Nepal Agriculture Research Journal
Vol. 16, No 1, pp. 163-183, 2025
DOI: https://doi.org/10.3126/narj.v16i1.80627

Soil fertility assessment of Hanumante sub-watershed at Suryabinayak municipality of Bhaktapur district

Mallika Dahal[1*], Naba R Pandit[2] and Roshan B Ojha[3]

[1]Himalayan College of Agricultural Sciences and Technology, Purbanchal University, Kirtipur, Nepal
[2]International Maize and Wheat Improvement Center (CIMMYT), Lalitpur, Nepal
[3]National Agricultural Environment Research Center, Nepal Agricultural Research Council, Lalitpur, Nepal
*Corresponding author's email: mallikadahal9@gmail.com
*ORCID: https://orcid.org/0009-0005-1629-866X

ARTICLE INFO

Research Paper

Received: January 31, 2025
Revised: February 05, 2025
Accepted: February 17, 2025
Published: June 25, 2025

Contents available at
http://www/sasnepal.org.np

Published by Society of Agricultural Scientists Nepal (SAS-Nepal).

ABSTRACT

Soil fertility assessment is critical for enhancing land productivity and ensuring sustainability of agricultural systems. An evaluation at the sub-watershed scale is lacking in Nepal. This research was carried out to assess the soil fertility status of Hanumante sub-watershed at Suryabinayak municipality of Bhaktapur district in June 2024 prior to the onset of the monsoon rain. A total of 30 composite soil samples were collected from the study area, representing two altitudinal land types (upland and lowland). These samples were collected from the field of 30 local farmers to assess soil fertility in conjunction with the household survey to understand their fertility management practices. Data was analyzed in SPSS using descriptive statistics and cross-tabulation between the soil fertility and fertility management practices. Findings revealed that predominant soil textural class in the sub-watershed was silty loam (70%), soil pH was moderately acidic (average pH 5.75), soil OM and total N were at 'medium' levels with average contents of 3.44% and 0.18%, available P and K were at 'high' and 'very high' levels with average of 348 kg/ha and 363 kg/ha and soil Ca and Mg were also at 'high' levels with average contents of 14,683 ppm and 1,189 ppm, respectively. Farmer-reported crop yields were relatively high in the lowland areas. However, the yields of maize and rice, as observed by farmers, declined by 50% in the last 10 years across both lowland and upland areas. Correlation analysis using a linear regression model showed no significant relationship ($p < 0.05$) between soil nutrients and farmer-reported crop yields. Most farmers have consistently used the same quantities of inorganic fertilizers for years with limited soil fertility management knowledge. These findings help farmers understand and make site-specific precision fertilizer management and support stakeholders in formulating effective strategies for ensuring soil health and sustainable soil fertility management in the study area.

Keywords: lowland, soil fertility, soil nutrients, sub-watershed, upland

Cited as: Dahal M, NR Pandit and RB Ojha. 2025. Soil fertility assessment of Hanumante sub-watershed at Suryabinayak municipality of Bhaktapur district. Nepal Agriculture Research Journal 16(1): 163-183. DOI: https://doi.org/10.3126/narj.v16i1.80627

INTRODUCTION

Nutrient mining is a prominent issue in Nepal due to soil erosion, intensive farming, and soil acidity. It is estimated that 60% of Nepal's soils have low organic matter (OM), 23% are low in phosphorus (P), 18% are low in potassium (K), and 67% are acidic (Kharal et al 2018).

Approximately 2 to 105 tons of soil and 310 kg of plant nutrients per hectare are lost annually due to soil erosion from agricultural land and cereal-based farming systems, respectively, while only 67 kg per hectare are replenished through fertilizers (MoALD, 2017). Key challenges affecting soil fertility and crop productivity in Nepal include soil erosion, flooding, soil compaction, aggregate destabilization, nutrients mining, imbalanced fertilization, soil acidification, limited use of organic manure, poor soil fertility management, intensive multiple cropping, and marginalization of agriculture (Pandit et al 2024, Ojha et al 2021). A country-level assessment was done to assess the soil fertility status along with fertilizer recommendations (NARC-NSSRC, 2021), however, site-specific studies of sustainable soil fertility management practices are required to assess the existing fertility management practices of farmers.

As a result, there is a rapid decline in soil health, soil fertility, and soil structure (Shrestha and Shrestha 2017, Karki and Ojha 2021, Thapa Chhetri and Moriwaki 2017). Moreover, the increasing trend of urbanization converting agricultural lands into built-up areas (Thapa Chhetri and Moriwaki 2017) has exacerbated these challenges. Bhaktapur district, located within the Hanumante River watershed, serves as the grain and vegetable hub of the populous Kathmandu valley. It has been a key supplier of fresh vegetables and cereal grains, particularly in difficult times such as the Nepal border blockade in 2015 and the Krishna Bhir slope failure disaster in 2000 on Prithivi Highway - a crucial transportation route (Maskey 2016). In recent years, the proposed area has become increasingly vulnerable due to soil erosion, land degradation, and urbanization activities. This has led to increased soil sealing and compaction, reducing rainwater infiltration and resulting in higher surface runoff, flooding, inundation, and erosion (Chaudhuri et al 2017, Sada 2012). This areas has been using inorganic fertilizers, initially ammonium sulfate and later urea, since the Government of Nepal started importing and distributing fertilizers in Nepal from 1962 (Karki et al 2021). Due to its high yield response on initially virgin and fertile soil, farmers ignored the use of P and K fertilizers, resulting in an imbalanced use of inorganic fertilizers and increasing soil acidity. Several studies (NARC-NSSRC 2021, Karki and Ojha 2021). Shrestha and Shrestha (2017) reported that rice and wheat yields declined by 40% and 35%, respectively over 10 years in Bhaktapur district. Despite these challenges, there is limited understanding of the soil health and fertility dynamics, and a lack of systematic evaluation in many watershed and sub-watershed areas, including Hanumante sub-watershed in Suryabinayak municipality, Bhaktapur district.

It is crucial to evaluate and monitor the soil fertility status of an area regularly to prevent soil and nutrient losses, maintain nutrient balance, soil health and fertility management for improving food and nutritional security and livelihoods (Tiwari et al 2009). Therefore, the objectives of this study were to assess the soil fertility status of the Hanumante sub-watershed in Suryabinayak municipality, Bhaktapur district, identify the variation of soil nutrients based on agricultural land use types and altitudes, explore existing soil fertility and cropping management practices and study farmers' perception on various issues affecting soil fertility and its management. This study aims to address data gaps at the micro level and support policymakers and executives to formulate and execute appropriate policies, strategies, plans and programs for soil health, fertility management and conservation considering a farm/plot as a working unit. This study also highlights the importance of farm fertility management of farming households and helps them in site-specific precision fertilizer management.

MATERIALS AND METHODS

Study area

The study area, Hanumante sub-watershed in Suryabinayak Municipality, Bhaktapur district, is located in the southeast of Kathmandu (Figure 1).

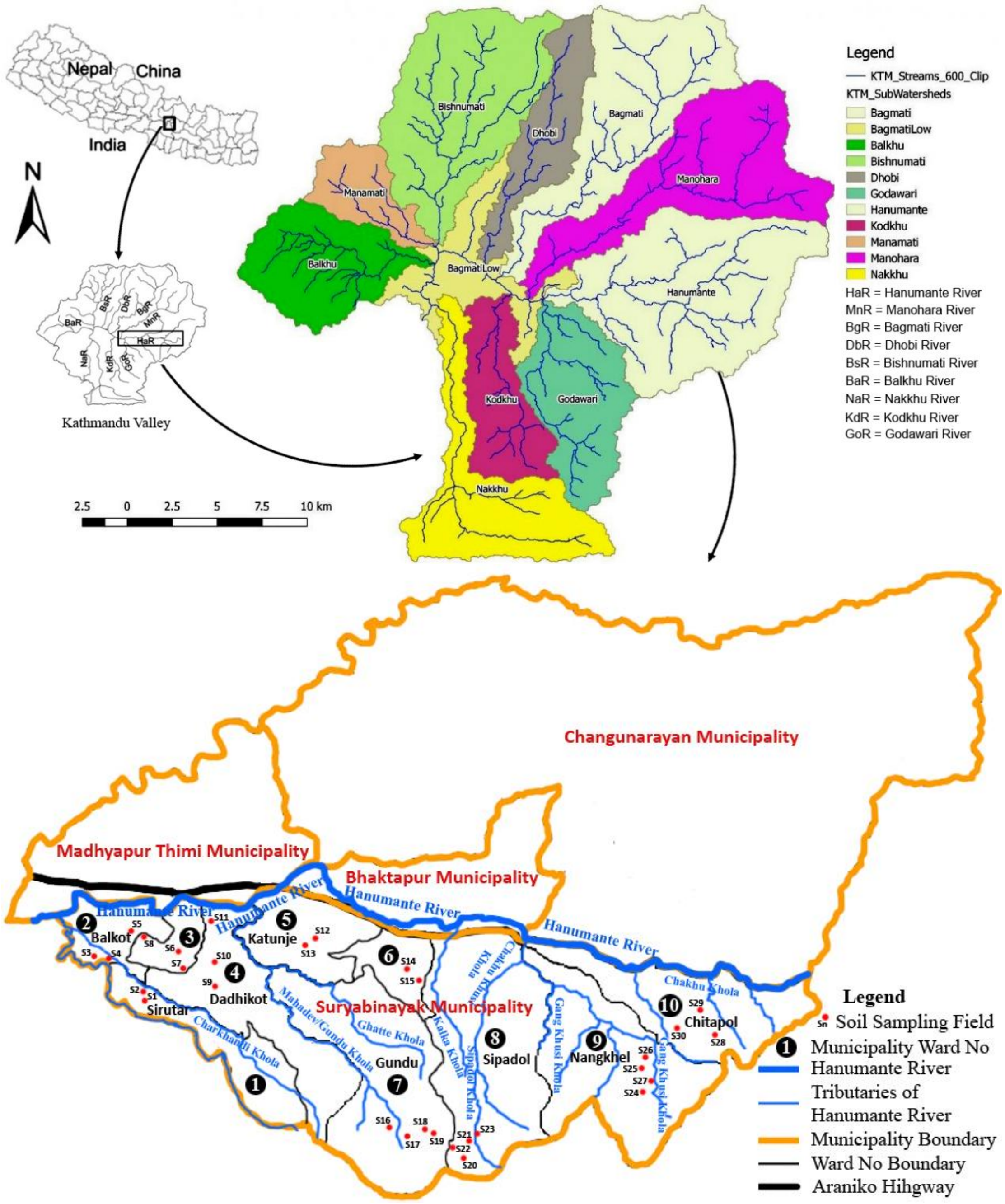

Figure 1. Map of Hanumante sub-watershed at Suryabinayak Municipality showing locations of soil sampling fields, Hanumante River and its tributaries and Hanumante watershed in Kathmandu Valley and Nepal (Kathmandu valley map source- S4W-Nepal 2018)

It lies between 85° 23' to 85° 29' east longitude and 27° 37' to 27° 40' north latitude and has an area of 42.45 sq. km (MoWS/GoN 2021, Sada 2012). Geographically, the municipality can be divided into two main areas: valley floor area (lowlands) in the north and the hilly area (uplands) in the south. Slope of land in the municipality ranges from 1 to 5 degrees from south and east to west, respectively in the valley floor areas and 5 to >30 degrees in the hilly areas (DCC 2017, Suryabinayak Municipality 2024). The sub-watershed in Suryabinayak Municipality encompasses the catchment areas of Hanumante River and its tributaries. considerably influencing local agriculture, water supply and ecology. It has rich bio-climatic and cultural diversity attributed to altitude variations ranging from valley floors at 1372 masl to hilltops at 2025 masl along with human settlements belonging to various castes and ethnic backgrounds. The soil in lowland areas is developed from fluvial non calcareous parent material whereas in upland areas, from phyllite and slate (NARC-NSSRC 2021, DMG/GoN 2020). The study area receives an average annual rainfall of around 1406 mm and the annual maximum and minimum temperatures are 27°C and 12°C, respectively (NSO 2024).

Soil sampling

Soil sampling was carried out by dividing the study area into different strata based on municipal administrative division (wards), land use types of *Bari* (rainfed unbunded terraces) and *Khet* (flat bunded terraces) and altitude classes of lowland (below 1400 masl) and upland (above 1400 masl). Soil samples were collected in June 2024, prior to the onset of the monsoon in the summer season. Altitude classes were selected based on the general trend of household migration, moving from upland (above 1400 masl) to lowland (below 1400 masl) villages within a small geographical unit in Nepal (KC et al 2017, MoLMCPA-GoN 2021, CM 2018). Stratified-purposive sampling method was used to collect a total of 30 composite soil samples from the agricultural fields of 30 local farmers. On average, 3 samples were taken from each of the 10 wards of municipality, aligning with the selected strata of altitude classes and land use types (Table 1).

Table 1. Soil samples collection details in the study area

Altitude class	Land use types	Ward 1	Ward 2	Ward 3	Ward 4	Ward 5	Ward 6	Ward 7	Ward 8	Ward 9	Ward 10	*Bari* land	*Khet* land	Lowland (< 1400 masl)	Upland (> 1400 masl)	Total
Lowland	*Bari*	1	1	1	2	1	1					7		15		15
(< 1400 masl)	*Khet*	1	2	2	1	1	1						8			
Upland	*Bari*							2	2	2	2	8			15	15
(> 1400 masl)	*Khet*							2	2	2	1		7			
Total		2	3	3	3	2	2	4	4	4	3	15	15	15	15	30

Composite soil samples, made up of 10-15 individual cores from a depth of 0-15 cm, were collected using a soil auger in a zigzag pattern considering site heterogeneity, and the required sample (500 g) was obtained by using the quartering process. The collected soil samples were properly processed by drying and sieving under ambient conditions at room temperature in a shed over a period of one week. After processing, the samples were promptly transported to the laboratory for analysis. Testing commenced the following day after sample delivery, and was completed within 10 days. Soil samples were tested at the laboratory of Agricultural Technology Center (ATC) Pvt. Ltd., Lalitpur, Nepal and analyzed for soil texture, soil pH, soil organic matter (OM), total nitrogen (N), available phosphorus (P), available potassium (K), available calcium (Ca) and available magnesium (Mg).

Household survey

A household (HH) survey was conducted with the same 30 farmers whose fields were sampled for soil analysis. A structured questionnaire was used to collect information on farmers' perceptions regarding soil health, fertility status and management practices. Information includes soil awareness, existing soil fertility management practices, cropping practices, land productivity and crop yields, use of organic amendments, accessibility, affordability and application of inorganic fertilizers as well as the linkages with agriculture development offices and Agriculture Knowledge Centers.

Soil analysis

Soil samples were analyzed following the standard procedure (Table 2). Seven soil parameters were selected for assessing the soil fertility.

Table 2. Soil physical/chemical properties with analytical methodologies

Parameters	Analysis method
Soil texture	Hydrometer method (Bouyoucos 1962)
Soil pH	Potentiometric (1:2.5 w/v) method (Jackson 1973, FAO 2021)
Organic matter (%)	Walkley-Black method (titration and colorimetric method) (Walkley and Black 1934, FAO 2019)
Total nitrogen (%)	Kjeldahl method (Bremner and Mulvaney 1982, FAO 2021)
Available phosphorus (ppm)	Modified Olsen's bicarbonate method (Olsen et al 1954, FAO 2021)
Available potassium (ppm)	Ammonium acetate (flame photometric) method (Jackson 1973, MoA/GoI 2011)
Available calcium (meq/100g)	Ammonium acetate extraction and EDTA (El Mahi et al 1987, MoA/GoI 2011)
Available magnesium (meq/100g)	Ammonium acetate extraction and EDTA (El Mahi et al 1987, MoA/GoI 2011)

Data analysis

The data were tabulated and analyzed in SPSS software using descriptive statistics such as frequency, percentage, and standard deviation. Descriptive statistics were analyzed by disaggregating data for lowland and upland areas, land use types into *Khet* and *Bari* and aggregating results for the whole area. Linear regression model was used to assess the correlation between soil chemical properties and farmer-reported crop yields. Bivariate correlation analysis was performed with Pearson correlation coefficient and two-tailed statistical test of significance between the dependent (farmer-reported crop yields) and independent (soil chemical properties such as pH, total N, OM, available P, available K) variables and correlation scatter plots were generated using 'chart builder' in the SPSS. The analyzed data were compared with standard values/ratings recommended by Nepal Agricultural Research Council Nepal/National Soil Science Research Centre (NARC/NSSRC) and interpreted the findings based on the information obtained through socio-economic HH survey.

RESULTS

Soil physical properties

Soil texture

The results of the study showed that most of the soils in the area have 30-50% sand, over 40 % silt and 8-16% clay particles, with 70% categorized as silty loam (SiL). When compared across the altitudinal land types, higher proportions of sand and clay particles were found in lowland areas while silt and clay particles in the upland areas were found in higher proportions (Figure 2).

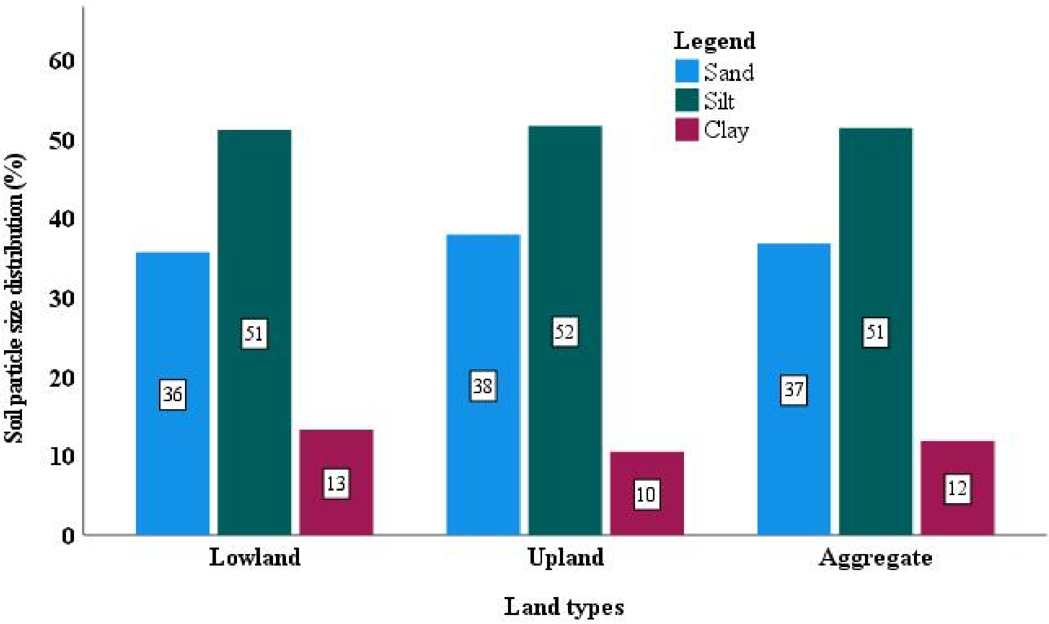

Figure 2. Average values of soil particle fractions across lowland and upland areas

Soil chemical properties

Soil pH

Our results showed that soil pH in the study area ranged from 4.25 to 6.78 with a mean of 5.75. When compared across the altitudinal land types, soil pH ranged from 4.25 to 6.33 with a mean of 5.52, indicating more acidic soils in the upland areas compared to lowland areas, where pH ranged from 4.36 to 6.78 with a mean of 5.98 (Table 3). Data showed that, based on the classification by NARC (2022), 20% of agricultural fields in the upland areas were extremely, 20% were strongly and 27% were moderately acidic than the fields in the lowland areas where 7% of the fields were extremely and 20% were moderately acidic (Table 3).

Table 3. Proportions and average values (content) of soil nutrients in the tested soil samples (proportion of agricultural fields) across the study area having different soil categories based on the standards/ratings for soil nutrient values for hills recommended by Nepal Agricultural Research Council Nepal/National Soil Science Research Centre (NARC-NSSRC, 2022). The aggregate value showed the mean with one standard deviation.

Soil properties	Range	Class	Proportion of soil samples (%)		
			Lowland	Upland	Aggregate
Soil pH	< 5	Extremely acidic	6.7	20.0	13.3
	5.0-5.5	Strongly acidic	-	20.0	10.0
	5.5-6.0	Moderately acidic	20.0	26.7	23.3
	6.0-6.5	Slightly acidic	66.7	33.3	50.0
	6.5-7.5	Nearly neutral	6.7	-	3.3
Average soil pH content			**5.98**	**5.52**	**5.75±0.63**
Soil OM (%)	1.0- 2.5	Low	13.3	20.0	16.7
	2.5 - 5.0	Medium	86.7	80.0	83.3
Average soil OM content			**3.69**	**3.19**	**3.44±0.85**
Total N (%)	0.05 - 0.1	Low	6.7	-	3.3
	0.1- 0.2	Medium	40.0	66.7	53.3

Soil properties	Range	Class	Proportion of soil samples (%)		
			Lowland	Upland	Aggregate
	0.2- 0.4	High	53.3	33.3	43.3
Average TN content			**0.19**	**0.17**	**0.18±0.06**
Available P (kg/ha)	55 -110	High	-	20.0	10.0
	> 110	Very high	100.0	80.0	90.0
Average P content			**444**	**253**	**348±185**
Available K (kg/ha)	112 - 280	Medium	46.7	26.7	36.7
	280 - 504	High	26.7	73.3	50.0
	> 504	Very high	26.7	-	13.3
Average K content			**394**	**332**	**363±206**
Available Ca (ppm)	2000-3000	High	6.7	-	3.3
	>3000	Very high	93.3	100.0	96.7
Average Ca content			**14,967**	**14,400**	**14,683±5,202**
Available Mg (ppm)	60-180	Medium	13.3	6.7	10.0
	180-360	High	-	6.7	3.3
	>360	Very high	86.7	86.7	86.7
Average Mg content			**1,468**	**910**	**1,189±936**

Soil organic matter

Soil organic matter (OM) in the area ranged from 1.77% to 4.91%, with an average value of 3.44%. In lowland areas, OM varied from 2.32% to 4.76% with a mean value of 3.69%. Similarly in upland areas OM varied from 1.77% to 4.91% with an average value of 3.19% (Table 3). The average soil OM contents in the lowland areas was higher than the upland areas with 80- 87% of agricultural fields having the medium level of soil OM content (2.5%-5%) (Table 3).

Soil total nitrogen

Soil total nitrogen (N) in the study area ranged from 0.07% to 0.32% with a mean value of 0.18%. In upland areas, total N (TN) varied from 0.11% to 0.32% with a mean value of 0.17%. In lowland areas, TN varied from 0.07% to 0.32% with an average value of 0.19% (Table 3). The average TN in the lowland areas was higher than the upland areas but agricultural fields in both lowland and upland areas, on average, had medium levels (0.1-0.2%) of TN (Table 3). Correlation analysis showed a strong positive correlation between the soil OM and TN levels across the study area ($r = 0.82$, $p < 0.01$), as well as within both lowland ($r = 0.72$, $p < 0.01$) and upland areas ($r = 0.94$, $p < 0.01$) (Table 3).

Available phosphorus

Soil available P (P_2O_5) in the area varied from 75 kg/ha to 772 kg/ha with a mean value of 348 kg/ha. When compared across altitudinal land types, available P ranged from 75 kg/ha to 522 kg/ha, with an average value of 253 kg/ha, in upland areas. In contrast, it ranged from 151 kg/ha to 772 kg/ha, with an average value of 444 kg/ha, in the lowland areas (Table 3). Our data showed that 80% of the agricultural fields in the upland areas had very high level of available P (>110 kg/ha) whereas all (100%) the agricultural fields had very high level of available P (>110 kg/ha) in the lowland areas (Table 3).

Available potassium

Soil available K (K2O) in the study ranged from 158 kg/ha to 1,115 kg/ha with an average value of 363 kg/ha. Comparison across altitudinal land types showed that available K ranged from 179 kg/ha to 484 kg/ha, with average value of 332 kg/ha, in upland areas where as it ranged from 158 kg/ha to 1,115 kg/ha, with an average value of 394 kg/ha, in the lowland areas (Table 3). Data showed that 27% of the agricultural fields in the lowland areas had high levels of available K (280–504 kg/ha), while another 27% exhibited very high levels (>504 kg/ha). Similarly, 73% of the fields in the upland areas had high levels of available K (280–504 kg/ha) (Table 3).

Available calcium

Results showed that available calcium (Ca) in the study area varied from 2,250 ppm to 23,250 ppm, with an average value of 14,683 ppm. Comparison across altitudinal land types showed that available Ca ranged from 7,250 ppm to 23,250 ppm, with an average value of 14,400, in upland areas and it ranged from 2,250 ppm to 23,250 ppm, with an average value of 14,967 ppm, in lowland areas. (Table 3). In both lowland and upland areas, most of the agricultural fields (97%) had very high level (> 3000 ppm) of Ca (Table 3).

Available magnesium

Available Magnesium (Mg) in the study area varied from 72 ppm to 4,211 ppm with an average value of 1,189 ppm. When compared across altitudinal land types, available Mg ranged from 142 ppm to 2,723 ppm, with an average value of 910 ppm, in upland areas whereas, it ranged from 72 ppm to 4,211 ppm, with an average value of 1,468 ppm, in lowland areas (Table 3). Most of the agricultural fields (87%) had very high level (> 360 ppm) of Mg in both the upland and lowland areas (Table 3).

Relationship between soil chemical properties and crop yield

Correlation between soil chemical properties vs. farmers-reported crop yields

Analysis of relationship between soil chemical properties (soil pH, soil OM, total N, available P, available K, available Ca and available Mg) and farmer-reported crop yield estimates of maize, rice and vegetables using linear regression model showed no significant linear relationship ($p < 0.05$) between the soil chemical properties and the crop yield estimates by the farmers (data not shown).

Crop production status in the past ten years

Farmers reported a sharp decline in the production of rice OPV, maize OPV and vegetables by 50%, 50% and 30%, respectively over the past decade. In recent years, they have started cultivating hybrid varieties of crops (Figure 3). According to the farmers, the low yield of maize OPVs was due to traditional, low-yielding maize OPV seeds that grew taller with weaker stalks, leading to smaller ears and making them prone to lodging and breakage during windy conditions in the rainy season.

Soil fertility management practices of local farmers

Soil awareness

In upland areas, 60% of farmers have the perception that soil is a living thing and needs to be taken care of, whereas in lowland areas, 53% of them have the perception that soil is a non-living thing and requires no care for it. None of the farmers did routine tests of soil on their own. However, 13% of farmers from both lowland and upland areas reported that soil tests were carried out by the Municipal Agricultural Office occasionally for some parameters such as pH and provided them with feedback on soil fertility management practices.

Soil fertility management practices adopted

Proportion of farmers practicing different soil fertility management practices in the study area are provided in Figure 4. Terracing, incorporation of crop residues into soil, crop rotation, intercropping, crop diversification, cultivation of legumes in crop rotations and application of organic manures, were some of the common practices adopted by local farmers in both the lowland and upland areas.

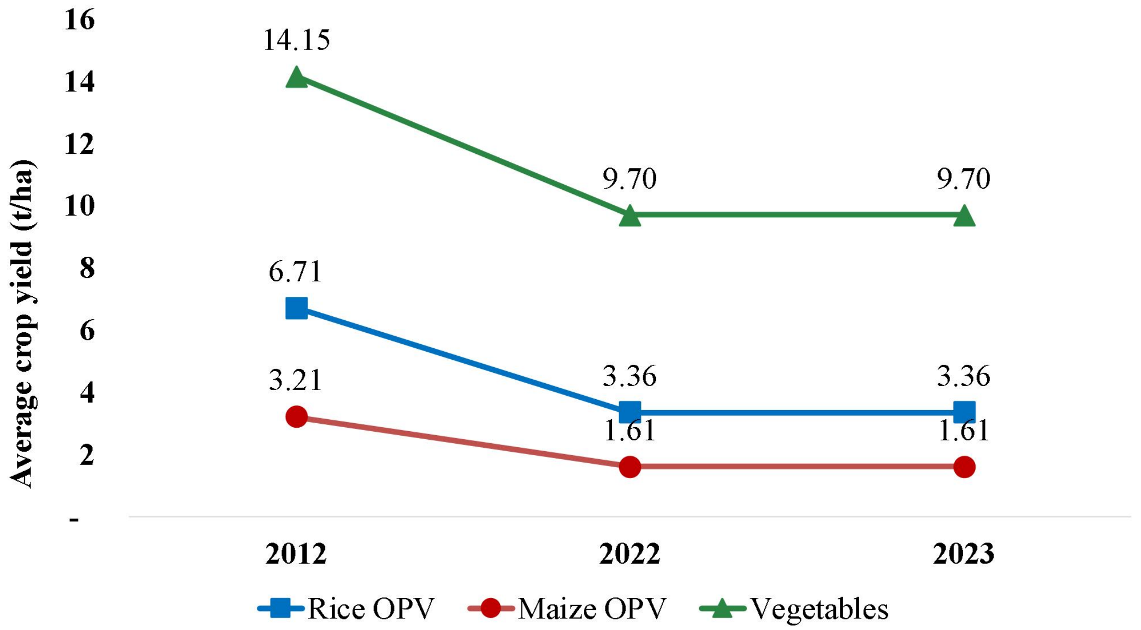

Figure 3. Farmers' perception on average crop yield trends in the past 10 years in 2012, 2022 and 2023.

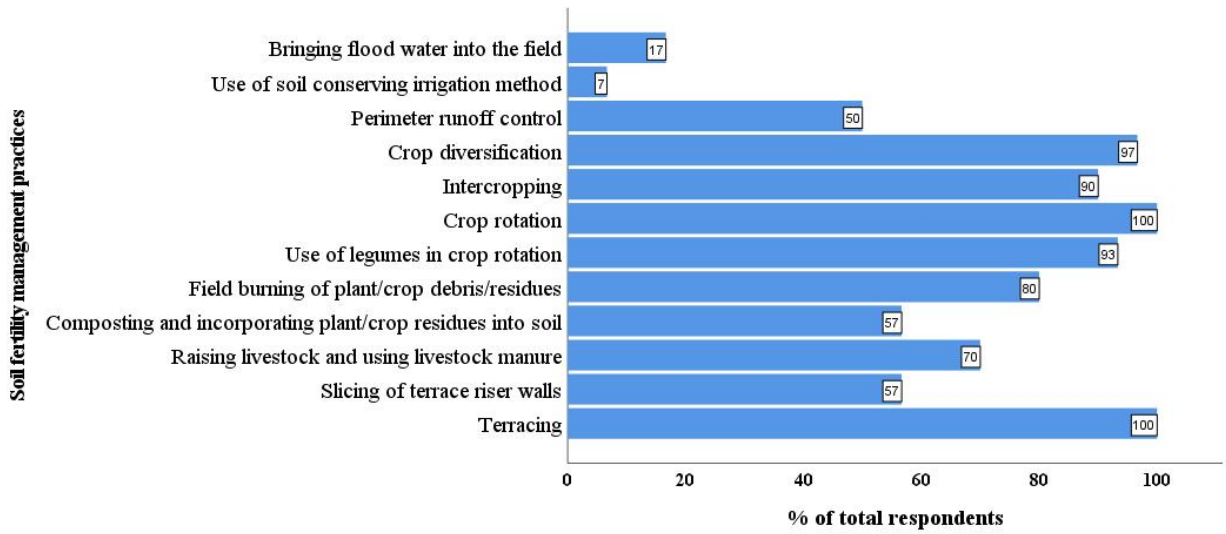

Figure 4. Soil fertility management practices adopted across lowland and upland areas

Crop rotation

HH survey data showed that in *Bari* land of upland areas, maize is used in crop rotation by 100% of farmers, and other rotated crops include Soybean (100%) (Figure 4), French Beans Pole Type (93%), Mustard (87%), Rice (67%), Yam (60%), Broadleaf Mustard (60%), Asparagus Beans (60%) and Garlic (60%). In contrast, in the *Bari* land of lowland areas, maize is also widely cultivated (100%) also in home garden, but the most prevalent crops in rotation are French Beans- Pole Type (100%), Pumpkin (100%), Garlic (100%), Cauliflower (93%), Soybean (86%), Broadleaf Mustard (80%), Cress (80%), Asparagus Beans (79%), Cucumber (73%), Broad Beans (64%), Radish (60%), Chili (60%) and Colocasia (60%). In *Khet* lands of upland and lowland areas, rice and wheat are used in crop rotation by 100% of farmers.

Most of the farmers cultivated some legume crops such as soybean, French beans- pole type and sword type, asparagus beans, broad beans in their fields (Figure 5) but none of them reported that they were aware of the importance of legumes in soil fertility management.

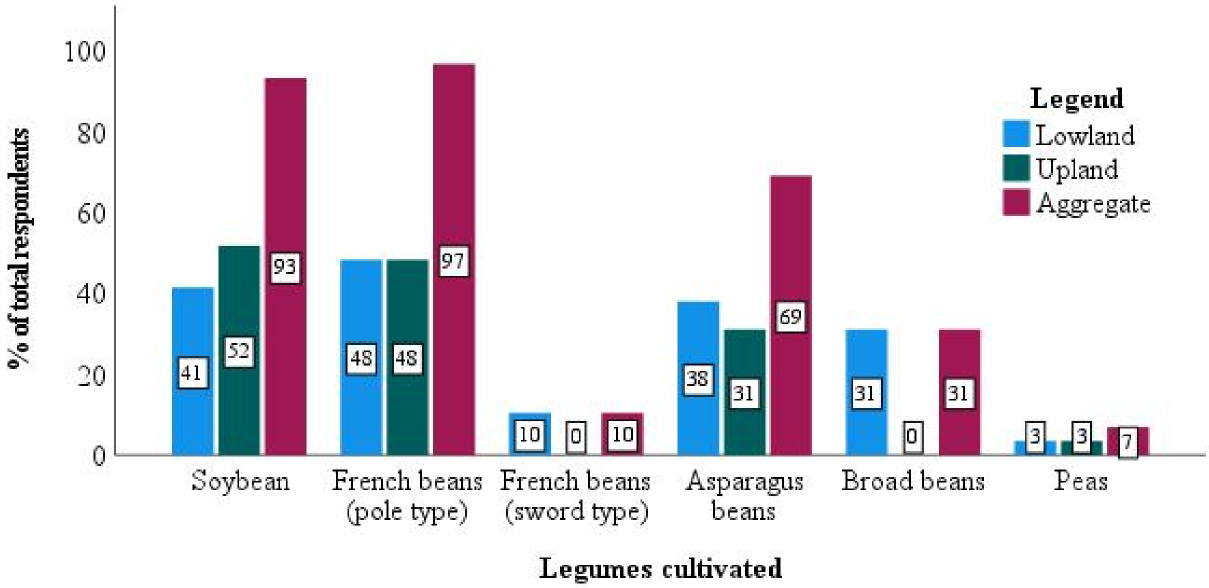

Figure 5. Farmers (in percent) engaged on cultivation of leguminous crops across lowland and upland areas

Cropping pattern

Farmers practiced different cropping patterns in the study area with rice-based cropping patterns prevalent in lowland areas and *Khet* lands and maize-based patterns dominant in upland areas and *Bari* lands (Figure 5). In upland areas, the most common cropping pattern was 'Maize + Legumes + Vegetables + Yam - Mustard/ Garlic/ Onion/ Vegetables,' followed by 'Maize + Legumes + Vegetables - Mustard' each practiced by 20% of farmers. Rice-based patterns were more prevalent in lowland areas, with patterns of 'Rice - Wheat', 'Maize + Legumes + Vegetables - Barley/ Potato/ Garlic/Vegetables' practiced by 20% and 13%.

Use of organic and inorganic fertilizers

Quantity of organic manure used for different crops

HH survey showed that in the upland areas, 27% of farmers used organic manure at the rate of 15-20 t/ha for OPV and/or hybrid rice, 13% used at the rate of 5-10 t/ha for hybrid maize and 7% applied at the rate of 10-15 t/ha for vegetables (Figure 5). In the lowland areas, 27% of farmers used 15-20 t/ha manure for OPV and/or hybrid rice, 13% used 15-20 t/ha for hybrid maize, and 13% used 1-2 t/ha for vegetables. They reported that animal urine was not used separately as fertilizer/organic pesticide by collecting it from the bedding in the cattle shed but was instead part of the livestock manure, mixed with dung and litter.

Quantity of urea used for different crops

In the upland areas, 27% of farmers applied urea at the rate of 100-200 kg/ha for OPV and/or hybrid rice, 47% at the rate of 100-200 kg/ha for hybrid maize and few (7%) used urea at the rate of 100-200 kg/ha for wheat. In the lowland areas, 13% of them used urea at the rate of 600-700 kg/ha for OPV and/or hybrid rice, 27% of them used at the dose of 100-200 kg/ha for hybrid maize and 13% of them used urea at the rate of 100-200 kg/ha for wheat. Maximum quantity of urea applied was 700-800 kg/ha by 3% HH for OPV/Hybrid rice, 500-600 kg/ha by 3% HH for hybrid maize, 700-800 kg/ha by 7% HH for wheat, 900-1000 kg/ha by 3% HH for cauliflower, 500-600 kg/ha by 3% HH for potato and 300-400 kg/ha by 3% HH for garlic.

Quantity of DAP used for different crops

In upland areas, 40% of farmers applied DAP at 100-200 kg/ha for hybrid and/or OPV rice and 27% of them applied 75-100 kg/ha for hybrid maize. In the lowland area, 13% of farmers applied DAP at 200-300 kg/ha for hybrid and/or OPV rice, 20% of them applied DAP at 75-100 kg/ha for hybrid maize and 13% of them applied DAP at the dose of 100-200 kg/ha for wheat. Maximum quantity of DAP applied was 600-700 kg/ha by 3% HH for OPV/Hybrid rice, 200-300 kg/ha by 3% HH for hybrid maize, 500-600 kg/ha by 3% HH for wheat, 100-200 kg/ha by 3% HH for cauliflower, 75-100 kg/ha by 3% HH for garlic. Nobody reported using DAP for potato.

Quantity of MOP used for different crops

Data revealed that a few farmers used MOP for crops. In upland areas, 7% of farmers applied MOP at the dose of 25-50 kg/ha for hybrid and/or OPV rice, hybrid maize and wheat. In the lowland areas, 7% of farmers applied MOP at the dose of 25-50 kg/ha for hybrid and/or OPV rice and hybrid maize and 3% of them applied MOP at the dose of 25-50 kg/ha for wheat. Maximum quantity of MOP applied was 100-200 kg/ha by 7% HH for OPV/Hybrid rice, 75-100 kg/ha by 7% HH for hybrid maize, 75-100 kg/ha by 7% HH for wheat, 75-100 kg/ha by 27% HH for cauliflower, 100-200 kg/ha by 3% HH for potato, 75-100 kg/ha by 3% HH for garlic.

History of inorganic fertilizers used in the area

According to HH survey, the length of time inorganic fertilizers are being used varies from 31 to 70 years (Figure 6). Longer-term use of fertilizers was more common in lowland areas and some of the farmers reported that inorganic fertilizers are being used in their fields since the beginning of import of inorganic fertilizers from India.

Time and method of fertilization by organic and inorganic fertilizers

In both lowland and upland areas, all 100% of farmers used organic manure and MOP before sowing/planting time. 100% of them used urea and DAP both at sowing/planting and later stages of crop growth. All farmers in both lowland and upland areas used the same methods of applying organic and inorganic fertilizers. All (100%) of them used the methods of 'broadcasting- basal application before last ploughing/puddling or before sowing or planting' for the application of organic manure and MOP. Similarly, 100% of them used the methods of 'broadcasting at sowing or planting' and 'broadcasting in standing crops (top dressing)' for the application of urea and DAP. None of the farmers followed the split-application method of N fertilizers.

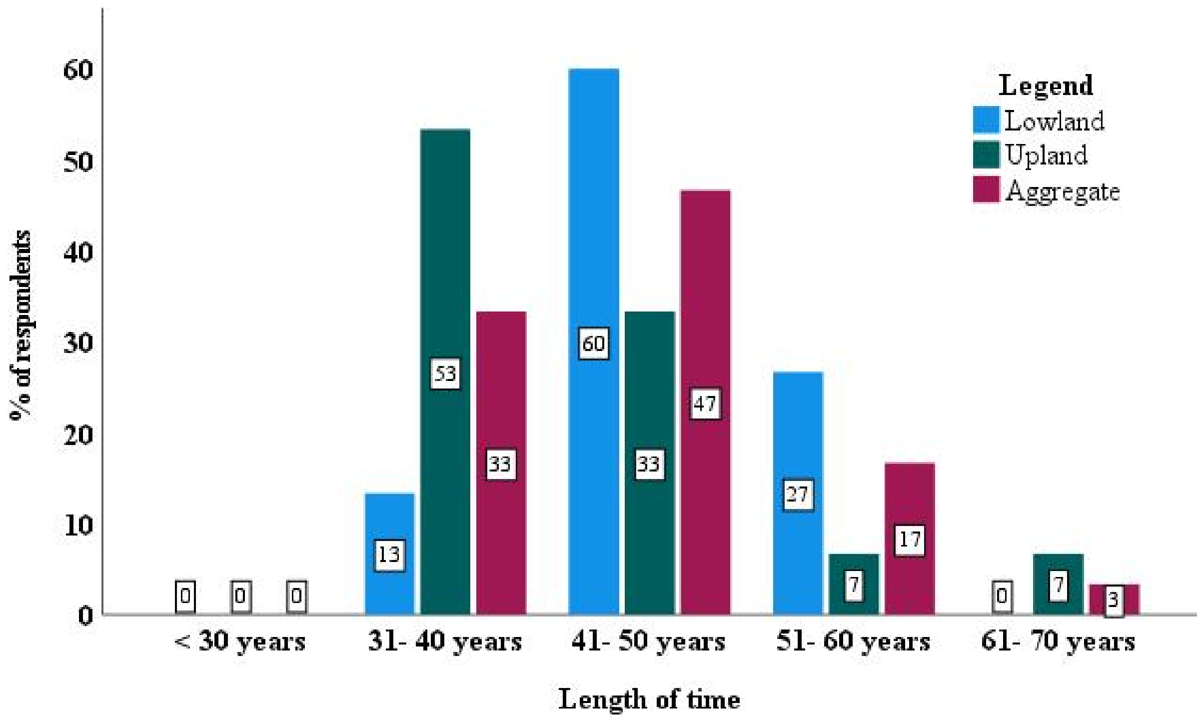

Figure 6. Length of time inorganic fertilizers are being used across lowland and upland areas

DISCUSSION

Most of the soils in the area have silty loam textural class as this area is deposited with lacustrine soil and alluvial deposit that likely to form the loam texture soil (Adhikari and Ojha 2021) The results were consistent with the Soil Map by the National Soil Science Research Center/NARC (NARC-NSSRC 2021). During the HH survey, it was observed that a farmer had converted *Khet* (paddy field) land into *Bari* (non-paddy field) land through creation of terraces, constructing terrace riser walls and filling the field with soils from external sources since more than 100 years of cultivation history, thus there were chances of forming medium to fine soil textural class.

The soil in the upland areas is mostly represented by acidic parent materials known as phyllite and slate (NARC-NSSRC 2021, DMG/GoN 2020). Relatively more acidic soil in the upland areas may be attributed also to higher slope gradients (5 to > 30 degrees) and presence of acid-forming parent material- phyllite than the lowland areas which have more gentle slopes (1-5 degrees) and the soil is developed mostly from fluvial non-calcareous parent material (Adhikari and Ojha 2021) Higher slope gradients in the upland areas lead more and faster rainfall runoff of base cations causing the soils to be more acidic (Karki et al 2021). Soils developed from phyllite have low buffering capacity contributing to the development of soil acidity (Karki et al 2021). Many farmers in the study area produced and used livestock manure and cultivated leguminous crops which help to improve soil pH. Nitrogen fixation by rhizobial bacteria produces organic compounds that act as bases, helping to neutralize soil acidity (Sharma et al 2024). However, these practices were not sufficient to maintain an optimum pH level. Most of the farmers in the area have been practicing imbalanced use of acid-forming nitrogenous fertilizers over the long term (over 30 years) resulting in fertilizer-driven acidification of soils. Continued imbalanced fertilization, leaching and runoff of base cations (Ca^{2+}, Mg^{2+}, K^{+}, etc), higher nutrient uptake accompanied by limited application of livestock manure or lower recycling of nutrients in soil and presence of acid-forming parent material may have contributed to development of soil acidity in the area as reported by Ghimire et al (2018) and Vista et al (2021).

Household survey showed that 70% of total farmer households surveyed (30) reared livestock such as cattle, goat, and/or poultry and used their manures in the field. Among the households rearing livestock, 43% reared cattle, 62% reared goat and 43% reared poultry. Sharma et al (2022) reported that among the livestock manures used in different farms of Bhaktapur district, cattle manure had the highest level of OM (50.75%), whereas goat manure had the second highest level (50.20%) and the poultry manure had the lowest level of OM (49.20%). Compost had also considerable level of OM (49.80%). Some farmers (57%) also practiced making some compost by piling particularly the soft plant/crop residues on the edges/sides of their fields. However, 80% farmers (24), including 100% (15) in upland areas and 60% (9) in lowland areas have also been following plant/crop residue field burning practices. The medium level of soil OM indicated that the application of organic amendments is still very limited. Ghimire et al (2018) and Panday et al (2019) reported that low to medium levels of soil OM may be associated with limited application of organic manure, continuous tillage, rapid decomposition and mineralization, surface runoff, topsoil erosion, and poor management of plant/crop residues. Crop residues are often used as animal feed or burned in the field, which has affected nutrient recycling in soil.

The average TN content at the medium levels may be related to the limited application of organic amendments to the soil. According to TNAU (2016), poultry manure has the highest level of TN (2.8%-6.2%) making it the most nitrogen-rich among the three manures of cattle, goat and poultry. Goat manure has a moderate level of N (2.0%-4.5%) that overlaps with cattle manure but can sometimes be higher. Cattle manure also has a moderate level of N (2.5%-4.0%). Besides manure, local farmers also cultivated legumes, which fix atmospheric N and increase the levels of N in the soil. However, the application of organic manures was limited, leading to a medium level of TN across both the altitudinal land types. Researches across diverse regions in various soil types including paddy soils in the Java Island of Indonesia (Wibowo and Kasno 2021), Great Plains regions of the U.S. (Barrett and Burke 2000) and Histosols and soil horizons with high OM content in different regions of Brazil (Pereira et al 2006) consistently demonstrated strong positive correlation between OM and TN content in soils. Weil and Brady (2017) reported that the distribution of soil N paralleled that of soil OM due to the fact that N along with other nutrients, are present in organic combination and are slowly released by the process of mineralization.

Medium levels of soil OM content in most of the agricultural fields validated the medium levels of average TN contents across both the altitudinal land types. Kharal et al (2018) found a strong correlation ($r = 0.92$, $p < 0.01$) between soil OM and TN levels in forest land, with contents of 3.55% OM and 0.18% TN, as well as in upland and lowland farms, which had 1.26% OM and 0.06% TN. Similarly, Krishnamurthy et al (2023) reported strong positive correlation ($r = 0.696\text{-}0.907$, $p < 0.01$) between OM and TN content in urban and rural composts in India. The findings of our present study are consistent with those of previous research, demonstrating a strong positive correlation between the soil OM and TN levels across the study area ($r = 0.82$, $p < 0.01$), as well as within both altitudinal land types. These results suggest that the moderate levels of soil OM may have contributed to the corresponding medium levels of TN.

The higher available P content could be due to the application of P-containing fertilizer (such as DAP) and the application of organic manure including FYM (Panday et al 2019). Among the livestock manures applied, poultry manure exhibits the highest available P levels (0.9%-2.9%). Goat and cattle manures have a lower and similar level of P with their ranges of (0.4%-1.1%) and (0.4%-1.0%), respectively (Sharma et al 2022, TNAU 2016). During the HH survey, it was found that most farmers used the same quantity of the inorganic fertilizer, DAP, for many years without conducting soil tests. Furthermore, during past periods of inorganic fertilizer shortages, DAP remained available in local markets for an extended period. Many farmers perceived DAP as a slow-acting (slow-release) fertilizer and believed that higher application rates were necessary to achieve fertilization effects comparable to those of urea. Most of them were unaware that DAP contains only 18% N and that the remaining 46% is P (P_2O_5). As a result, during these shortages, excessive amounts of DAP- and consequently P were inadvertently applied in an attempt to match urea's nitrogen fertilization level, potentially contributing to elevated levels of available P in the soil.

The higher available K content may be associated with the nature of parent materials, weathering, land use systems, fertilizer source and their leaching rate, and crop residue determines the availability and distribution of K content in soils (Panday et al 2019; Akbaş et al, 2017; Tening & Omueti, 2000; Vimalashree et al, 2000). However, Kalbande and Swamynatha (1976) found no direct relationship between parent material K content and soil K distribution in black soils developed on different parent materials in Tungabhadra River catchment in India. Soils that contain more clay also tend to have large reserves of K which are available to the crop and produce higher soil K indices on analysis (Kharal et al 2018, Hargreaves 2015). K uptake by plants is limited by high levels of Ca in some soil (Weil and Brady 2017) causing higher levels of available K in soils.

Farmers apply livestock manures which also contribute to an increase in soil K content. Goat manure has the highest level of available K (2.0%-2.9%) whereas poultry manure also contains a higher level of K (0.8%-2.9%) and is comparable with the level of cattle manure. Cattle manure has a slightly lower level of K (0.7%-2.5%) among the three manures (Sharma et al 2022, TNAU 2016). The increased input of OM increases the soil cation exchange capacity (CEC), which can reduce the leaching rate of positively charged K (K^+) (Panday et al 2019). Some farmers (57%) also practiced making composts of soft plant/crop residues which are important source of organic K. According to Li et al (2020), K in crop straw is highly mobile at the cellular and tissue levels and can be easily released from decaying straw to the soil within 60 days of application.

During the HH survey, it was learned that many farmers in the area applied Muriate of potash (MOP) to their cereal crops (maize, wheat and rice) regularly e.g. every three years and to their vegetable crops (mostly cauliflower, potato and garlic) every year to kill insects and pests in the soil. Many of them think that MOP kills insects and pests in the soil directly as they are unaware of the actual roles of K in increasing plants' resistance to insects, pests, and diseases.

High levels of available Ca and Mg in most of the agricultural fields across both lowland and upland areas may be contributed by the parent material/mineralogy, texture, amelioration of soil acidity and use of animal excreta based organic manure (Khadka et al 2018, Pagani et al 2020). The increased input of OM increases the soil cation exchange capacity (CEC), which can reduce the leaching rate of positively charged nutrients, Ca^{2+} and Mg^{2+} (Panday et al 2019). According to reports, poultry manure has the highest Ca level (1.7%-6.9%) among the three manures. Goat manure has a moderate level of Ca (0.8%-1.9%). Cattle manure has the lowest level of Ca (0.5%-0.8%) (TNAU 2016). Similarly, it is reported that cattle and poultry manures have comparatively higher level of Mg with ranges of (0.5%-0.8%) and (0.3%-0.8%), respectively. Both of these types of manures have almost similar levels available K. Goat manure has a relatively lower level of Mg (0.3%-0.6%) (TNAU 2016). Moreover, local farmers cultivated leguminous crops such as soybeans, broad beans, French beans (pole and sword types) and asparagus beans. The incorporation of crop residues from such leguminous crops provide moderate amounts of Ca and Mg in the soil (Sharma et al 2024, Kumawat et al 2022). According to Weil and Brady (2017), K levels are known to limit the uptake of Mg even when significant quantities of Mg are present in the soil causing its level to remain high.

Correlation analysis using linear regression model showed no significant linear relationship ($p < 0.05$) between the soil chemical properties and the farmers-reported crop yields. This is likely due to the homogenous, predominantly medium-to-high levels of soil chemical properties and nearly identical crop yields. The study speculates that decreased crop yields stem from several factors. It may be due to acid stress (low pH), water stress, soil structural degradation, disease and pest infestations, crop raiding by wild animals and lack of high-yielding OPV seeds. Farmers reported scarcity of irrigation water due to erratic rainfall, destruction of traditional canals by urbanization, and drying wells. There is an inherent limitation in the yield potential of OPVs, while hybrids can give 25–30% higher grain yield as compared to the better OPVs (Gairhe et al 2021). According to farmers, local cultivars of maize grew taller and exhibited poor stalk mechanical strength and stalk lodging resistance, leading to a higher rate of stalk breakage below the ear, particularly during windy conditions in the later stages of growth. Maize lodging significantly reduced crop yields. Pests and diseases were also identified as major problems in the area. Some upland farmers experienced substantial yield losses due to crop raiding by wild animals like wild boars, deer and porcupines. Additionally, increased soil clumping and compaction were reported, possibly linked to the increased use of rotary power tillers, coupled with limited organic fertilizer application and continuous imbalanced inorganic fertilizer use. Urbanization's impact, including land fragmentation and the shadows cast by tall buildings on nearby fields, also caused shade stress and yield declines.

The majority of the farmers have a very low level of soil awareness. Many of them considered soil as a non-living thing requiring no care for its improved health and fertility status. Most of the farmers (80%) in the area practice burning plant/crop residues in the field. Farmers cultivated some legume crops such as soybean, French beans- pole type and sword type, asparagus beans, broad beans in their fields (Figure 5) but none of them reported that they were aware of the importance of legumes in soil fertility management. Similarly, they were unaware of the components of the 4R nutrient stewardship which has tremendous benefits in addressing the issues of environmental stress, N use efficiency, crop productivity, soil health. It promotes the use of the right fertilizer source, at the right rate, at the right time, and in the right place (Pandit et al 2022). However, all farmers in the study area (100%) followed traditional, imbalanced blanket fertilization practices passed down from their older generations. During the HH survey, a respondent commercial farmer expressed strong dissatisfaction with the agriculturists/agriculture officials for not recommending the maximum level of inorganic fertilizers that could produce the highest crop yields. He shared his experiences of achieving high yields of vegetable crops, such as cauliflower, by applying inorganic fertilizers at doses of 1000:500:60 kg/ha (Urea:DAP:MOP) and reported that he has been applying such maximum doses consistently in his fields.

Data showed that the dose of organic manure, N, P and K used by the farmers are not consistent with the recommended dose for different crops (AITC-MoALD 2024). There is a long history of inorganic fertilizer use in some parts of the study area, most probably stemming from the beginning of inorganic fertilizer imports from India some 70 years ago. According to local farmers, before the introduction of inorganic fertilizers around 1953 AD, there was a traditional practice of digging up black, clayey, fertile sediment layers (popularly known as Kalimati) from 15-20 meters deep underground pits and using them as manure to improve soil in the fields.

Comparison of soil properties across altitudinal land types revealed that lowland areas exhibited higher soil nutrient levels than upland areas, leading to increased crop yields in the lowland areas (maize by 2%, rice by 11%). Most agricultural fields in the upland areas were more acidic than the lowland areas, and the levels of soil OM, TN, P, K, Ca, and Mg were also slightly higher in the lowland areas than in the upland areas. Average soil OM and TN were at 'medium' levels, whereas available P and K were at 'very high' and 'high' levels, respectively, and available Ca and Mg were also at 'very high' levels in both altitudinal land types. Clay and sand particle contents were in higher proportions in lowland areas, while silt particle content was in a higher proportion in the upland areas.

CONCLUSION

Our results revealed that soil fertility of the study area was found to be moderate to high in which soil pH was reported at a moderately acidic level, soil OM and total N were at 'medium' levels, available P (P_2O_5) and K (K_2O) were at 'very high' and 'high' levels and available Ca and Mg both were also at 'very high' levels in most of the agricultural fields. However, farmers witnessed the decline in crop yields of rice OPV, maize OPV and vegetables in the area by around 30-50% in the last 10 years. Most farmers have been using the same quantity of inorganic fertilizers for years without soil tests and lack knowledge and skills of proper soil health and fertility management practices including site-specific precision fertilizer management. There was unnecessary overuse of scarce agricultural inputs, such as inorganic fertilizers, leading to the wastage of resources in many areas where soil nutrient levels were already high. None of the farmers were aware of the negative impacts of increased soil acidity, and none approached local agricultural offices for support on sustainable soil fertility management for their lands. This could be further examined why the farmers hesitated or did not contact the concerned authorities. There might be some gaps that need to be identified. A campaign to increase the awareness about the importance of soil quality should be delivered to farmers. The research findings on soil physical and chemical properties will help farmers make informed management decisions based on their proper understanding of the current conditions of their soils within the context of existing agricultural practices in their fields. These results can be useful in developing effective soil health and fertility management strategies, providing recommendations for best management practices within the locality, and contributing to enhancing soil health and fertility status and improving the livelihoods of the farmers in the area.

Acknowledgements

We are highly indebted to the local farmers, stakeholders and supporting institutions who contributed to this research for their time, kind cooperation, and support.

Authors' Contributions

MD, NRP, and RBO were involved in the research design. MD was engaged in conceptualization of the research design and implementation, including the collection and analysis of composite soil samples and household surveys, as well as data analysis and preparing the draft manuscript. NRP provided guidance, supervision, and support for the research. NRP and RBO reviewed and provided critical feedback on the draft manuscript. RBO provided overall scholarly guidance, supervision, and support for the research, including critical revision and finalization of the manuscript. All authors listed have made a substantial, direct and intellectual contribution to the research and approved it for publication.

Conflicts of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Publisher's Note

All claims made in this article are those of the authors alone; they do not necessarily reflect the views of any affiliated organizations, the publisher, the editors, or the reviewers.

References

Adhikari BR and RB Ojha. 2021. Geology and Physiography. In: The Soils of Nepal (RB Ojha and D Panday, eds). Springer International Publishing, pp.29-39. https://doi.org/10.1007/978-3-030-80999-7_4

AITC-MoALD. 2024. Agriculture and Livestock Diary 2081. Agriculture Information and Training Center (AITC). Ministry of Agriculture and Livestock Development (MoALD), Government of Nepal. Hariharbhawan, Lalitpur, Nepal. https://aitc.gov.np/uploads/documents/agriculture-diary-2081-file-2081-03-2pdf-6568-329-1719146649.pdf

Akbas F, H Gunal, N Acir. 2017. Spatial variability of soil potassium and its relationship to land use and parent material. Soil & Water Res., 12(4): pp.202−211. 10.17221/32/2016-SWR

Barrett JE and IC Burke. 2000. Potential nitrogen immobilization in grassland soils across a soil organic matter gradient. Soil Biology and Biochemistry. 32(2000), pp.1707-1716. 10.1016/S0038-0717(00)00089-4.

Bremner JM and CS Mulvaney. 1982. Nitrogen—Total. In: Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. Agronomy Monograph no. 9 (2nd ed). (AL Page, ed). American Society of Agronomy. ASA-SSSA, USA. https://doi.org/10.2134/agronmonogr9.2.2ed

Bouyoucos GJ. 1962. Hydrometer Method Improved for Making Particle Size Analyses of Soils. Agronomy Journal, 54, pp.464-465. https://doi.org/10.2134/agronj1962.00021962005400050028x

Chaudhuri RR, SWA Qazi and S Panday. 2017. Influence of Urbanization on Soil Infiltration Rates- A Case Study. Urban India, 37(2), pp.88-99. https://doi.org/10.1016/j.ufug.2013.04.001

CM. 2018. Risk Sensitive Land Use Plan (RSLUP) of Changunarayan Municipality (CM). Changunarayan Municipality (CM) Office, Kharipati, Bhaktapur. https://opendata.changunarayanmun.gov.np/media/publication_files/4RSLUP_ChanguNarayan_DraftFinal_June_20191.pdf

DCC. 2017. District Profile of Bhaktapur District by Nepal Geographic Information System Society (NEGISS). District Coordination Committee Bhaktapur. Friends Service Council Nepal (FSCN). https://app.naxa.com.np/download?file=http://app.naxa.com.np/uploads/publication/file/31.pdf%20&&%20title=District%20Profile%20of%20Bhaktapur%20District,%20Nepal%202017

DMG/GoN. 2020. Geological Map of Bagmati Province. Survey Department, Department of Mines and Geology/Ministry of Industry, Commerce and Supplies/Government of Nepal.

Kathmandu. Retrieved 2024, from https://dmgnepal.gov.np/uploads/documents/province-3pdf-1669-964-1718993990.pdf
El Mahi YE, IS Ibrahim, HM Abdel Magid and AMA Eltilib. 1987. A Simple Method for the Estimation of Calcium and Magnesium Carbonates in Soils. Soil Science Society of America Journal, 51(5), pp.1152-1155. https://doi.org/10.2136/sssaj1987.03615995005100050010x
FAO. 2019. Standard operating procedure for soil organic carbon Walkley-Black method (titration and colorimetric method). GLOSOLAN-SOP-02. Food and Agriculture Organization of the United Nations (FAO), Rome. https://openknowledge.fao.org/server/api/core/bitstreams/e498d73e-1711-4d18-9183-aa8476387e2c/content
FAO. 2021. Standard operating procedure for soil available phosphorus- Olsen method. GLOSOLAN-SOP-10. Food and Agriculture Organization of the United Nations (FAO), Rome. https://openknowledge.fao.org/server/api/core/bitstreams/d69a78fc-3ccd-4a9d-a77a-7e729be66c4a/content
FAO. 2021. Standard operating procedure for soil nitrogen - Kjeldahl method. GLOSOLAN-SOP-14. Food and Agriculture Organization of the United Nations (FAO), Rome. https://openknowledge.fao.org/server/ api/core/bitstreams/17a0e476-f796-4608-a869-295a367c0b56/content
FAO. 2021. Standard operating procedure for soil pH determination. GLOSOLAN-SOP-06. Food and Agriculture Organization of the United Nations (FAO), Rome. https://openknowledge.fao.org/server/ api/core/bitstreams/6ad6862a-eadc-437c-b359-ef14cb687222/content
Gairhe S, KP Timsina, YN Ghimire, J Lamichhane, S Subedi, and J Shrestha. 2021. Production and distribution system of maize seed in Nepal. Heliyon, 7(4), e06775, pp.1-12. https://doi.org/10.1016/ j.heliyon.2021.e06775
Ghimire D, BR Baral and D Panday. 2018. Assessment of Spatial Variability of Soil Chemical Properties under Small-holder Farmers' Field: a Case Study from Kavrepalanchowk District of Nepal. Current Agriculture Research Journal, 6(3), pp.337-343. http://dx.doi.org/10.12944/CARJ.6.3.12
Hargreaves P. 2015. Soil Texture and pH Effects on Potash and Phosphorus Availability. The potash Development Association (PDA): London, UK. https://www.pda.org.uk/wp/wp-content/uploads/2015/ 10/PDA-news2015-1.pdf
Jackson ML. 1973. Soil Chemical Analysis. Prentice Hall of India Private Limited, 1st ed, New Delhi, India.
Kalbande AR and R Swamynatha. 1976. Characterisation of Potassium in Black Soils Developed on Different Parent Materials in Tungabhadra Catchment. Journal of the Indian Society of Soil Science, 24: pp.290-296.
Karki KB and RB Ojha. 2021. Land Degradation. In: The Soils of Nepal (RB Ojha and D Panday, eds). Springer International Publishing, Switzerland, pp.127-142. https://doi.org/10.1007/978-3-030-80999-7_10
Karki KB, DP Sherchan, D Panday and R Ghimire. 2021. Soil Fertility and Nutrient Management. In: The Soils of Nepal (RB Ojha and D Panday, eds). Springer International, Switzerland, pp.111-126. https://doi.org/10.1007/978-3-030-80999-7_9
KC B, T Wang and P Gentle. 2017. Internal Migration and Land Use and Land Cover Changes in the Middle Mountains of Nepal. Mountain Research and Development, 37(4), pp.446-455. https://doi.org/ 10.1659/MRD-JOURNAL-D-17-00027.1
Khadka D, S Lamichhane, P Bhantana, AR Ansari, S Joshi and P Baruwal. 2018. Soil fertility assessment and mapping of Chungbang farm, Pakhribas, Dhankuta, Nepal. Advances in Plants & Agriculture Research, 8(3), pp.219-227. https://doi.org/10.15406/apar.2018.08.00317

Kharal S, BR Khanal and D Panday. 2018. Assessment of Soil Fertility under Different Land-Use Systems in Dhading District of Nepal. Soil Systems, 2, 57, pp.1-8. DOI: https://doi.org/10.3390/soilsystems2040057

Krishnamurthy R, C Ramadoss, KM Ramanathan, J Bennett and KT Narasimhan. 2023. A study on the relationship between Nitrogen and Organic matter in Urban and Rural Composts. Madras Agricultural Journal. 52 (Feb-feb). pp.52-60. DOI: https://doi.org/10.29321/MAJ.10.A03823

Kumawat A, SD Bamboriya, RS Meena, D Yadav, A Kumar, S Kumar, A Raj and G Pradhan. 2022. Legume-based intercropping to achieve the crop, soil, and environmental health security. Advances in Legumes for Sustainable Intensification, pp.307-328. DOI: https://doi.org/10.1016/B978-0-323-85797-0.00005-7

Li C, X Zhao, X Liu, D Lu, X Chen, H Wang and J Zhou. 2020. Rice and wheat yield and soil potassium changes in response to potassium management in two soil types. Nutrient Cycling in Agroecosystems, 117, pp.121-130. DOI: https://doi.org/10.1007/s10705-020-10056-y

Maskey S. 2016. A Case Study of the Krishna Bhir Slope Failure Disaster: Past and Present Scenario at a Glance. International Journal of Rock Engineering and Mechanics, 2(1), 1-9. https://www.researchgate.net/publication/301286663_A_Case_Study_of_the_Krishna_Bhir_Slope_Failure_Disaster_Past_and_Present_Scenario_at_a_Glance

MoAD. 2017. Statistical Information on Nepalese Agriculture. Ministry of Agricultural Development, Monitoring, Evaluation and Statistics Division: Kathmandu, Nepal.

MoA/GoI. 2011. Soil Testing in India - Methods Manual. Department of Agriculture & Cooperation, Ministry of Agriculture (MoA), Government of India (GoI). New Delhi. https://agriculture.uk.gov.in/files/ Soil_Testing_Method_by_Govt_of_India.pdf

MoLMCPA-GoN. 2021. Preparation of Present Land Use Report of Changunarayan Municipality of Bhaktapur District. Government of Nepal, Ministry of Land Management, Cooperatives and Poverty Alleviation (MoLMCPA), Survey Department, Topographical Survey and Land Use Management Division, Minbhawan, Kathmandu, Nepal.

MoWS/GoN. 2021. 35173-015: Urban Water Supply and Sanitation (Sector) Project. Asian Development Bank. Retrieved July 4, 2024, from https://www.adb.org/sites/default/files/project-documents/35173/35173-015-sddr-en_12.pdf

NARC-NSSRC. 2021. Soil Map. NARC's National Soil Science Research Center (NSSRC). Nepal Agricultural Research Council (NARC). Retrieved May 4, 2024, from https://soil.narc.gov.np/soil/soilmap

NARC-NSSRC. 2022. Soil Health Card (MatoSwasthataPraman-Patra). Ratings for Soil pH and Nutrient Values Based on Soil Analysis (in Nepali). Government of Nepal (GoN), Nepal Agricultural Research Council (NARC), National Soil Science Research Centre (NSSRC), Khumaltar, Lalitpur, Nepal.

NSO. 2024. Environment Statistics of Nepal 2024. National Statistics Office (NSO), Office of the Prime Minister and Council of Ministries, Thapathali, Kathmandu, Nepal, pp. 15, 26. Retrieved July 4, 2024, from https://data.nsonepal.gov.np/dataset/89490a80-ec55-49ff-a8ad-8961320c0ecb/resource/96c2b8f2-b42b-42ac-a36c-00dedbe5cea9/download/environment_statistics_of_nepal_2024.pdf

Ojha RB, KB Karki and D Panday. 2021. Soil Issues and Future Perspective. In: The Soils of Nepal (RB Ojha and D Panday, eds). Springer International Publishing, pp.151-157, DOI: https://doi.org/10.1007/978-3-030-80999-7_12

Olsen SR, CV Cole, FS Watanabe and LA Dean. 1954. Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate. Circular. No. 939. United States Department of Agriculture (USDA), Washington, DC. https://ia803207.us.archive.org/21/items/ estimationofavai939olse/ estimationofavai939olse.pdf

Pagani A, JE Sawyer and AP Mallarino. 2020. Calcium and Magnesium Management. Iowa State University in cooperation with The Fertilizer Institute (TFI), Natural Resources Conservation Service (USDA-NRCS), International Plant Nutrition Institute (IPNI). https://www.agronext.iastate.edu/soilfertility/4r/ppt/Chapter-6%20Ca%20and%20Mg%20Management_Ver6.pdf

Panday D, RB Ojha, D Chalise, S Das, and B Twanabasu. 2019. Spatial variability of soil properties under different land use in the Dang district of Nepal (MT Moral, ed). Cogent Food & Agriculture, 5(1). DOI: https://doi.org/10.1080/23311932.2019.1600460

Pandit NR, D Choudhary, S Maharjan, K Dhakal, SP Vista, and YK Gaihre. 2022. Optimum Rate and Deep Placement of Nitrogen Fertilizer Improves Nitrogen Use Efficiency and Tomato Yield in Nepal. soil systems, 6(3), 72. DOI: https://doi.org/10.3390/soilsystems6030072

Pereira MG, A Espindula, GS Valladares, LH Cunha dos Anjos, V de Melo Benites, and N Schultz. 2006. Comparison of Total Nitrogen Methods Applied for Histosols and Soil Horizons with High Organic Matter Content. Communications in Soil Science and Plant Analysis, 37(7–8), pp.939–943. DOI: https://doi.org/10.1080/00103620600584743

S4W-Nepal. 2018. Watersheds of Kathmandu Valley. https://s4w-nepal.smartphones4water .org/tag/watersheds-of-kathmandu-valley. Retrieved 10 1, 2024, from https://s4w-nepal.smartphones4water.org/tag/ watersheds-of-kathmandu-valley

Sada R. 2012. Hanumante River: emerging uses, competition and implications. Journal of Science and Engineering (JScE), 1, pp.17-24. DOI: https://doi.org/10.3126/jsce.v1i0.22489

Sharma R, S Kandel, S Khadka and S Chaudhary. 2022. Nutrient contents in different sources of organic manures used in different farms of Bhaktapur district, Nepal. Journal of Agriculture and Natural Resources, 5(1), pp.150-156. DOI: https://doi.org/10.3126/janr.v5i1.50705

Sharma N, R Kumar, AP Singh, R Sharma, P Sharma, JS MeCarty and F Farooq. 2024. Legumes in Cropping System for Soil Ecosystem Improvement: A Review. Legume Research- An International Journal, Review Article, pp.1-9. DOI: https://doi.org/10.18805/LR-5289

Shrestha L and NK Shrestha. 2017. Assessment of climate change impact on crop yield and irrigation water requirement of two major cereal crops (rice and wheat) in Bhaktapur district, Nepal. Journal of Water and Climate Change, 8(2), pp.320-335. DOI: https://doi.org/10.2166/wcc.2016.153

Suryabinayak Municipality. 2024. Brief Introduction to Suryabinayak Municipality. Retrieved July 6, 2024, from https://www.suryabinayakmun.gov.np/en/node/4

Tening AS and JAI Omueti. 2000. Potassium availability in soils from different parent materials in the subhumid zone of Nigeria. Communications in Soil Science and Plant Analysis, 31(3-4), pp.509-519, DOI: 10.1080/00103620009370453

Thapa Chhetri DB and R Moriwaki. 2017. Monitoring urban growth, land use and land cover using remote sensing and gis techniques: a case study of Bhaktapur district, Nepal. IRACST – Engineering Science and Technology: An International Journal (ESTIJ), 7(1), pp.1-8.

Tiwari KR, BK Sitaula, RM Bajracharya and T Børresen. 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. Nutrient Cycling in Agroecosystems. Springer Science+Business Media B.V. 2009, 86(2), pp.241-253. DOI: https://doi.org/10.1007/s10705-009-9289-0

TNAU 2016. Livestock Production and Management ICAR eCourse PDF eBook. Tamil Nadu Agricultural University (TNAU), Indian Council of Agricultural Research (ICAR). AgriMoon Education. https://agrimoon.com/wp-content/uploads/Livestock-Production-and-Management.pdf, pp.3-4.

Vimalashree H, M Shivanna, SV Patil, P Munikrishnappa and BN Maruthi Prasad. 2020. Studies on the Effect of Different Sources of Potassium on Forms and Distribution, Release Kinetics and Fixation Characteristics in Alfisols. Int. J. Curr. Microbiol. App. Sci. 9(12): pp.877-883. DOI: https://doi.org/10.20546/ijcmas.2020.912.105

Vista SP, KB Karki, YK Gaihre, S Sharma, and BR Baral. 2021. Soil Properties In: The Soils of Nepal (RB Ojha and D Panday, eds). Springer International Publishing, Switzerland, pp.91-110. DOI: https://doi.org/ 10.1007/978-3-030-80999-7_8

Walkley A and IA Black. 1934. An Examination of the Degtjareff Method for Determining Soil Organic Matter, and a Proposed Modification of the Chromic Acid Titration Method. Soil Science, 37(1), pp.29-38. DOI: https://doi.org/10.1097/00010694-193401000-00003

Weil RR and NC Brady. 2017. The Nature and Properties of Soils (Global Edition/15th ed). Pearson Education Limited, Edinburgh Gate, Harlow, Essex CM202JE, England, pp.381-382.

Wibowo H and A Kasno. 2020. Soil organic carbon and total nitrogen dynamics in paddy soils on the Java Island, Indonesia. IOP Conference Series: Earth and Environmental Science, 648, 012192, pp.1-9. 10.1088/1755-1315/648/1/012192