The Nutritional Quality of Forage Grass Changes Due to Changing Soil Chemistry Resulting from Different Land-Use Management in the Oroba Valley, Kenya

Isaboke Job [1], Osano Odipo [1], Humphrey S. Olivier [2], Dowell M. Sophia [2] and Watts J. Michael [2]
[1]Department of Environmental Biology and Health, School of Environmental Studies, University of Eldoret, Eldoret, Kenya

[2]Inorganic Geochemistry, Centre for Environmental Geochemistry, British Geological Survey, Nottingham, NG12 5GG, UK

Corresponding author's email address: jisa1@bgs.ac.uk

Abstract

Threats from land degradation may escalate problems of inadequate food supply and poverty that already afflict the inhabitants of the Oroba Valley, Nandi County, Kenya. The steepness and inadequate application of good agricultural management systems expose the area to soil degradation, including erosion, depletion, and leaching of nutrients. Here, forage grass contributes to 60% of animal nutrient intake and this study investigated the macronutrient levels of forage grass from four differently managed farms and their vulnerability to soil erosion. Grass and soil were sampled from four differently managed plots in a randomised block design: plots 1 and 2 contained five sections (blocks), while plots 3 and 4 contained six sections. Grass samples were collected and analysed for five macronutrients (Mg, P, Ca, Cr, and Fe) by ICP-MS. Analysis of soils for characteristics of all soils from the pilot plots were classified as non-calcareous since their pH values range from 5.4 - 6.5. Organic matter (OM) distribution in the pilot plots depends on the amount of available plant reduces; most were cleared for animal consumption, as shown on the lower grounds of all pilot plots. The pH levels across the pilot plots dictated the distribution of macronutrients analysed in this study. Different plants have different optimum pH ranges for macronutrient uptake after considering all others around the plant's environment. Redistribution of macronutrients in the gradient of individual pilot plots majorly depends on the movement of soil by erosion. Results from the study have shown that different land management (erosion mitigated farmland and non-mitigated, newly farmed, and virgin land) affects the soil chemistry, hence changing grass's absorption regime for macronutrients to grass. For example, Mg, P, and Cr distribution variation between the mitigated and non-mitigated plots in the study. Macronutrients are essential for plant growth, health/resilience and yield; land degradation affects the soil chemistry and interrupts the natural balance of macronutrients input into the food chain leading to failure of achieving SDG 2 and 3 (Zero hunger, good health and wellbeing).

Keywords: Macronutrients, Land degradation, Soil erosion

INTRODUCTION

Land degradation results from soil acidification, alkalisation, depletion of soil nutrients, and reduction in soil organic matter, compaction, or soil erosion, all of which compromise the productivity of agricultural lands in Kenya (Mulinge et al., 2016; Nkonya et al., 2016). Key drivers of land degradation are poor agricultural practices, deforestation, overgrazing, mining activities, urbanisation, climate change, and land-use change (Gichenje et al., 2019). These may directly or indirectly accelerate various physical, biological, and chemical processes in soils, such as soil erosion, loss of beneficial soil microbes, soil acidification, and increased soil salinity (Saljnikov et al., 2022). Soil erosion is the major cause of land degradation, affecting 60% of the world's farmland (Pimentel, 2006), and in Kenya, it causes an estimated loss of 134 t ha^{-1} per year for slopes with average LS-factors (slope) of 0–10 (Angima et al., 2003). Agriculture accounts for 33% of Kenya's Gross Domestic Product (GDP) and another 27% of GDP indirectly through connections to other industries (FAO, 2022). Kenya's most productive agricultural regions are the western and Rift Valley counties. Nandi County is a Rift Valley County with steep slopes from hills and valleys. Due to the population growth rate in the county and lack of employment, most residents have rely on on agricultural activities (KNBS, 2019). Increased cultivation on the steep slopes of Nandi hills has increased the susceptibility to soil erosion, estimated to be >5 t ha^{-1} $month^{-1}$ (Humphrey et al., 2022). The high erodibility factor estimated on the slopes of Nandi hills is due to poor crop cultivation practices and tillage, reducing the soil organic matter levels, disrupting soil structure, and compacting the soil particles. Compacted soil reduces infiltration and increases surface runoff which washes down the macronutrients as a form of soil erosion (Gao et al., 2017; Khosravi Aqdam et al., 2022). Soil chemistry changes due to degradative action may cause a decrease in pH levels that reduce nutrient availability, aluminium toxicity, impaired root growth, and increased susceptibility to diseases; the consequence of decreased infiltration rate is increased surface runoff.

In Kenyan rural settings, grass provides 60% of the nutritional requirements to grazing livestock. At Oroba Valley, different grass species provide fodders for livestock (Ali et al., 2014; Liu et al., 2021). Forage grass is the key provider of the minimum required macro/micro-nutrients of soil–plants–animal–human food chain at the valley. Population growth in the Oroba Valley has led to subdivisions of the land parcels that make it hard to institute proper soil erosion control measures. The valley is steep, and extensive agriculture is conducted. Soil erosion control measures are being practiced, including terraces, strip farming, contour farming, and conservation agriculture. Encroachment of high-erosion-risk areas and poor cultivation management practices increase the chances of erosion and leaching/transfer of essential macro-elements down the slope, changing the soil pH and reducing organic matter content. Change in pH and reduction of organic matter hinders plants' availability and uptake of macronutrients depending on the species (Fageria et al., 1998). Increased soil erosion from poor land management leads to soil degradation and reduced availability of macronutrients for plants; lack of macronutrients in the food chain affects the good health and well-being of the animals and humans depending on those crops (Fageria et al., 2010).

This study aims to investigate the nutritional status of grass and the spatial distribution of macronutrients within the Oroba valley as an example of an elevated steep-sided valley experiencing different land management methods following different periods of land clearance. Four differently managed plots were examined (no mitigation, mitigated, recently farmed, and uncultivated farms) with the following objectives: (1) determine the concentration and distribution of selected nutritional elements in the forage grass. (2) assess the effects of land management on concentrations of selected macronutrients in the grass along the gradient of Oroba valley, Kenya.

MATERIAL AND METHODS

Study area

The Oroba Valley in Nandi County, Kenya, is characterised by a rural economy based on a mixed livestock and crop farming on very steep hills and valleys (Humphrey et al., 2022; Ndung'u et al., 2020; Owino et al., 2020; Yego et al., 2018). The area depends on forage grass as the key plant that residents of Oroba Valley use to feed their livestock, ranging from goats, cows, sheep to donkeys. Four pilot plots with different land management practices (1) no mitigation, (2) mitigated, (3) newly farmed, and (4) uncultivated farms were identified along the Oroba valley in Nandi hills, Nandi County, within the Winam Gulf catchment of

Lake Victoria. The plots were situated on the GPS coordinate (Arc 1960 UTM Zone 37S) in Figure 1. The study plots 1-4 had different management practices from various farmers: Plot 1 farmed without any mitigation measures against soil erosion and surface runoff. The owner practiced mixed farming on the same piece of land for over 20 years; Plot 2 it has been cultivated for over 20 years, and farmers also practiced mixed farming, but they employed terracing as a mitigation measure against surface runoff and soil erosion; Plot 3 has been farmed (mixed farming) for less than two years (2020-2022); while Plot 4 has been recently cleared but not cultivated, but used for cattle grazing. The pilot plots are located at steep slopes of the Oroba valley, as illustrated in Figure 1b, with details of individual management of the plots summarised in Table 1.

Table 1: Plot description of land management and techniques of farming

	Plot 1 (No mitigation)	**Plot 2 (Terraces)**	**Plot 3 (New farmed)**	**Plot 4 (Pristine)**
Description	Farmed land for over 20 years, used for animal grazing and food crop farming.	Farmed plot for over 20 years. Farmed for food crops and animal feeds.	Newly cultivated for less than five years. Planted for food crops and animal feeds.	Never been farmed. Grazing of animals at the plot.
Fertilisation	Use of Diammonium phosphate (DAP) fertiliser and animal manure on the farm.	Use of animal manure and DAP fertiliser on the farm.	Use of animal manure and DAP fertiliser on the farm.	No fertilizer.
Plant protection	No Herbicide nor pesticide was used.	In most areas of the plot, Pesticides are used.	No Herbicide nor pesticide was used.	No Herbicide nor pesticide was used.
Farming criteria	Steep slope farming without any soil erosion mitigation method.	Steep slope farming with terrace soil erosion mitigation method.	Vertical slope farming without mitigation method applied.	No farming, no mitigation.

Data collection

A Randomised block design was employed to collect grass samples for analysis, and plot history was recorded after a short open-ended questionnaire was administered to the owners. Four plots were examined, and GPS coordinates were recorded. Plots 1 and 2 were divided into five equal sections. In comparison, plots three and four were divided into six equal sections used as blocks during sampling. Each section randomly selected three points, grass, and soil samples were collected. GPS coordinates were recorded for analysis from each point where grass samples were obtained. A total of 66 grass and topsoil samples (0 - 20 cm) were collected from the four pilot plots.

Soil pH and Organic matter

Soil samples from the sections of the respective plots were analysed for pH based on a US EPA SW-846 Test Method 9045D for calcareous soils. In brief, 5 g of the soil (2 mm) was agitated and combined with a calcium chloride slurry ($CaCl_2$) to a final ratio of 1:2.5 (soil: solution). Organic matter (OM) content was evaluated by loss-on-ignition (LOI) at 450 °C for 1 g of soil, using a <53 µm particle size (Watts et al., 2019b).

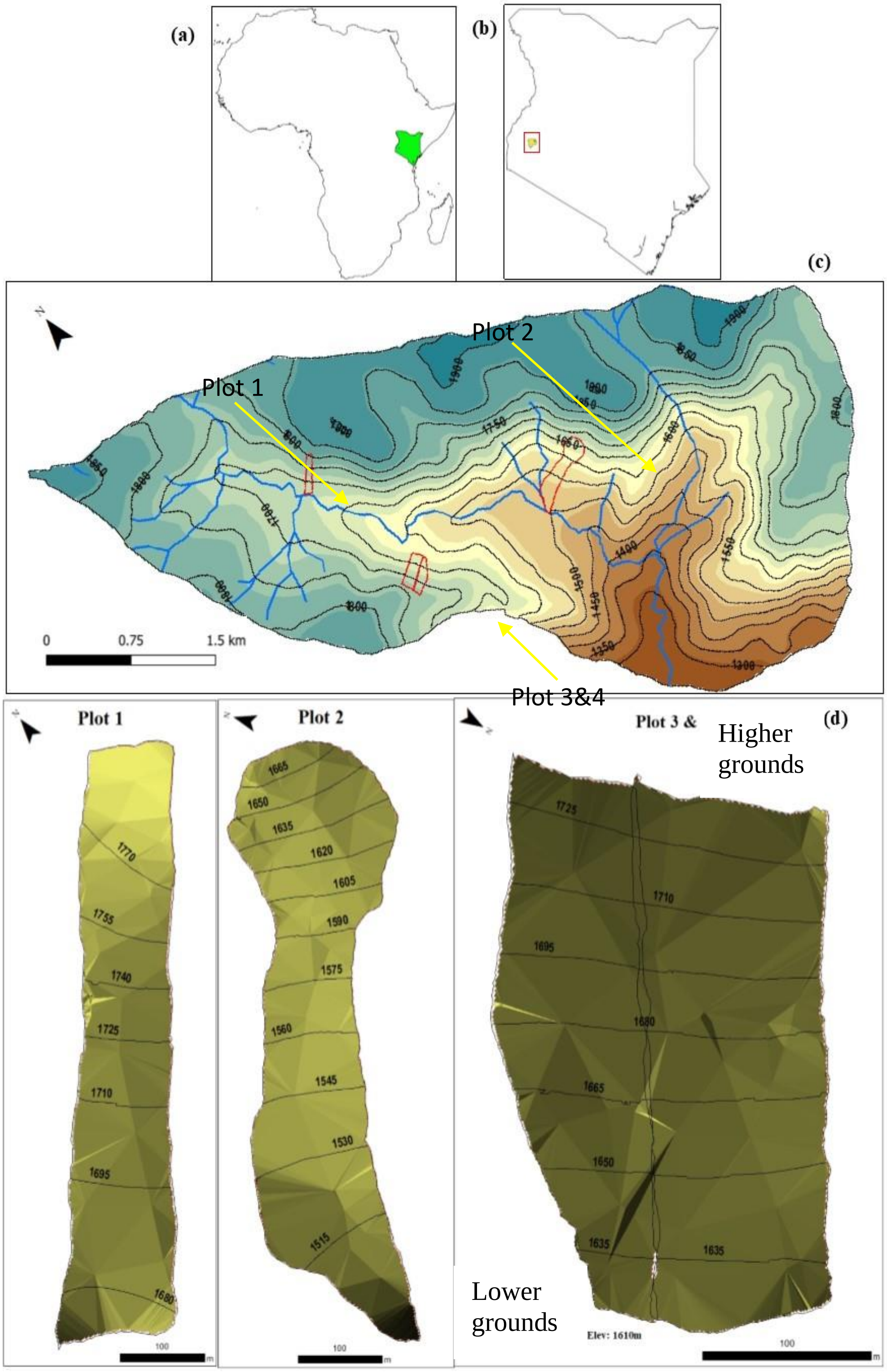

Figure 1: A study area map showing; (a) Africa, (b) Kenya with the position of Kibos catchment, (c) Oroba valley slope gradient with the position of pilot plots, and (d) the pilot plots with the contoured lines of an interval of 15m

Grass Samples Preparation, Digestion and Analysis

Plants collected from the selected sections of study plots were brushed and rinsed with distilled water at each location and air-dried (25 – 30ºC) on their return to the laboratory. Further, air drying in the laboratory glasshouse was done to remove moisture from the grass samples. Plant samples (grass) were ground (KM-1500 grinder), and 0.5 g of the sample was weighed for digestion using a microwave-assisted digester (MARS Xpress, CEM) for trace and macronutrients. For the digestion, 10 ml of 65 % of the HNO_3 was added to each sample, and the solution was shaken to mix and left for 30 min. The container was capped, placed in the microwave digester PFA vessels, and heated to 100 ºC for 15 min. The vessels were cooled, 1 ml of H_2O_2 was added, and the solution was left for 30 min. The solution was heated again at 200 ºC for 25 min. 30 ml of deionised water was added to the vessel then the mixture was poured into 60 ml Nalgene battle. The vessel was rinsed with 9 ml of deionised water, which was added to the 60 ml bottle. The solution bottle was filled to make the final solution of 50 ml that was transferred to the ICP-MS for analysis of 57 elements (Watts et al., 2019b).

After the microwave digestion, all samples were analysed by an Agilent 8900 triple quadrupole ICP-MS (Agilent 8900 ICP-QQQ) using collision cell mode (He, O_2, and H_2). Sc, Ge, Rh, In, Te, and Ir were used for standardisation to correct the signal drift (Watts et al., 2008; Watts et al., 2019a). More supporting data is available in the Supplementary Tables and Figure to increase the accuracy and precision of the measurements.

Statistical analysis

Analysis of variance was conducted to determine the effects of different farming systems and the uptake of elements by grass from the soil. This approach is outlined by (George & Mallery, 2018; Kaur et al., 2018) in evaluating this data using a standard t-test, calculating the mean, standard deviation, and correlation coefficient. ArcGIS (ArcMap 10.5) software was used to generate maps and raster interpolation techniques. Ordinary Kriging geo-statistics was used to display the spatial distribution of macronutrients from all four plots.

RESULTS AND DISCUSSION

Soil characteristics

Soil pH

Four pilot plots representing different land use management systems were studied. The first three plots are subsistence farms, mainly cereal, pulses, and vegetables for animals (especially grass) and humans, while plot 4 is a pristine land that has not been developed for agriculture, as described in Table 1. The pH of all the plots was determined and found to be acidic as follows: Plot 1: 5.4 - 6.0 (median 5.6), Plot 2: 5.8 - 6.1 (median 5.9), Plot 3: 5.9 - 7.2 (median 6.2), and Plot 4: 5.1 - 7.1 (median 6.0), as indicated in Figure 2. Soil pH levels primarily influence the uptake of elements; for example, K and Cu positively correlated with the low pH levels and concentrations in plants. At the same time, Mg, P, Ca, and Fe showed a negative correlation. According to (Hurst et al., 2013), Se intake in Malawi was affected by the pH level difference in which alkaline soil areas indicated higher levels of Se uptake in maize plants than in acidic soils. Different nutrients have different optimal pH ranges for mobility along the food chain. pH levels outside those ranges can lead to nutrient deficiencies (Fageria et al., 2010; Fageria et al., 2013; Joy et al., 2014; Watts et al., 2019b). All soils with pH values from 5.40 to 6.52 were classified as non-calcareous, as Watts et al. (2019b) and Joy et al. (2014) described. Calcareous soils are those that contain significant levels of calcium carbonate and have an impact on both physical and chemical soil characteristics that are important for plant growth, such as soil-water relationships and soil crusting (Al-Busaidi et al., 2003; Taalab et al., 2019; Watts et al., 2019b).

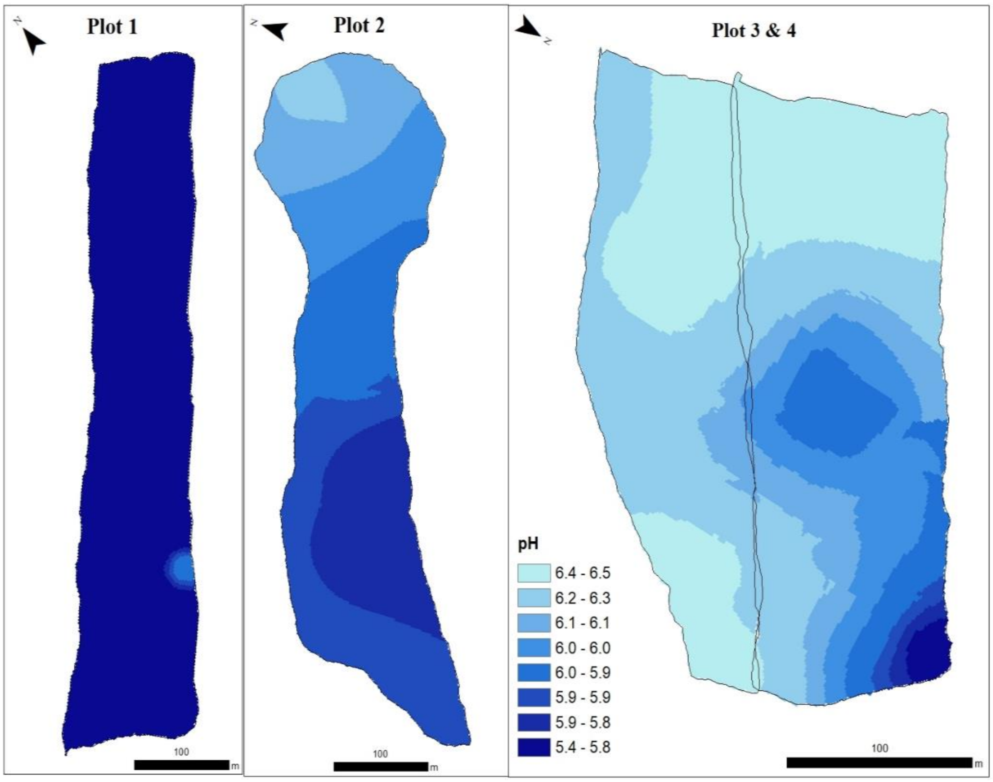

Figure 2: Kriging interpolation soil pH for the pilot plots from the study area

Soil organic matter

The results showed no difference in the relationship between the percentage of organic matter from the four plots. The highest recorded mean percentage of organic matter was seen in Plot 3, with a percentage range of 10.6 - 17.1 %, as shown in Figure 3. The median of the organic matter from all the plots was as follows: Plot 1: 6.9 ± 2.9 %, Plot 2: 6.5 ± 2.1 %, Plot 3: 8.5 ± 3.5 %, and Plot 4: 7.2 ± 3.4 %. Plant productivity is linked to the organic matter capacity of the soil. Organic matter (OM) improves soil structure, allowing for better water infiltration and air circulation, promoting root growth, soil retention, and plant nutrient uptake.

Secondly, OM can act as a reservoir of nutrients for plants, as it can retain macronutrients such as N, P, and K (Wood et al., 2016). Consequently, landscapes with a variable OM usually show variations in productivity. Plants growing in well-aerated soils are less stressed by drought or excess water.

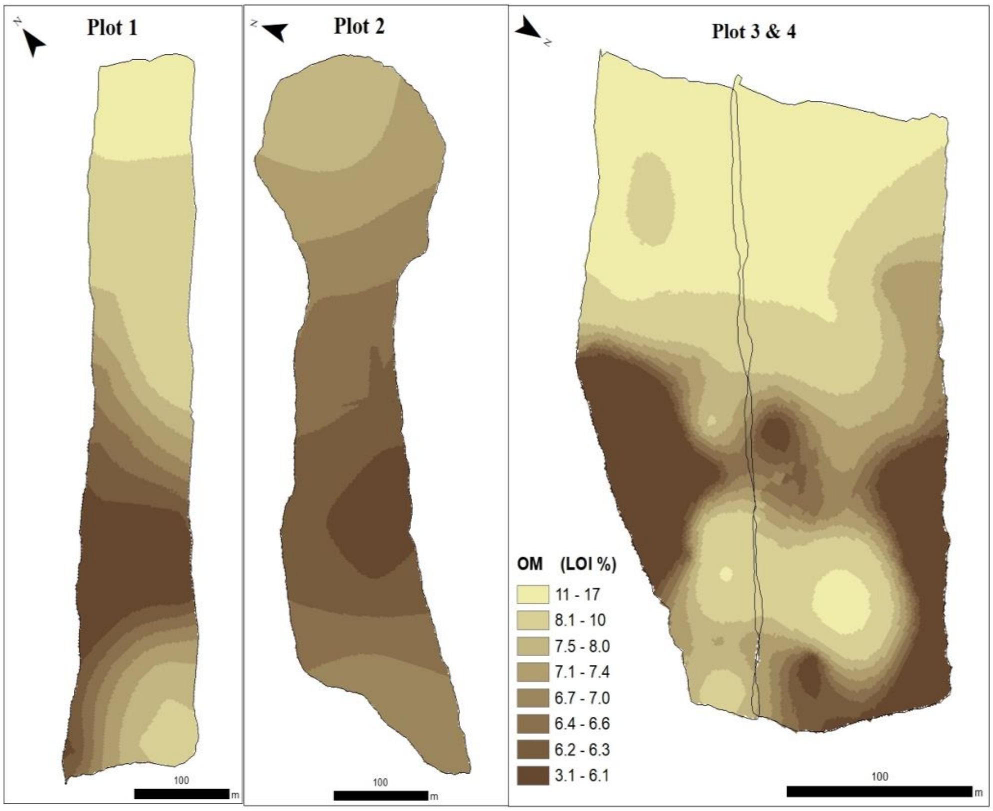

Figure 3: Kriging interpolation Loss of Ignition (% organic matter) for the pilot plots from the study area

In soils with less compaction, plant roots can penetrate and flourish more readily (Kononova, 2013; Lehmann & Kleber, 2015). From the results percentage, OM varies from plot to plot, with plots 1 and 2 recording the lowest OM of 6.9 and 6.5 %, respectively. Study plots 1 and 2 of 20 years of farming and removing plant materials have caused the reduction of OM content in the soil. The development of terraces reduces topsoil transfer by surface runoff and retains OM at the higher grounds of Plot 2, as shown in Figure 3.

Macronutrients Distribution from Grass

Five macronutrients (Mg, P, Ca, Cr, and Fe) for plant and animal health were studied in grass. Grass from different land managements were sampled and analysed; Plot 1, farmed for 20 years, has no mitigation measures as described in Table 1 and Plot 2 with mitigation measures. Plot 2 contains a well-demarcated terrace. These terraces have been formed over a span of many years by continual mechanical movement of soils from more elevated sections to lower sections progressively and annually. According to Dorren and Rey (2004), terraces can significantly decrease erosion if well-planned, correctly built, and well-maintained. If poorly maintained, it can provoke land degradation by nutrient leaching and landslides. Terraces require permanent soil cover, as indicated by Chow et al. (1999) and other additional soil conservation practices. Poorly maintained terraces increase the loss of macronutrients.

Table 2. Mean with standard deviations concentrations for grass samples, as mg kg^{-1} (plot 1, n = 12; plot 2, n = 13; plot 3, n =12; plot 4, n =16)

	Plot 1	Plot 2	Plot 3	Plot 4	ANOVA
Measurement	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**P-value**
pH	5.6 ± 0.1	5.9 ± 0.1	6.3 ± 0.4	6.1 ± 0.4	0.000
LOI	7.6 ± 2.9	6.8 ± 2.1	8.9 ± 3.6	8.4 ± 3.4	0.241
Mg	3294 ± 1211	3530 ± 1455	4017 ± 1347	2861 ± 685	0.091
P	2101 ± 966	2672 ± 1320	1792 ± 975	1370 ± 1127	0.024
Ca	7314 ± 2077	4823 ± 1071	5812 ± 2867	5820 ± 2038	0.039
Cr	56.8 ± 25.7	28.9 ± 12.5	22.5 ± 25.6	28.8 ± 16.7	0.001
Fe	2629 ± 1435	3483 ± 2719	2084 ± 1841	2315 ± 2486	0.406

Magnesium

Results from Plots 3 and 4, as displayed in Figure 4, showed an even distribution of Mg element across the gradient of the study plots compared to Plots 1 and 2. Comparison between the plots demonstrated no significant difference in concentration between the four plots (p-value 0.09), as shown in Table 2. In Plot 1 and 2, Mg was elevated at the high grounds at 5058 and 6359 mg kg^{-1}, respectively.

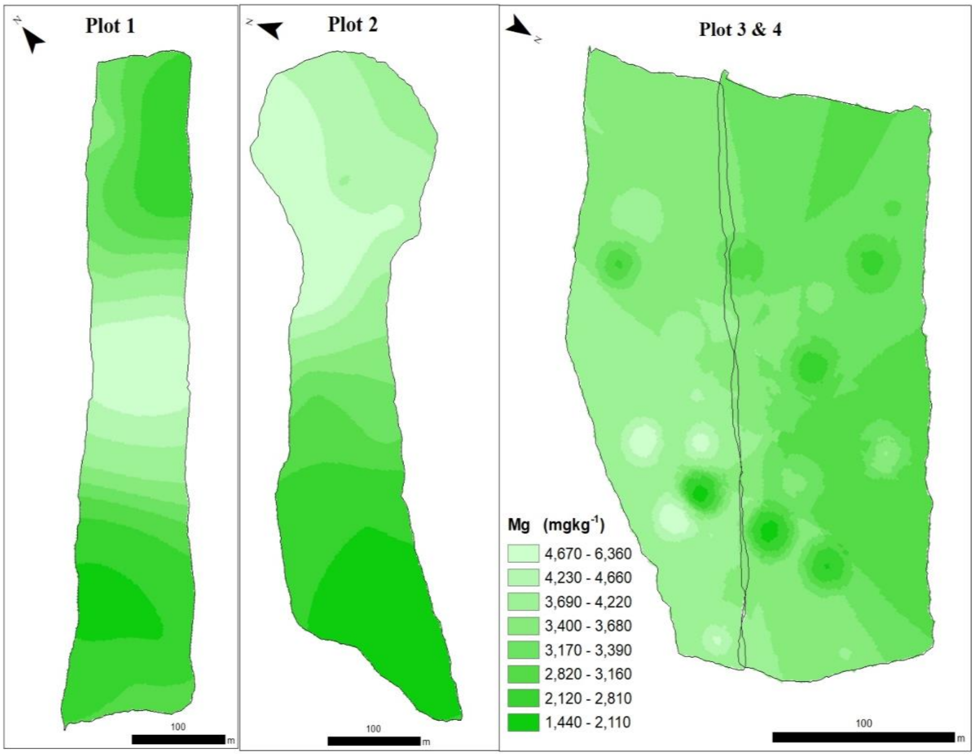

Figure 4: Kriging interpolation magnesium (mg kg-1) for the pilot plots from the study area

According to Humphrey. et al. (2022), Mg soil concentrations in Nandi hills range from (4215 - 7549 mg kg^{-1}) as shown in the Western Kenya Soil Geochemistry 2022 predictive web tool. Mg is retained on the surface of the clay and OM particles in all exchangeable forms available to plants; this nutrient will not readily leach from soils. Mg is also a mineral nutrient with highly positive impacts on photosynthesis, enzyme activation, and the formation and utilization of ATP. Therefore, plants' growth, especially sink organs (e.g., root and seed formation), is significantly affected by a low supply of Mg in soil. Similarly, adequate Mg nutrition is essential for grazing animals since a low Mg supply in soils may induce grass tetany, a potentially fatal metabolic disorder in animals (Cakmak, 2013).

Phosphorous

Figure 5 shows a phosphorous (P) distribution along the gradient of four pilot plots in Oroba valley. The results show that P is concentrated at the lower grounds in all four plots. There was a significant difference between the concentration in the plots, as shown in Table 2, with a p-value of 0.024. Plot 2 contained the highest concentration of P, ranging from 3369 - 1975 mg kg^{-1} with a mean of 2673 ± 1321 mg kg^{-1}. Erosion decreases soil nutritional capacity by moving the OM down the gradients. OM enriches the nutrients in soil after decomposition, for example, P, N.

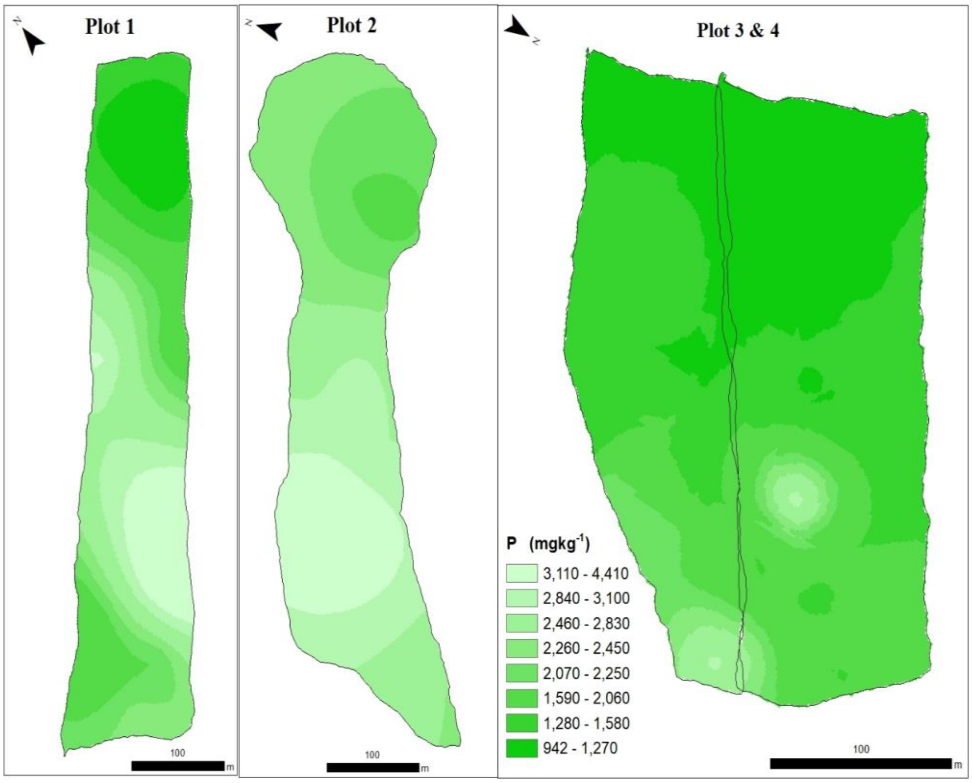

Figure 5: Kriging interpolation phosphorous (mg kg^{-1}) for the pilot plots from the study area

Ca and other macronutrients (Quinton et al., 2010; Sharpley & Smith, 1990). Phosphorus in the soil is often bound to various minerals, OM, and microbial biomass, making it less available for plant uptake. P is a relatively immobile element in soil, and it reacts with other elements to form compounds that are not readily soluble in water (Audette et al., 2020). Factors, including soil pH, OM, and other elements such as Fe and Al, influence p binding in soil. Generally, acidic soils (pH below 5.5) tend to have higher amounts of bound P. In contrast, acid to neutral soils (pH between 6 - 7) tend to have more available P.

Acidic soils tend to promote the formation of $FePO_4$ and $AlPO_4$, while alkaline (above 7) soils promote the formation of $Ca_3(PO4)_2$ (Audette et al., 2020; Thomason, 2002), which is inaccessible. The orthophosphates, $H_2PO_4^-$ and HPO_4^{2-}, are the primary forms of phosphorus taken up by plants. When the soil pH is less than 7.0, $H_2PO_4^-$ is the predominant form.

Although less common, certain organic phosphorus forms can also be directly taken up by plants. P moves to the root surface through diffusion. However, mycorrhizal fungi, which develop a symbiotic relationship with plant roots and extend threadlike hyphae into the soil, can enhance phosphorus uptake, especially in acidic soils low in P (Phillips, 2017). These explain how P concentration in grass plants from the pilot plots positively correlated with OM distribution. OM forms complexes with organic P, increasing P uptake by plants and enriching soils with mineralization.

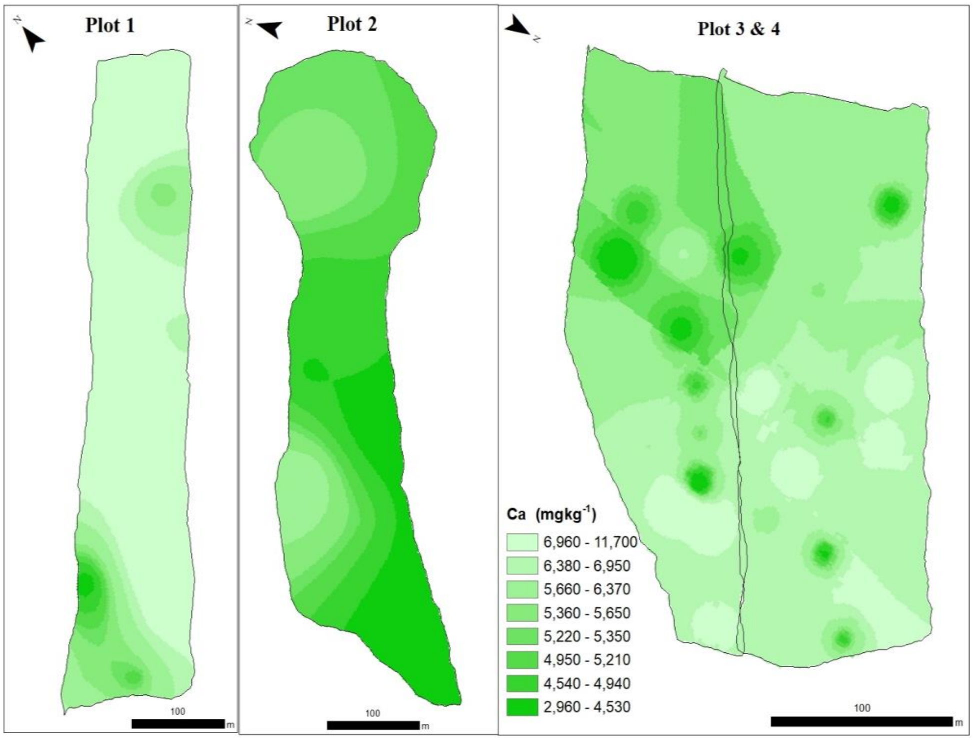

Figure 6: Kriging interpolation Calcium (mg kg^{-1}) for the pilot plots from the study area

Calcium

The higher grounds of Plot 1 and 2 showed a high concentration of Ca in grass compared to other sections, which are the steepest points in the pilot plots. Plots 3 and 4 showed an even distribution across their respective gradients, as shown in Figure 6. Plot 2 also indicated the lowest mean concentration of 4823 ± 1071 mg kg^{-1}. Plots 1 and 2 showed a significant redistribution of Ca from high to lower grounds with a p-value of < 0.05, while Plots 3 and 4 showed less redistribution along the gradient. Calcium uptake by plants occurs primarily through the roots and is influenced by several factors, including soil pH, Ca availability, and other soil properties. At high pH levels (above 7.0), Ca can be less available to plants due to the formation of insoluble compounds with other elements (e.g., P and C) in the soil, which is insoluble in water. In acidic soils (below 6.0), the solubility of Ca can increase. However, excessive Al and Mn can also reduce Ca uptake by plants (Ruan et al., 2004). Plot 1 contains the highest amount of Ca with a mean of 7314 ± 2077 mg kg^{-1}, as compared to other pilot plots but has the lowest pH value ranging from 5.4 – 5.8 (Figure 2). Plant roots possess fine root hairs that increase the surface area available for nutrient absorption, including calcium. However, some plants can regulate the pH in their rhizosphere (the soil surrounding the roots) by releasing alkaline substances, such as bicarbonates. These root hairs release protons (H^+) into the soil, which can help mobilize calcium from insoluble forms. Additionally, mycorrhizal associations, where plants form symbiotic relationships with beneficial fungi, can enhance calcium uptake in acid soils (Jones et al., 2004; Rorison, 1986).

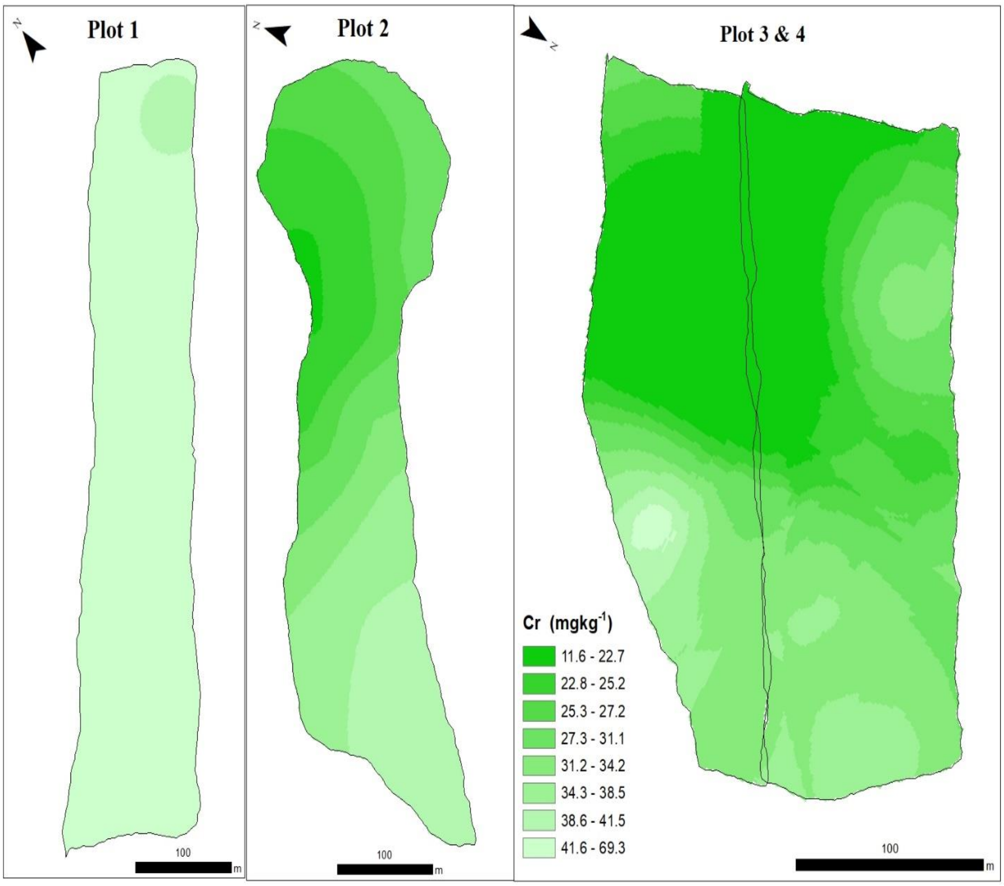

Figure 7: Kriging interpolation chromium (mg kg^{-1}) for the pilot plots from the study area

Chromium

There was a high distribution of Cr in the study plots, as shown in Figure 7, with the highest concentrations recorded at the lower grounds of Plots 2, 3, and 4. Plot 1 contained the high concentrations of Cr in the grass with a mean of 56.8 ± 25.7 mg kg^{-1}, while Plot 3 contained the lowest with a mean of 22.5 ± 25.6 mg kg^{-1}, respectively, as indicated in Table 2. The availability of Cr in the soil is pH dependent; in acidic soils (pH below 6), Cr tends to be more soluble and available to plants. Conversely, in alkaline soils (pH above 7), Cr forms insoluble compounds and becomes less available to plants (Grove & Ellis, 1980; Hamilton et al., 2018). The presence of other elements in the soil can also affect the availability of Cr to plants. For example, high levels of Ca and Fe can reduce the uptake of Cr by plants (Ertani et al., 2017). Elevated levels of Ca and Fe in the soil interfere with the uptake of other divalent cations, including Cr. This is because Ca^+ and Fe^+ compete with Cr^+ for binding sites on the root surface and within the plant. Cr availability and uptake are influenced by soil pH. Maintaining an optimal pH range for plant growth can help minimize the antagonistic effects. Adjusting the soil pH to slightly acidic or neutral conditions in some cases enhances chromium availability. OM also helps to bind with Cr, making it less available to plants. Cr exists in different oxidation states in soil, ranging from trivalent (Cr (III)) to hexavalent (Cr (VI)). Trivalent Cr is considered less toxic than hexavalent Cr. OM helps reduce Cr's toxicity by reducing hexavalent Cr to trivalent Cr by maintaining the biological atmosphere using microorganisms with specific enzymes, such as chromate reductases, that facilitate the reduction reaction (Barrera-Díaz et al., 2012; Fendorf et al., 2000). Plants' uptake and accumulation of Cr (III) varies depending on plant species, environmental conditions, and the availability of Cr (III) in the soil. Plot 1 is relatively more acidic than other pilot plots creating an environment that chemically reduces Cr (VI) to Cr (III) as shown in Figure 7. Acid soils enhances the reaction of $NaHSO_3$ and $Na_2S_2O_5$ with Cr (VI) to convert it to Cr (III) (Ahmad et al., 2015) and also, high concentration of Fe in the soil increases the reduction of Cr (IV) in acidic conditions. The Fe (II) reacts with Cr (VI), causing it to be reduced to Cr (III) while simultaneously forming Fe (III) (Wang et al., 2019).

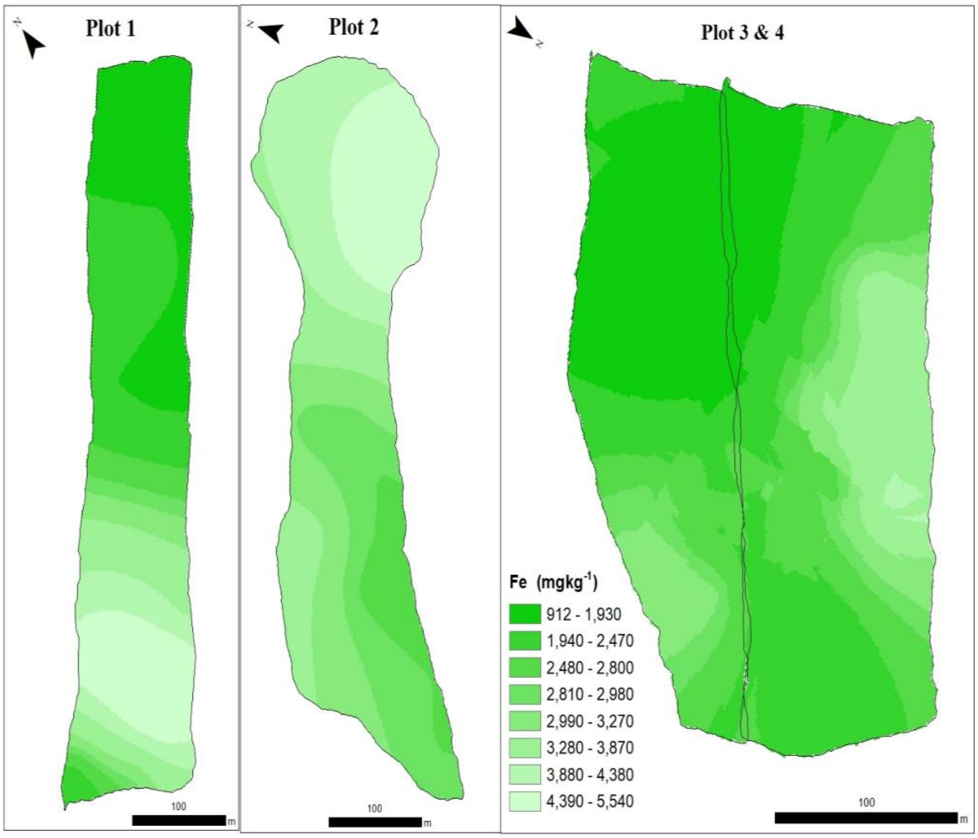

Figure 8: Kriging interpolation iron (mg kg^{-1}) for the pilot plots from the study area

Iron

Plot 2 recorded less mobility of Fe molecules from the high grounds to lower ground compared to other pilot plots p-value <0.05. Figure 8 shows a map indicating a high concentration of Fe in the lower grounds of Plot 1 and an even distribution in Plots 3 and 4. According to Colombo et al. (2014), Fe is normally highly concentrated in the soil as supported by Humphrey. et al. (2022) in the predictive Western Kenya Soil Geochemistry 2022 web tool showing the concentration along the study area ranging between 51107 - 35262 mg kg^{-1} hence more uptake by plants. Soil characteristics ranging from soil texture, pH, and OM affect macronutrient uptake by plants (Comerford, 2005). The formation of terraces in Plot 2 helps reduce the Fe redistribution along the gradient. The reaction of Fe oxides, such as hematite and goethite, can form coatings on soil particles. These coatings can contribute to soil aggregation and stability by acting as a cementing agent, binding soil particles together. This can enhance soil structure and resistance to erosion. Soils rich in iron oxides may exhibit improved resistance to erosion due to the presence of these coatings (Wang et al., 2018; Yi et al., 2019). Due to poor soil erosion mitigation measures, the results show in Figure 8 how Fe is highly concentrated at lower grounds.

Cultivation loosens the soil particles, increasing the decomposition of organic matter and saturation of elemental content in the soil. This process helps increase macronutrient mobility to the plants' roots (Ehrmann & Ritz, 2014). Subsequently in forage grass in farmed areas rather than in pristine areas. In Plots 1, 2, and 3, farmers practice the monocropping farming of maize and beans. Monocropping depletes specific elements depending on the planted crop, which can also impact the elemental concentrations as the remains of the plants are not decomposed in the plot but are used by farmers as animal feeds, hence reducing OM. These deplete the soil of nutrients and OM, and the latter may make the soil more susceptible to erosion, as it becomes less stable and less able to retain moisture. In addition, the inability to rotate crops brought about by the dwindling of the land resource leads to degradation of the soil structure, loss of elements downstream, and loss of nutritional elements through increased infiltration capacity (Karlen et al., 2006; Man et al., 2021).

CONCLUSION

Land management and soil characteristics impact the uptake of macronutrients by plants, especially forage grass. Results from the study indicate that land management affects soil chemistry, hence changing plants' absorption regimes for macronutrients. Different land management methods can affect the rate of soil erosion and leaching, directly correlating with the rate of macronutrient loss. The steepness of the plot slopes increased the likelihood of macronutrient loss through erosion and surface runoff hence the need for mitigation as indicated by the difference in the soil concentrations of Fe and P compared to Plot 1 (no mitigation) and Plot 2 (mitigated soils). Plot 2 is one of the plots with soil erosion mitigation measures. However, the plot is highly affected by nutrient loss, for example, by P and Cr concentration drift. This is because of poor construction of the terraces by manually moving soil to the terrace barriers.

Soil characteristics such as pH, OM content, texture, and nutrient status significantly impact plant elemental uptake. Elements have optimum pH ranges that change their status to the available forms for plant uptake; from the study, change in pH has affected the even distribution of elements in forage grass across all four plots. Soil pH affects the solubility and availability of nutrients in the soil. For example, at low pH values, elements such as Cr can become more soluble and toxic to plants. In contrast, elements such as Fe and P can become less available for plant uptake at high pH values. Organic matter improves soil structure, increases water-holding capacity, and enhances nutrient retention and release. Therefore, sustainable land management practices (prevent and mitigate land degradation and restore degraded soils; control soil erosion; improve soil-water storage; manage soil organic matter for soil carbon sequestration; and manage and enhance soil fertility) training to the farmers at Oroba Valley will contribute to achieving the United Nations strategic development goal number two and three (SDG 2: improve nutrition, sustainable agriculture, and curb hunger; SDG 3: good health & well-being of all ages).

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