Soil Fertility Improvement Practices and Round Potato Production among Smallholder Farmers in Two Gradients in Southern Highlands, Tanzania

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Abstract

The current study aimed to describe soil fertility improvement practices and to evaluate round potato production among smallholder farmers in lower and upper gradients in southern highlands, Tanzania. Household surveys, focus group discussions, and key informant interviews were used to collect data on farmers' perception of soil fertility, farmers' management practices for improved soil fertility and round potato production. Farmers perceived soil fertility as moderate and employed relay cropping, agroforestry, and fertiliser use simultaneously as soil fertility improvement practices. However, industrial fertilisers were perceived as environmentally unfriendly and harmed/burnt crops, likely due to over-application. Overall, potato farm size (1.9 acres) and yields (12 t/acres) were higher in the lower than in the upper gradient. However, there were differences in cultivation cycles, two per annum in the upper gradient compared to one in the lower. The variations in potato farm size and yields between gradients were due to the variation in terrain and temperature. Consequently, farmers in the upper gradient increased cultivation frequency as a compensation strategy. It was concluded that farmers employed various practices simultaneously to improve soil fertility, and potato farm management differed between the two gradients due to the existing climatic conditions. Furthermore, farmers were over-applying fertilisers in the field; hence the need for training on appropriate fertiliser uses for sustainable land and farm management.

Keywords: Farmers' perception; Fertiliser uses; Lower gradient; Soil fertility; Uporoto highlands

Introduction

Round potato (*Solanum tuberosum* L.) is among the essential tuber crops rich in different nutrients and forms a daily diet of about one billion people worldwide (Chilipa *et al.,* 2021; Chindi *et al.,* 2021; Devaux *et al.,* 2021). Globally, the potato was estimated to be cultivated in 16.4 million hectares (ha) of land with an annual yield of 359 million tonnes (t) and a trade valued at 51.7 billion USD as of 2020 (FAO, 2022). Moreover, potato demand and consumption are growing worldwide due to the rapid increase in human population, economic growth and changes in eating habits (Chilipa *et al.,* 2021; Devaux *et al.,* 2021). Potato farming is crucial in food security and poverty alleviation, especially among smallholder farmers who produce 90% of all potatoes in developing countries (Devaux *et al.,* 2021; Kyomugisha *et al.,* 2018; Wubet *et al.,* 2022). In Sub-Saharan Africa (SSA), with Tanzania included, potatoes are cultivated on highlands with altitudes ranging from 1500 m to 3500 m above sea level (a.s.l.), temperature of 7-21°C and rainfall of at least 1000 mm per annum (Muthoni and Kabira 2015; Minda *et al.* 2018b, 2019).

Due to increased cultivated areas, potato production and yield have been experiencing an upward trend in Tanzania, especially in the southern highlands (Devaux *et al.,* 2021).

Nevertheless, potato is a nutrient-demanding crop; Mugo *et al.* (2020) reported that it grows well on soil with an average of 2.5 g/kg Nitrogen (N), 30 mg/kg Phosphorus (P) and 0.2 Cmol/kg Potassium (K) in African highlands. Xu *et al.* (2019) estimated it takes about 4 kg N, 0.7 kg P, and 3.5 kg K for the whole potato plant to produce 1mg of potato tuber. Therefore, it is imperative to replenish soil nutrients after potato harvesting to ensure optimum and sustainable production in the subsequent seasons. However, most smallholder farmers in SSA do not have resources. Since they cannot access industrial fertilisers due to high prices and limited availability, which leads to a low yield of 8.3 t/ha in Tanzania compared to 30 t/ha in large-scale commercial farms (Devaux *et al.,* 2021; Muthoni and Kabira, 2015; Svubure *et al.,* 2015).

Therefore, the Tanzania government has provided industrial fertiliser subsidies to smallholder farmers and promoted organic fertiliser use and other soil fertility improvement practices. These soil improvement practices include relay or rotational cropping, agroforestry and compost uses. The aim is to maintain soil fertility and potato production performance to enhance farmers' food security and support their livelihoods (Cedrez *et al.,* 2020; Holden, 2018). It should be noted that highlands where potatoes are cultivated receives heavy rainfall, which could cause soil erosion and nutrient leaching if there is a lack of proper soil management practices (Hailu *et al.,* 2015; Mugo *et al.,* 2020). There have been extensive studies on soil fertility management and round potato production practices in African highlands to warrant different recommendations and policies (Muthoni and Kabira 2015; Svubure *et al.* 2015; Okello *et al.* 2017; Kyomugisha *et al.* 2018; Mugo *et al.* 2020).

However, there are limited studies (Minda *et al.,* 2019, 2018a, 2018b) in African highlands and none in Tanzania on the effects of slope gradients on soil management and round potato production to improve soil fertility. Consequently, it is vital to investigate the effect of gradient on potato production practices since gradient affects rainfall and temperature, which could prolong the cultivation period and cause soil erosion due to surface runoff (Minda *et al.,* 2019, 2018b). Therefore, this study evaluated the effect of lower and upper gradients on round potato production among smallholder farmers in southern highlands, Tanzania. Also, the study aims to describe the existing soil fertility management practices among smallholder potato farmers in the two gradients. Findings from the current study can be used to provide recommendations for sustainable land management in lower and upper gradients to improve soil fertility and increase potato yield.

Methodology

Study area description

The study was conducted in the Uporoto highlands, part of the Rungwe district (8°30`-9°30`S and 33°-34°E) in southern highlands, Tanzania. The district is divided into three agro-ecological zones (highlands, midlands and lowlands) having an altitude of 1900-2700 m a.s.l., receives 2500 - 3500 mm rainfall from October to May and has a temperature ranging from 5-18°C (Sokoni 2014, Gwambene and Liwenga 2016, National Bureau of Statistics, NBS and Rungwe District Council, RDC 2017). The area has well-drained and volcanic soil (pumice), its topography is mountainous and vegetation dominated by temperate grassland. The climatic condition and soil characteristics gave the highland 8-9 months of crop cultivation (NBS and RDC, 2017). Agriculture is the significant economic activity in the area, and round potato is the most important crop in terms of area cultivated, its economic return and yields of up to 503,622 t as of 2019 (Pers. comm.). Uporoto highlands were selected for this study because of their long history and importance in round potato production in the district. In addition, unsustainable land management practices, heavy rainfall and runoff could make the highland susceptible to soil erosion and risk decline in round potato production. Therefore, the area was used as the case study to provide information on the effects of gradients on land management and possible outcomes in terms of round potato yield, cultivation and soil fertility in African highlands.

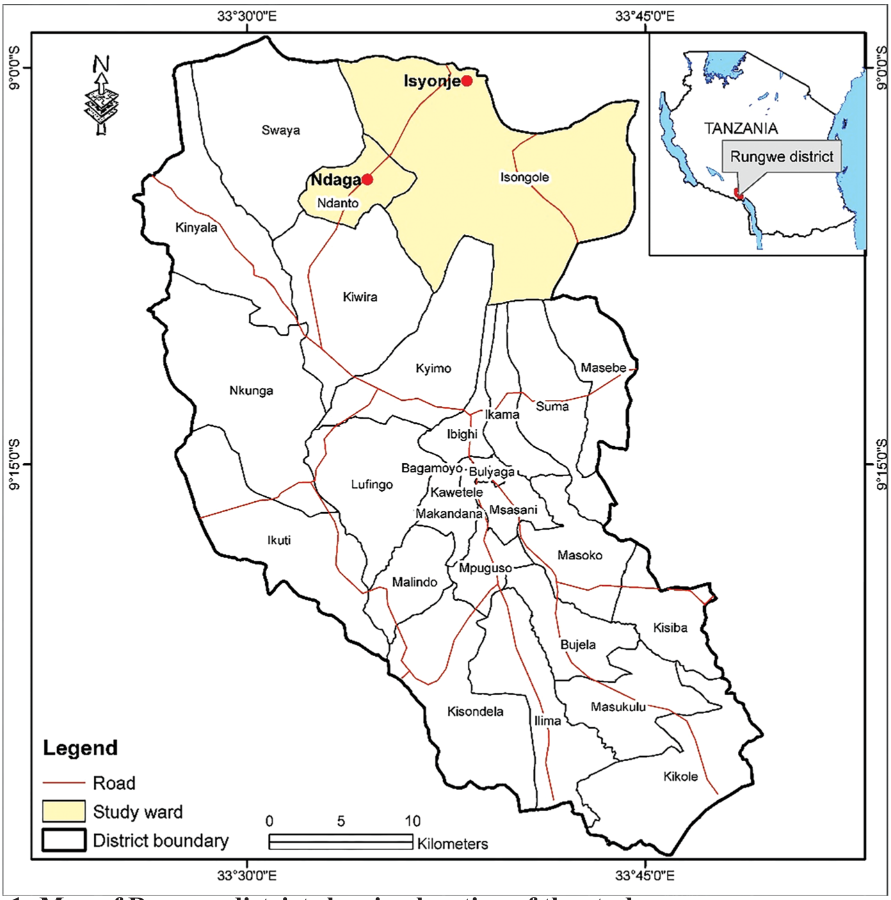


Figure 1: Map of Rungwe district showing location of the study area

Study design and data collection

Data was collected in two villages, namely Ndaga (1930 m a.s.l., representing the lower gradient) and Isyonje (2272 m a.s.l., representing the upper gradient) in Uporoto highlands (Fig. 1). The two villages were selected because of their easy accessibility and variations in land management practices, which impact soil fertility differently. A household survey (HHS), focus group discussion (FGD), and key informants' interview (KII) were used to collect primary data during the study. Random sampling was used to select respondents for HHS, whereby 136 households (86 in lower gradient and 50 in upper gradient) out of 1336 were interviewed using a structured pre-tested questionnaire. The sample size was calculated as 10% of the population due to the homogeneity of the farming practices in the respective gradient. The selected respondents (41% female and 59% male) were interviewed on the issues related to round potato production, land management practices and soil fertility using local Swahili language. Only respondents who gave verbal consent were included in the study, and in most cases, the head of the household was interviewed. However, if the head was absent, another household member, i.e., a partner or child (>18 years old) with enough information related to farm management, was interviewed.

One FGD was conducted in each selected location, which included a mixture of different genders and age groups. Each FGD comprised 9-12 participants (men, women, and youth) involved in round potato production. The researchers identified the FGD participants during a household survey and were later invited to the respective gradient's discussion. The selection criteria for the FGD participants were long-term residence in the area, age and gender to avoid over-representation of one social group. Following a checklist, the FGDs were conducted in Swahili to collect information on potato production and land management practices in the respective gradients. The ward executive officer, agricultural extension officer, village council members, agro-input dealers, round potatoes brokers, famous potato producers and influential elders were interviewed as the KIs. The KIs were asked questions on round potato production and the prospect of land management practices used to improve soil fertility in the study area.

Data Analysis

Household survey data were coded and categorised into lower and upper gradients representing Ndaga and Isyonje villages. Statistical Package for Social Sciences (SPSS) version 20 was used to analyse households' information on socioeconomic, potato production, land management practices, and fertiliser uses. Results were presented as descriptive statistics using percentages or mean reported on text, table or figure. In the case of multiple responses, a percentage of cases were reported with the sum exceeding 100%. Pearson chi-square and independent-sample t-test were used for percentage and mean comparisons between the two gradients, and the difference was declared significant at $p < 0.05$. Content analysis was used to analyse FGDs and KIIs data, whereby collected information was outlined and organised thematically to supplement and explain observed trends from analysed household data.

Results

Socioeconomic aspects

Most respondents had received formal education (92%), and 67% of the interviewed respondents were married. There were no statistical differences ($p>0.05$) in household size or structure between the lower and upper gradients (Table 1). However, many respondents in the lower gradient (55.8%) compared to the upper gradient (29.1%) owned land privately. This variation in land tenure was statistically significant ($p < 0.05$); other land tenure systems in the gradients are shown in Table 1 below. The FGDs' participants mentioned agriculture as the main economic activity in with round potato, maize and beans as the main crops in the area. According to KIs, the round potato was the primary source of livelihood and contributed about 90% of households' income. Also, some households engaged in business, livestock keeping and timber production in the highlands.

Table 1: Demographic characteristics and land tenure among interviewed households (n=136) in Uporoto highlands.

	Lower gradient	Upper gradient
Household structure and size (mean number of people)		
Age group (years)		
0 – 17	2.2	2.0
18 – 35	2.0	1.8
36 – 60	1.7	1.7
≥61	2.4	1.4
Total	4.7	4.3
Land tenure (% of respondents)		
Private/individual	55.8a	29.1b
Family	21.2	25.5
Leased	17.3	23.6
Inheritance	3.8	20.0
Caretaker	1.9	1.8

The values in the rows with different letters were statistically different

Round potato production

There were statistical differences in the size of land ($p=0.029$) used to cultivate potatoes per household between two gradients, whereby it was higher in the lower gradient (1.9 acres) compared to the upper gradient (1.5 acres). Respondents in the lower gradient cultivated potatoes on average once yearly, while those in the upper gradient did it twice. Cultivation frequency per year between the gradients was statistically significant ($p<0.001$). The FGD participants mentioned cultivating local and improved potato varieties. Local varieties included Ndelenga, Loti, Alika, Kagiri, Malawi, Sasamuka, and Kasumuni. The KIs added that these local varieties were cultivated by fewer farmers and mainly used for subsistence. The local varieties took longer to mature and were not preferred by customers since they had irregular shapes, making them difficult to peel using machines. Additionally, FGDs' participants mentioned cultivating Obama, Tigo, Kidinya, and CAP (Diacol Capiro) as the alternative varieties. Farmers claimed these improved varieties took a relatively short time to mature, had a longer shelf life, were highly preferred by consumers and produced high yields. Interviewed respondents mentioned overall potato yields of 88 - 120 bags (8.8 – 12 t/acre) in the lower gradient and 58-79 bags (5.8 - 7.9 t/acre) in upper gradients, whilst 1 bag ≈ 100 kg. The reported potato yield differed significantly ($p<0.05$) between the two gradients. The FGD participants and interviewed KIs claimed that most potatoes were sold at the farm gate with prices ranging from 30,000 - 35,000/= Tshs (13 - 15 USD) per bag weighing 100 kg. The sold potatoes were transported to urban centres within the country and neighbouring countries, namely Zambia and Congo (DRC).

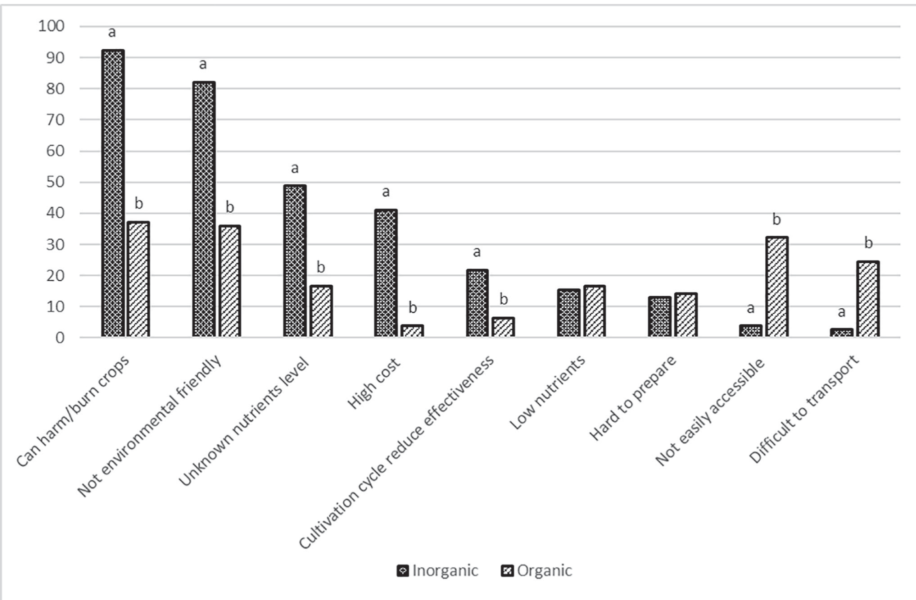
Soil fertility management practices

Many respondents perceived soil fertility to be moderate in their farmlands (75% in the lower and 77% in the upper), and the KIs

Table 2: Farmer (n=136) perceptions regarding soil fertility and their soil improvement practices in Uporoto highlands

Soil fertility perception (% of respondents)		
Fertility status	Lower gradient (n = 86)	Upper gradient (n = 50)
Very fertile	17.1	17.0
Moderate fertile	75.0	76.6
Not fertile	7.9	6.4
Soil improvement practices (% of respondents)		
Incorporation of crop residues	82.7	90.7
Application of inorganic fertiliser	62.7	67.4
Crop rotation	29.3a	4.7b
Relay cropping	22.7a	55.8b
Agroforestry	9.3a	39.5b
Application of manure	9.3a	27.9b

The rows with different letters were statistically different.



The adjacent bars with different letters were statistically different

Figure 2: Challenges faced by respondents (n = 136) using inorganic or organic fertilisers to improve soil fertility

and FDGs used potato yields as the primary indicator of soil fertility losses. The KIs and FGDs' participants thought soil fertility had been decreasing in the study area due to continuous cultivation, excessive use of industrial fertiliser and potato being the nutrients demanding crop. Respondents employed various practices to improve soil fertility, such as leaving crop residues in the fields (83% in lower and 91% upper gradients) and incorporating them into the soil during the following cultivation season. There were more farmers ($p<0.05$) engaged in relay cropping, agroforestry, and manure use in the upper than lower gradient (Table 2). In addition, it was reported by the KIs that farmers were using a combination of different soil improvement practices simultaneously.

Respondents had different ($p<0.05$) perceptions and faced various challenges when using inorganic (industrial) or organic (manure) fertilisers. Farmers thought the major limitations of using organic and inorganic fertilisers were that they could harm/burn their crops (92% for inorganic and 37% for organic) and were not environmentally friendly (82% for inorganic and 36% organic). Other limitations and farmers' perceptions regarding fertiliser use are shown in Figure 2 below.

Discussion

Round potato production in gradients

Round potato production contributed to about 90% of households' income in Uporoto highlands, indicating potato production's central role in poverty alleviation through generated income, food security and well-being among rural households in African highlands. Farmers seemed to be aware of consumer preferences and were shifting from local to improved varieties to adapt and respond to changes in market preferences. The shift could be useful in enhancing productivity and justifying high fertiliser uses due to potential economic returns, as reported by Mpogole (2013) and Kolech *et al.* (2015). Farmers' selection of improved potato varieties, such as Obama, is also driven by its resilience to potato late blight diseases compared to other varieties (Harahagazwe *et al.,* 2016; Kolech *et al.,* 2015). Reported potato yield in the current study was within 3.5 - 13.5 t/acre reported by Chindi *et al.* (2021) and Okello *et al.* (2017) in Ethiopian and Kenyan highlands, respectively. The high yields showed the suitability of improved potato varieties in African highlands.

However, potato yield was higher in the lower (8.8 – 12 t/acre) compared to the upper gradient (5.8 - 7.9 t/acre) per cultivation. The observed yield variations between the two gradients were similar to Minda *et al.* (2018) and (2019), who reported a decline in potato yield and an extended cultivation period as altitude increased. Potato yield variation between gradients could be attributed to low temperature and daylight length since the upper gradient is on the peak of the Uporoto highlands. It was also observed that farmers in the upper gradient were cultivating potatoes twice compared to once for the lower despite the expected longer growth period in higher altitudes. High cultivation frequency could have been the farmers' compensation strategy due to lower yields and long rainfall periods (8 - 9 months) in the studied area, which supported more than one cultivation cycle. Furthermore, upper gradient farmers had smaller land plots (1.5 acres) allocated for potato production, and this is due to poor terrain, i.e. mountainous. The limitation could also have forced farmers to increase cultivation frequency per unit of land to support their livelihoods. Farmers' incorporation of local knowledge and an increase in cultivation frequency were also reported by Kolech *et al.* (2015) in Ethiopia. These managerial practices showed farmers' entrepreneurial skills and ability to adopt new solutions to increase their annual yield and capture the existing market.

The potato price per bag reported in the current study (30,000 - 35,000/= TSh ≈ 13 - 15 USD) was higher than 17,000 - 22,000/= reported by Nyunza and Mwakaje (2012) in Tanzania but lower than 73.5 - 103.8 USD reported by Kyomugisha et al. (2018) in Uganda. Tanzanian price variation is due to currency depreciation because 10 years had passed between the two studies. The price increase could also be due to increased potato demand and the location of Uporoto Highlands, which is closer to Zambia, where potatoes are exported. Extremely high potato prices in Uganda compared to Tanzania could be attributed to value addition among Ugandan farmers (Kyomugisha *et al.,* 2018). Other reasons are local currency depreciation against the USD, as the current study was conducted during the COVID-19 pandemic when global trade was interrupted.

Nonetheless, selling potatoes at farm gates could be oppressive to farmers and expose them to low prices depending on farm accessibility and negotiation skills (Mpogole *et al.,* 2012; Nyunza and Mwakaje, 2012). The lower potato prices could reduce farmers' profit margins and make them switch to other more profitable economic activities, e.g. timber plantations, to generate income (Arvola *et al.,* 2019; Mhando *et al.,* 2022). Although the switch could sustain farmers' livelihoods, this will threaten national and community food security. Therefore, there is a need to improve farmers' access to formal markets and increase their bargaining power through cooperatives to ensure they fetch premium prices with a reasonable return for cultivated potatoes that could encourage intensive agricultural input uses.

Land tenure, management and soil fertility

Private land ownership (Table 1) was higher among lower gradient respondents (55.8%) compared to those in the upper gradient (29.1%), probably due to mountainous terrain in the upper gradient, which limited land availability. The variations are also due to more respondents in the upper gradient (20%) managing inherited land than in the lower gradient (4%). The land tenure system influences land management practices, which affects soil fertility (Akram *et al.,* 2019; Shittu *et al.,* 2018). The interviewed KIs and FDGs associated soil fertility with potato yield; this is well-founded since soil fertility is defined as the ability of soil to support a plant's optimum growth and yield (Ding *et al.,* 2016). Interviewed households described their soil fertility as moderate, which was pessimistic since there were no reports or signs of erosion as seen elsewhere in African highlands (Hailu *et al.,* 2015). Also, soil supported potato growth and its yield was well within values reported elsewhere (Chindi *et al.,* 2021; Okello *et al.,* 2017), as was discussed above. Perhaps their response was due to the intensive application of fertiliser that is explained by continuous cultivation and potato being nutrients demanding crop; this was also mentioned in FGDs and has been widely reported worldwide (Devaux *et al.,* 2021; Mugo *et al.,* 2020). Understanding this perception regarding soil fertility is crucial, especially when using farmers to indirectly assess soil conditions or plan interventions to improve soil fertility in African highlands. In addition, future studies should investigate the effect of gradients on soil fertility using a more objective approach, i.e. laboratory analysis and provide appropriate soil management strategies.

Farmers were engaged in various practices to improve or maintain soil fertility with most respondents incorporating crop residues into the soil (Table 2); this is an easy and cheap way to recycle nutrients back into the soil (Chen *et al.,* 2021; Yuan *et al.,* 2011). Farmers left the residues briefly (~3 weeks) and tilled them immediately before the subsequent growing season. The practice increases the decomposition rate since the highlands receive heavy rainfall and not sufficient sunlight to facilitate surface decomposition (Araujo *et al.,* 2022; Sarkar *et al.,* 2020). The practice also improves soil moisture retention and reduces surface runoff (Du *et al.,* 2022). High relay cultivation in the upper gradient and high crop rotation in the lower is due to differences in land size and growth period, as was discussed above. Relay cropping and crop rotation using maize as was the case in the current study, is ineffective in restoring soil fertility since maize is also a nutrient-demanding crop (Setiyono *et al.,* 2010). It is unlikely that farmers were unaware of this and probably motivated by profit; hence, the use of crop residues and fertilisers simultaneously could have aimed at over-fertilisation to support potato and maize production. There is a need to further investigate soil nutrients profile and assess these practices effectiveness on soil nutrient availability and leaching.

Otherwise, higher manure uses (Figure 2) in the upper gradient could have been due to its low cost and smaller size of cultivated land (1.5 acres), which means a smaller amount of manure was needed, as was also argued by Muluneh *et al.* (2022). Surprisingly, most farmers (Fig. 2) mentioned that inorganic fertiliser can harm their crops, which could only be due to over-application of the fertiliser, which leads to yellow/brown leaves, hence the perception of the burnt plant (Rahman and Zhang, 2018; Savci, 2012). The practice is expensive due to fertiliser losses and causes leaching of nutrients, which can end up in water bodies, causing algae blooming (Gutiérrez *et al.,* 2015); hence, the notion of inorganic fertiliser was environmentally unfriendly. There is a need to improve agricultural extension services and disseminate information regarding standard fertilisers' application per site's soil condition and crop cultivated to ensure sustainable management of available resources. Inaccessibility and difficulty in transporting were among the factors limiting the use of manure; this could be explained by poor topography, especially in upper gradients where it was mainly used and not all farmers in the studied area kept cattle. It seems farmers were aware of different soil improvement practices and their choices of these measures were motivated by accessibility and cultivated land size.

Conclusions

Respondents perceived soil fertility as moderate in the studied area due to the obtained yields. Nonetheless, many farmers in upper than lower gradient practised relay cropping, agroforestry, and manure use as soil fertility improvement practices because of existing differences in cultivated land size and growth period. Furthermore, farmers in the two gradients claimed both inorganic and organic fertilisers to be harmful to their crops and environmentally unfriendly. The perception was likely due to fertiliser over-application; hence, farmers should be provided with knowledge on appropriate fertiliser uses for sustainable land and farm management. Otherwise, all farmers were cultivating improved potato varieties; however, farm yields were lower in the upper than in the lower gradient due to the variations in weather conditions. However, respondents in the upper gradient had higher cultivation frequency as a compensation strategy to lower yields. Generally, farmers were practising different practices to improve soil fertility simultaneously, and farm management differed between two gradients due to variations in climatic conditions.

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Conflict of Interest

The authors declare no conflict of interest.

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