high amount of urea and DAP fertilizer in agriculture land which result in to decrease in pH in lowland soil (Diwakar et al., 2008). Thus, the use of lime and organic fertilizer may help to get neutral pH in lowland soil.

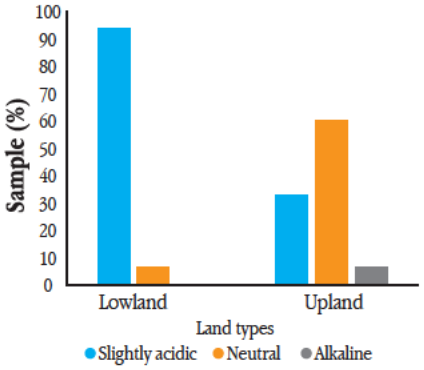

Figure 2 Classification and distribution of soil pH in lowland and upland

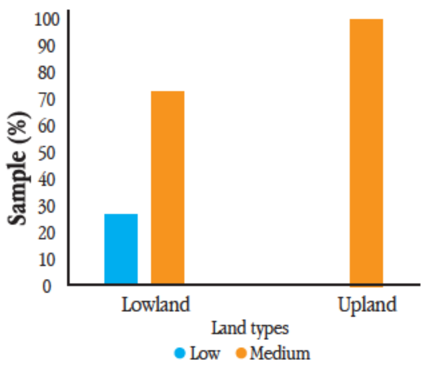

Figure 3 Classification and distribution of soil OM in lowland and upland

Organic matter (OM)

Soil organic matter is an essential nutrients after their decomposition by microbes. In the present study, the OM ranged from 2.26 to 4.77% with mean 3.52% in lowland and from 2.56 to 4.58% with mean 3.95% in upland (Table 4). The results show that high organic matter content in upland soil than the lowland with significant difference at $p<0.05$. This result is consistent with the findings of Ghimire et al. (2018) in Churia region of the central Nepal, and Regmi and Zoebisch (2004) in Mid-hill of Nepal. Distribution of soil sample, with respect to the soil OM content, indicates that about 27% sample has low OM, while 73% has medium OM in lowland and all of the soil sample has medium OM in the upland. It indicates that the OM content is medium in both types of lands (Fig. 2).

According to Kharel et al. (2018), more tillage practice and use of animal manure support the higher organic matter content in upland soil. Although, an intensive cropping pattern has removed essential plant nutrients from the soil, thereby exerting pressure on topsoil fertility (Pandey et al., 2018), higher value of OM in upland might be attributed to the biomass that left over the land after crop harvesting and the leaf fallen from the tree and decomposition by microbial activity (Bo-Jie et al., 2004). Fertilizer input and agriculture management practices might have increased the amount of soil organic matter.

Total nitrogen (TN)

Nitrogen is the most essential nutrients for the plant growth, which comprise about 1.5-2.0% of plant dry matter and approximately 16% of the total plant proteins (Alvarez et al., 2012; Lima et al., 2007). The average TN content in soil was found to be higher in upland than lowland, i.e. 0.108% and 0.079%, respectively (Table 4). However, there was no significant difference at $p<0.05$ level of significance in nitrogen level in upland and lowland. The study indicates, about 20% soil samples of lowland fall into low to medium class, while about 47% of the total samples in upland meet medium and 20% soil sample have low and very low nitrogen content (Fig. 4).

The average total nitrogen content in upland soil had higher than the lowland. The similar has been reported by Kharel et al. (2018) in Mid-hill of Nepal and Kalu et al. (2015) in Panchase area of western Nepal. Likewise, Kharel et al. (2018) have reported strong positive correlation between organic matter and total nitrogen. Therefore, the satisfactory condition of organic matter might be the reason for medium level of nitrogen content in soil of both types of lands. Moreover, use of chemical fertilizer in lowland might have cause increase in concentration of total nitrogen in soil.

Available Phosphorus (P)

In agriculture, available phosphorus is a key nutrient after nitrogen. The lack of available phosphorus in agricultural soil limits the growth of both cultivated and uncultivated plants (Foth & Ellis, 1997). Phosphorus is an essential nutrient for maturity of crop as well as for growth of plants roots. The results show that the available phosphorus ranged from 28.0 to 220.0 kgha^{-1} with the mean value 106.28 kgha^{-1} in low lands, while it ranged from 6.79 to 239.4 kgha^{-1} with 93.7 kgha-1 mean value in upland soil (Table 4). This shows that the higher mean value of P in lowland, however, there is no significant difference at $p<0.05$ in P of upland and lowland agricultures. The study indicates that about 40% of the total soil samples in lowland and upland soils have very high phosphorus content, while about 46% soil samples have high phosphorous and remaining soil samples have low to medium level phosphorous. In addition, 20% soil samples have high and remaining soil samples ranged from very low to medium phosphorus content (Fig. 5).

The high content of P in lowland soil sample might have been caused due to use of DAP fertilizer in rice based farming system in the study area. Available P in cultivating soil strongly depends on soil pH (Lindsay, 1979). Besides pH, availability of OM and application of P fertilizer also control of available P, erosion and runoff are also associated with its loss from top soil (Pandey et al., 2018). However, there is no prefect relation between the soil pH and P in the present study. Moreover, only 20% to 50% of the total phosphorus applied is absorbed by the crops during their growth and remaining unused P is retained to the soil (Richardson et al., 2009). The low to medium phosphorus in upland soil may be due to small amount of OM reducing the organic phosphorus source substantially (Pavinato et al., 2008).

Table 4 Status of soil fertility parameters in lowland and upland

Parameters	Lowland					Upland				
	pH	OM	N	P	K	pH	OM	N	P	K
Mean	5.94	3.52	0.079	106.28	15.93	6.62	3.95	0.108	93.67	36.49
Min.	5.6	2.26	0.014	28.79	9.68	5.7	2.56	0.028	6.79	13.71
Max.	6.62	4.77	0.175	220.54	26.34	7.6	4.58	0.175	239.4	83.87
SD	0.25	0.80	0.71	52.68	5.45	0.47	0.49	0.07	72.09	21.36
Variance	0.06	0.65	0.50	2775.26	29.66	0.22	0.25	0.004	5179.31	456.49

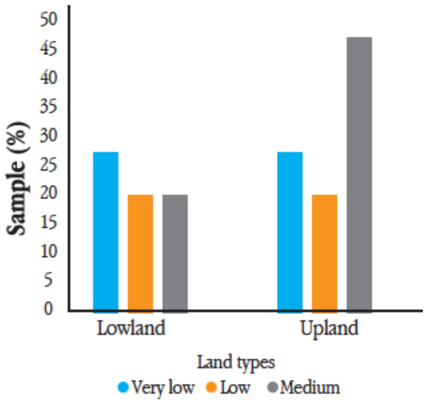

Figure 4 Classification and distribution of total nitrogen in lowland and upland soil

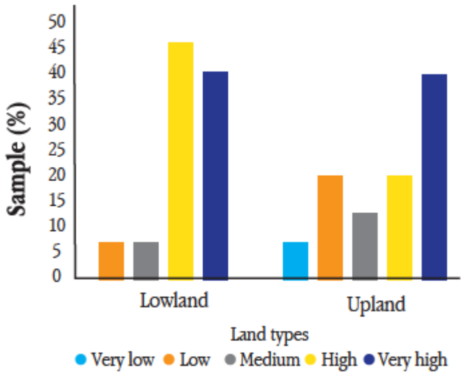

Figure 5 Classification and distribution of available phosphorus in lowland and upland soil

Available Potassium

Available potassium is the third most required nutrients which plays an important role in biochemical and physiological processes of plants (Wang, 2013). The present results show that concentration of available potassium is mostly very low to low class in uplands, while all samples belong to very low class in lowlands (Fig. 6). The average available K for upland was found to be 36.49 $kgha^{-1}$ with the standard deviation 21.36. In lowland, the value was 15.93 $kgha^{-1}$ with standard deviation 5.45 (Table 4). This result shows that the higher average available K in upland soil, though no significant difference at $p<0.001$ of upland and lowland soils. However, Regmi and Zoebisch (2004), and Kharel et al. (2018) have reported significantly higher concentration of K in lowland soil.

Water logging is common in lowland agricultural system in the study area, thus available K is lost from leaching (Harter, 2007). Potassium is found in the above ground mainly in straw which are most abundant metallic cation in plant cell (nearly 2 to 3% by dry weight) (Ravikumar, 2013). After crop harvesting, crop field are almost clear in lowland, however, most of the crop biomass is left in the upland soils in the study area. Therefore, the high concentration of potassium is seen in upland soil in compared to the lowland.

Nutrient index of soil chemical parameters

Soil nutrient indices were calculated to determine the soil fertility status of organic matter, total nitrogen, available phosphorus and available potassium (Table 5). Most of the soil nutrients fall into medium level, while available potassium fall into low nutrient index class, in both types of land. The use of excessive amount of chemical fertilizers, overgrazing during off-season, mismanagement of soil tillage practice, etc. might be the cause of low soil nutrient index in both types of agriculture land (Ghimire et al., 2018). However, soil fertility management for sustainable crop growth and yield production should be focused on organic fertilizer management, as it closely linked with the soil macro and micro-nutrients (Pandey et al., 2018). Farmers in hilly region of Nepal are facing several serious problems due to high slope, top soil erosion in rainy season and also long drought. However, farmers are still trying to manage soil fertility by using chemical fertilizers as well as organic fertilizers. Among the total, 66% farmers use mixed fertilizers, i.e. organic and inorganic, while rest of the farmer use only chemical fertilizer. Moreover, mostly chemical fertilizers are used for rice, wheat and maize production. Therefore, the condition of soil nutrients decreased in lowland soil than the upland.

Table 5 Classification of soil nutrient index of study area

Fertility parameters	Lowland		Upland	
	Values	Index	Values	Index
Organic matter (%)	1.73	Medium	2	Medium
Total Nitrogen (%)	1.87	Medium	1.73	Medium
Available Phosphorus ($kgha^{-1}$)	2.8	High	2.33	Medium
Available Potassium ($kgha^{-1}$)	1	Low	1	Low

Conclusion

In general, soil fertility parameters like pH and organic matter are higher in upland soil, while, phosphorus is higher in lowland. The majority of the soil samples represent slightly acidic in lowland, while in upland soil represent slightly acidic to neutral pH. Moreover, almost all soil samples are in medium class organic matter in upland soil, but lowland soil ranged from low to medium class. Similarly, total nitrogen ranged from very low to medium class, very low to very high available phosphorus and very low to low available potassium contents in both types of land system. In addition, based on the soil nutrient index, soils in the study area can be characterized as medium class for organic matter and total nitrogen in both types of land and low class for available potassium. Moreover, available phosphorus is higher in lowland and medium in upland soil. This indicates that the decline of overall soil fertility status in lowland soil as compared to the upland. Therefore, soil fertility should be maintained for better production and sustainable management of soil using organic fertilizer instead of chemical fertilizer. Likewise, farmers should be cautious on soil tillage, irrigation and crop rotation for sustainability of soil nutrients management.

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References

Alvarez, J.M., Vidal, E.A., & Gutiérrez, R.A. (2012). Integration of local and systemic signaling pathways for plant N responses. *Current Opinion in PlantBiology*, 15(2), 185–191.

Balla, M.K., Tiwari, K.R., Kafle, G., Gautam, S., Thapa, S., & Basnet, B. (2014). Farmers dependency on forests for nutrients transfer to farmlands in Mid-hills and High mountain regions in Nepal (case studies in Hemja, Kaski, Lete and Kunjo, Mustang district). *International Journal of Biodiversity Conservation*, 6, 222-229.

Bremner, J.M., & Mulvaney, C. (1982). Total nitrogen. In A.L. Page, R.H. Miller, D.R. Keeney, (Eds.) *Methods of soil analysis* (pp. 595-624). American Society of Agronomy and Soil Science Society of America, Madison, WI, USA.

Chapman, J.L., & Reiss, M.J. (1992). *Ecology: principles and applications*. Cambridge University Press: Cambridge, UK.

Desavathu, R.N., Nadipena, A.R., & Peddada, J.R. (2018). Assessment of soil fertility status in Paderu Mandal, Visakhapatnam district of Andhra Pradesh through Geospatial techniques. *Egyptian Journal of Remote Sensing and Space Science*, 21, 73-81.

Deshar, B.D. (2013). An overview of agricultural degradation in Nepal and its impact on economy and environment. *Global Journal of Economic and Social Development*, 3, 1-20.

Diwakar, J., Prasai, T., Pant, S.R., & Jayana, B.L. (2008). Study on major pesticides and fertilizers used in Nepal. *Scientific World*, 6(6), 76-80.

Eshwara Reddy, 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), 162-166.

Foth, H.D., & Ellis, B.G. (1997). *Soil fertility*. Lewis CRC Press LLC., USA.

Ghimire, D. & Panday, D. (2016). Interconnection of climate change, agriculture and climate justice: Complexities for feeding the world under changing climate. *Development*, 59, 270-273.

Ghimire, P., Bhatta, B., Pokhrel, B., & Shrestha, I. (2018). Assessment of soil quality for different land uses in the Chure region of central Nepal. *Journal of Agriculture and Natural Resources*, 1, 32-42.

Harter, R.D. (2007). *Note Acid Soils of the Tropics*. In ECHO Technical Note No. 48.

Issaka, R.N., Buri, M.M., Nakamura, S., & Tobita, S. (2014). Comparison of different fertilizer management practices on rice growth and yield in the Ashanti region of Ghana. *Agriculture, Forestry and Fisheries*, 3, 374-379.

Jackson, M. (1973). *Soil Chemical Analysis*. Prentice Hall of India Pvt Ltd.: New Delhi, India.

Kalu, S., Koirala, M., Khadka, U.R., & KC, A. (2015). Soil quality assessment for different land use in the Panchase area of Western Nepal. *International Journal of Environmental Protection*, 5(1), 38-43.

KC, A., Bhandari, G., Wagle, S.P., & Banjade, Y. (2013). Status of soil fertility in a community forest of Nepal. *International Journal of Environment*, 1, 56-67.

Khan, A., Uranw, N., Yadav, R., Singh, Y., Patel, D., & Yadav, R. (2017). Evaluation of soil fertility status from Kanchanpur District, Far-Western Development Region of Nepal. *International Journal of Current Microbiology and Applied Science*, 6, 961-968.

Kharel, S., Khanal, B., & Panday, D. (2018). Assessment of Soil Fertility under Different Land Use Systems in Dhading District of Nepal. *Soil System*, 2(4), 57.

Kulshreshtha, S., Devenda, H., Dhindsa, S., & Singh, R. (2003). Studies on causes and possible remedies of water and soil pollution in Sanganer town of Pink city. *Indian Journal of Environmental Science*, 7, 47-52.

Lima, P.S., Rodrigues, V.L.P., de Medeiros, J.F., de Aquino, B.F., & da Silva, J. (2007). Yield and quality of melon fruits as a response to the application of nitrogen and potassium doses. *RevistaCaatinga*, 20(2), 43–49.

Lindsay, W.L. (1979). *Chemical equilibrium in soils*. John Wiley and Sons Ltd., New York.

MoEST (2006). *Rural energy policy*. Ministry of Environment, Science and Technology, Kathmandu, Nepal.

NARC (2013). *The objective of soil test and methods to take sampling for test (in Nepali)*. Nepal Agriculture Research Council Fact Sheet. Soil Science Division, Lalitpur, Nepal.

Nduwumuremyi, A. (2013). Soil acidification and lime quality: sources of soil acidity, effects on plant nutrients, efficiency of lime and liming requirements. *Research & Reviews: Journal of Agriculture and Allied Sciences*, 2(4), 26–34.

Novara, A., Pisciotta, A., Minacapilli, M., Maltese, A., Capodici, F., Cerdà, A. & Gristina, L. (2018). The impact of soil erosion on soil fertility and vine vigor. A multidisciplinary approach based on field, laboratory and remote sensing approaches. *Science of the Total Environment*, 622, 474-480.

Olsen, S.R., Cole, C.V., Watanabe, F.S., & Dean, L.A. (1954). *Estimation of available phosphorus in soils by extraction with sodium bicarbonate*. United States Department of Agriculture: Washington, D. C., USA.

Pandey, D., Maharjan, B., Chalise, D., Shrestha, R.K., & Twanabasu, B. (2018). Digital soil mapping in the Bara district of Nepal using kriging tool in ArcGIS. *PLoS ONE* 13(10): e0206350. https://doi.org/10.1371/journal.pone.0206350.

Paudel, S., & Sah, J.P. (2003). Physiochemical characteristics of soil in tropical sal (*Shorea robusta* Gaertn.) forests in eastern Nepal. *Himalayan Journal of Science*, 1, 107-110.

Pavinato, P.S., Merlin, A., & Rosolem, C.A. (2008). Organic compounds from plant extracts and their effect on soil phosphorus availability. *Pesquisa Agropecuária Brasileira*, 43, 1379-1388.

Ramamoorthy, B., & Bajaj, J. (1969). Available nitrogen, phosphorus and potassium status of Indian soils. *Fertiliser news*.

Ravikumar, P. (2013). Evaluation of nutrient index using organic carbon, available P and available K concentrations as a measure of soil fertility in Varahi River Basin, India. Proceedings of the International Academy of Ecology and Environmental Sciences, 3, 330.

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. *Nepal Agriculture Research Journal*, 5, 38-44.

Richardson, A.E., Barea, J.M., McNeill, A.M., & Prigent-Combaret, C. (2009). Acquisition of phosphorus and nitrogen in the rhizosphere and plant growth promotion by microorganisms. *Plant soil*, 321, 305-339.

Rijal, S. (2001). Soil fertility decline in Nepal: Problem and strategy. *Nepal Journal of Science Technology*, 3, 41-46.

R-Studio, T. (2016). R-Studio: Integrated Development Environment for R., R-Studio, Inc., Boston, MA.

Shrestha, A., Bishwakarma, B., & Allen, R. (2014). Climate smart management options for improving the soil fertility and farm productivity in the Middle-hills of Nepal. *Universal Journal Agricultural Research*, 2, 253-263.

Toth, S., & Prince, A. (1949). Estimation of cation-exchange capacity and available Ca, K, and Na contents of soils by flame photometer techniques. *Soil Science*, 67, 439-446.

Walkley, A., & Black, I.A. (1934). An examination of the method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*, 37, 29-38.

Wang, M., Zheng, Q., Shen, Q., & Guo, S. (2013). The critical role of potassium in plant stress response. *International Journal of Molecular Science*, 14(4), 7370–7390.

World Bank Group (WBG). Fertilizer consumption (Kilogram per hectare of arable land). https://data.worldbank.org/indicator/AG.CON.FERT.ZS?end=2016&start=2002&view=chart

Yang, Y., & Zhang, S. (2008). Approach of developing spatial distribution maps of soil nutrients. *In Proceedings of International Conference on Computer and Computing Technologies in Agriculture* (pp. 565-571), Boston, MA.