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Soil and Nutrient Losses under Cultivated Bush and Climbing Beans on Terraced Humid Highland Slopes of Southwestern Uganda

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Authors' contributions

This work was carried out in collaboration with all authors. Author GG initiated the research and conducted it. Authors JAO, MMT and JGM designed the study and supervised the research. Authors GG and AZ managed the literature searches and reviewed the manuscript drafts and participated in the data collection. Author CLK analysed the soil properties in relation to the field and statistical analyses. Author RB provided part of the technical input in the overall research project. All authors read and approved the final manuscript.

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ABSTRACT

Highland regions characterized with terraced slopes in East Africa are faced with serious soil and nutrient losses that have affected agricultural productivity. However, limited studies have analysed the soil and nutrient losses on terraced slopes of these humid highland regions. Therefore, this study was conducted to assess the effects of climbing beans over the traditional bush beans' cultivation on soil erosion control in Bufundi sub catchment, Kabale District, South-western Uganda. Runoff trap approach was employed to assess erosion and the sites were characterized

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for soil physico-chemical properties. Terraced slopes planted with climbing beans showed significantly lower ($P<0.05$) annual runoff and soil loss of 36 m^3 $ha^{-1}yr^{-1}$ and 121 kg ha^{-1} yr^{-1} over bush beans, 248 m^3 $ha^{-1}yr^{-1}$ and 548 kg $ha^{-1}yr^{-}1$, respectively. Annual soil nitrogen, phosphorus and potassium losses were significantly higher from bush beans (1.87 kg N ha^{-1} yr^{-1}; 0.6 kg P ha^{-1} yr^{-1} and 0.12 kg K ha^{-1} yr^{-1}) over climbing beans (0.49 kg N ha^{-1} yr^{-1}; 0.1 kg P ha^{-1} yr^{-1}; and 0.03 kg K ha^{-1} yr^{-1}). The total economic value of bush beans due to erosion was higher (75424 Ug shillings/ha) than that of climbing beans (15597 Ug shillings/ha). Generally, runoff, soil and nutrient losses were very low from both bean types. However, climbing beans were superior to bush beans in controlling runoff, soil and nutrient losses confirming their effectiveness in controlling erosion down the catchment.

Keywords: Economic value; erosion; macronutrients; hydraulic conductivity; soil texture.

1. INTRODUCTION

Sustaining agricultural productivity and livelihoods in the tropical humid highland ecosystems is increasingly becoming an enormous challenge [1,2,3]. The fragility of the slopes coupled with the increasing population and limited livelihood opportunities has led to increased soil erosion [4,5,6,7]. A compendium of literature reveals high soil erosion in the highlands [7,8,9,10,11,12,13] emphasizing soil and nutrient losses as a key land degradation challenge in most of the humid high land ecosystems of East Africa; that has resulted in negative effects on soil fertility. Soil and nutrient losses have been estimated to affect 50% of the total arable land productivity area in the East African humid highlands [14].

In the Ugandan perspective, soil and nutrient losses have been reported to be the most severe and extensive form of land degradation in the hilly and mountainous farming systems leading to loss of nutrients, and contributing to the declining agricultural productivity [15,16,17,18]. According to [19], Uganda's highland regions experience soil loss of more than 30 tha^{-1} on an annual basis. Soil and nutrient losses impose a series of onsite and offsite environmental effects, which include eutrophication and excess turbidity to the drainage network and reservoirs [20]. These impacts increase the maintenance costs for terraces and drainage channels/streams and filling of ephemeral gullies as well as the cost of replacing the lost nutrients mainly nitrogen (N) and phosphorus (P) [21].

According to [12], efforts on soil and nutrient loss control in the humid highlands started back during the British colonial period, when terraces and other conservation measures were force fully introduced in East Africa including SW Uganda. Despite these conservation measures, challenges of soil and nutrient losses have persisted ostensibly due to poor farming practices, expensive technologies, high population growth, etc. Therefore, a search for supporting technologies has been on-going, together with research on innovative methods that can enhance food productivity and environmental management [7,10,13,22,23]. One such venture is the Sub Saharan Africa challenge program with the concept of Integrated Agricultural Research for Development (IAR4D) developed and implemented by Forum for Agriculture Research in Africa (FARA) [24] which has a main focus to improve farmers' productivity without compromising the environment [25]. The IAR4D innovation platform has spearheaded bean studies in the Lake Kivu humid highlands in south-western (SW) Uganda. Planting of climbing beans in pure stands was introduced within the south-west highlands and on the slopes of Mountain Elgon so as to increase productivity [26]. Although the land under bean cultivation constitutes 20% of the total land area in Uganda, still there is a lack of information on the effectiveness of climbing beans in controlling the soil and nutrient losses in comparison with the traditional bush beans.

Despite the fact that bean studies have been conducted in the East African humid highlands with the example of SW Uganda, these studies have largely centered on improving yields, improving resistance to drought, pests and diseases, low soil fertility, less cooking time varieties and improving nutritional value [27,28, 29,30]. There has been limited attention on the contribution of these different bean types in controlling soil erosion and studies that have explored erosion in the cropping systems have largely remained broad on annual crops [31,32,33].

Therefore, the main objective of the study was to assess soil and nutrient loss variability on the terraced slopes cropped with climbing and bush beans within the Sub Saharan Africa challenge program innovation platforms (IPs) in SW Uganda. The study was mainly comparative between these two bean types and limited to erosion assessment and its economic implications. This study did not consider crop yields, pests and diseases since these aspects have already been described by several authors in the field of bean production programs [27,29, 34,35,36].

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The study was undertaken in a humid highland region of Bufundi sub catchment located in Kabale district, south-western Uganda, between latitudes 1º and 1º 34''S and longitudes 29º 18''E and 30º 9''E (Fig. 1). The Bufundi highlands are part of the East African pre-Holocene volcanics bordering Lake Bunyonyi [37]. The terrain is

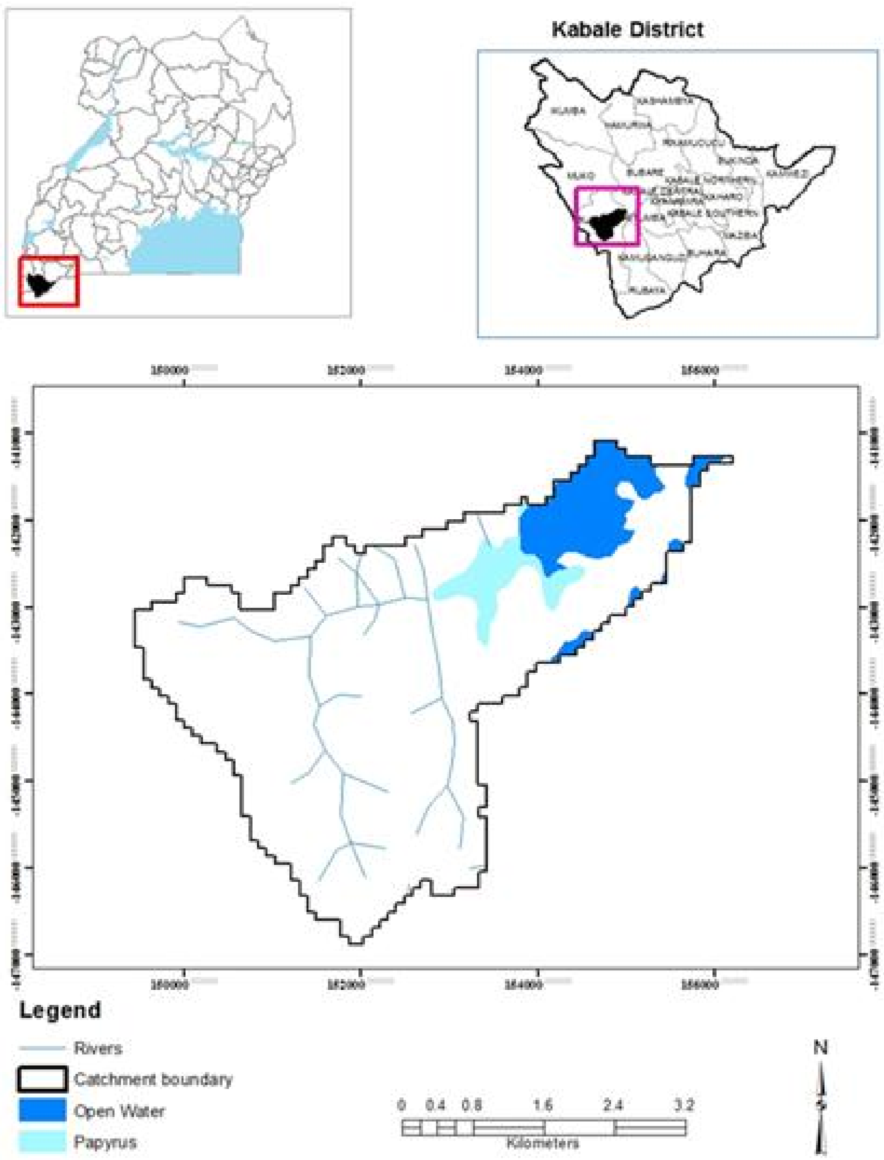

Fig. 1. Map of Bufundi sub catchment

dominated by hills coupled with degrading terraces and valleys with most slopes ranging between 12 to 50% but may go as high as 80% [38]. The soils in Bufundi are typically Luvisols, Histosols and Ferrasols (Fig. 2) with declining fertility due to continuous cultivation and susceptible to extreme soil erosion [38]. Histosols are very rich in organic matter (>14%) with incompletely decomposed plant residues, with or without clay, sand and silt [39]. In these organic layers, the infiltration increases, hence less susceptible to soil erosion [40]. Luvisols have strong accumulation of clay in the B-horizon with high cation exchange capacity and moderate weathering and Luvisols with high silt content are susceptible to structure deterioration if tilled in wet conditions and on steep slopes, they are easily eroded [39,41]. Ferrasols are highly weathered soils rich in sesquioxide clays and with low cation exchange capacities [39]. Ferrasols have distinctive soil structure with a weak micro-aggregates, but strong macro-aggregates hence this structure makes Ferrasols fairly porous and less susceptible to erosion than other soils in the tropics [42]. The catchment has a bimodal rainfall with average annual rainfall between 900 mm to 2200 mm with a mean annual temperature of 16.7ºC [43]. The major land uses in the sub-catchment include small scale farmland and woodlots (*Eucalyptus*).

2.2 Runoff, Soil and Nutrient Losses Determination

In order to determine runoff, soil and nutrient losses, data collection was conducted during the long rain season (February- July, 2012) and short rain season (September - December, 2012). Three sites with slope elevation ranging between 23% and 29% at the mid-slope of the hill at least 800 m apart were identified for the study. The soil classification at these sites was Acric Ferrasols. Within each site, six erosion plots were constructed within the terraces with each plot measuring 2 m by 9 m to measure runoff using a pipe sampler [45]. Erosion plots were sealed off using several iron sheets measuring 3 m long and 0.3 m high. From the six erosion plots installed in each site, two treatments (bush beans and climbing beans) were planted at a spacing of 50 cm * 25 cm and 50 cm * 20 cm, respectively in each three erosion plots. Farmers managed the plots like any other field in order to represent the management across the catchment A small container was tied at the end of the erosion trap to capture 4% of the total runoff through the slit. However, each plot was calibrated with a known volume of water to. establish its runoff transmission coefficient which was later used to determine the actual

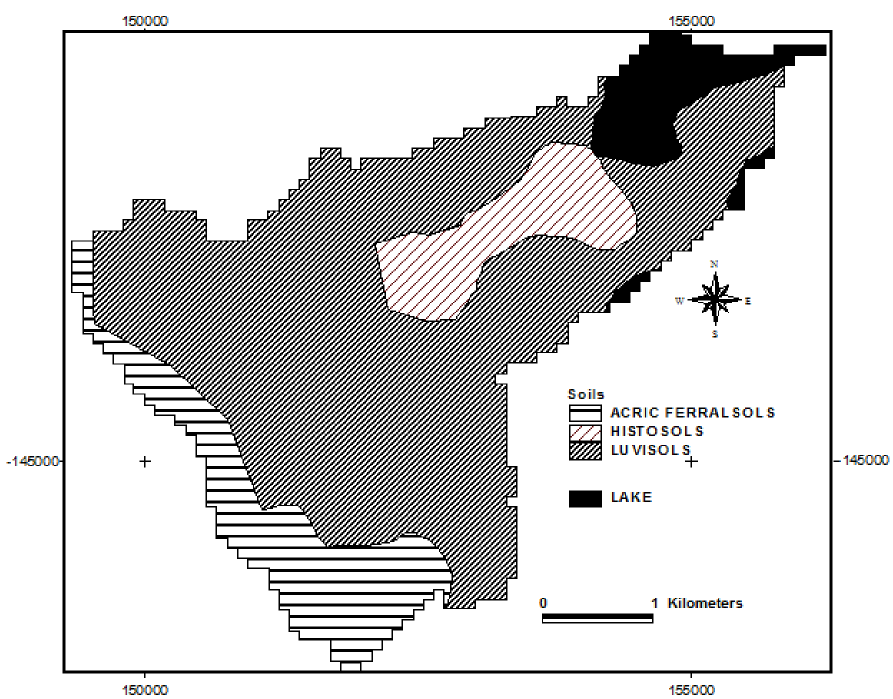

Fig. 2. The major soil type of Bufundi sub catchment. Source: [44]

total plot runoff [46]. Total runoff (water and sediments) collected in the container and measured using a measuring cylinder following a rainfall event. Total runoff was then put in clean plastic bottles and periodically delivered to the Department of Soil Science laboratory at Makerere University for subsequent analyses. Event runoff was multiplied by the coefficient of transmission to get the plot runoff per rainstorm event, and then extrapolated to a hectare basis, by multiplying the obtained value with 555.6. Seasonal runoff loss was obtained by summing up the different runoffs registered for different rainfall events and the two seasonal runoff collections were eventually summed up to obtain the annual loss per ha.

In the laboratory, each runoff sample was homogenized and divided into two portions. The first portion was filtered using filter paper and the filtrate was oven dried at 105ºC for 24 hours for sediment determination. The amount of soil loss in the plot was obtained by multiplying the sediment concentration by runoff and transmission coefficient and then expressed on ha basis. Seasonal soil loss was obtained by summing up all the seasonal collections and then annual soil loss obtained by summing up the two seasonal soil losses. The remaining portion of the runoff sample was also filtered for first portion and the filtrate air dried and analyzed for macro nutrients: N, P and potassium (K) using the procedures from [47]. Seasonal nutrient losses were determined by summing up all the seasonal collections and then annual nutrient loss obtained by summing up the two seasonal nutrient losses.

2.3 Soil Physical and Chemical Characterization

In order to characterize soil physical and chemical properties of the study sites, soil samples were taken within each erosion plot to determine saturated hydraulic conductivity using constant head method and bulk density using core oven drying method [48] at the end of each bean growing season. Two soil samples were collected using soil core measuring 5 cm long by 5cm internal diameter in each soil depths of 0-15 cm and 15 -30 cm. Two composite soil samples from each soil depth at each site and treatment were taken at planting and at harvesting to assess the characteristics of soil chemical properties under the two different bean types in the study area. Soil organic carbon (SOC), total N, available P and exchangeable bases: K, sodium (Na), calcium and magnesium (Mg) were analyzed using [47].

2.4 Rainfall Measurement

In order to measure the amount of rainfall received at each study site, a manual recording rain gauge was installed. The amount of rainfall events was summed and a number of rainy days were manually recorded. Annual rainfall was determined by summing up the two seasonal rainfalls.

2.5 Data Analysis

Data were entered into Microsoft Excel and imported into Genstat Discovery Version 13 for statistical analysis. One and two way analysis of Variance (ANOVA) were performed in order to ascertain whether there are differences in the means of runoff, soil and nutrient losses between the two bean types and the experimental sites.

3. RESULTS OF THE STUDY

3.1 Rainfall Characteristics within the Study Area

Mean monthly rainfall ranged from 0.5 mm to 591.8 mm and monthly rainy days ranged from 1 to 11 days. The highest mean monthly rainfall was observed in the long rainy season (February to July) coupled with the highest number of rainy days (Fig. 3). The rainfall and rainy day trends are similar to those reported by [49] in the southwestern region.

3.2 Soil Physic-chemical Characteristics

Soils cropped with beans were mainly clay loam, except the top soil for bush beans which was sandy clay loam. However, the clay and sand contents varied significantly ($P<0.05$) among sites (Table 2).

Soil bulk densities and saturated hydraulic conductivity at the top soil and sub soil were moderately low and varied significantly ($P<0.05$) among sites, bean types and sites (Table 2). Climbing bean registered higher saturated hydraulic conductivity than bush beans for all the experimental sites and depths and there was more water movement at a depth of 0-15 cm due to the high soil organic matter content (Table 2).

The soils in the study area had sufficient nutrients required for normal bean growth (Table

1) though with slight variations between the bean types and depth. For example, soil organic matter ranged between 2.84% and 3.80% with the highest observed in climbing beans at the top soil (0-15 cm) while the least in bush beans at the sub soil (15-30 cm) (Table 1). Soil organic matter was significantly different ($P<0.05$) between depths, bean types and sites (Table 2). The highest soil organic matter content was registered in climbing beans plots at a depth of 0-15 cm (Table 2).

Nitrogen and available P did not vary significantly with either bean types or soil depths, except among sites where N and P were significantly different ($P<0.01$) (Table 3). However, mean available P was higher in climbing beans and at a depth of 0-15 cm (Table 1).

Exchangeable K was also significantly higher ($P<0.05$) in climbing beans than bush beans (Table 1). When compared among the experimental sites, exchangeable K, Ca and Mg varied significantly ($P<0.05$) between depths, bean types and sites (Table 2). Generally, all parameters were above their respective critical values.

3.3 Runoff, Soil and Nutrient Losses from Climbing and Bush Beans

The mean annual runoff varied significantly ($P<0.05$) between climbing beans (36 m^3 ha^{-1} yr^{-1}) and bush beans- (248 m^3 ha^{-1} yr^{-1}) (Fig. 4). Runoff generation from each bean growing season was also significantly different between climbing and bush beans at $P<0.05$ (Fig. 5). Bush beans contributed with the highest seasonal runoff (363 and 161 m^3 ha^{-1} $season^{-1}$) than climbing beans (55 and 22 m^3 ha^{-1} $season^{-1}$) during the long and short rainy seasons, respectively (Fig. 5). The percentage rainfall that ended up as runoff ranged from 3.6% to 21.9% in the short and long rainy season periods, respectively (Fig. 6). The low runoff to rainfall ratio in the short over the long rainy season is likely to be due to low runoff observed in the short rainy season from both bean types. The low percent rainfall that ended up as runoff from climbing beans over bush beans is due to the ground cover characteristics noted by [30] and other several authors [50,51,52,53] who have concluded that the higher the canopy/ground cover, the lower runoff coefficient due to increased infiltration rate. Therefore, climbing beans' ground cover reduced runoff down the catchment, hence translating into low runoff coefficient.

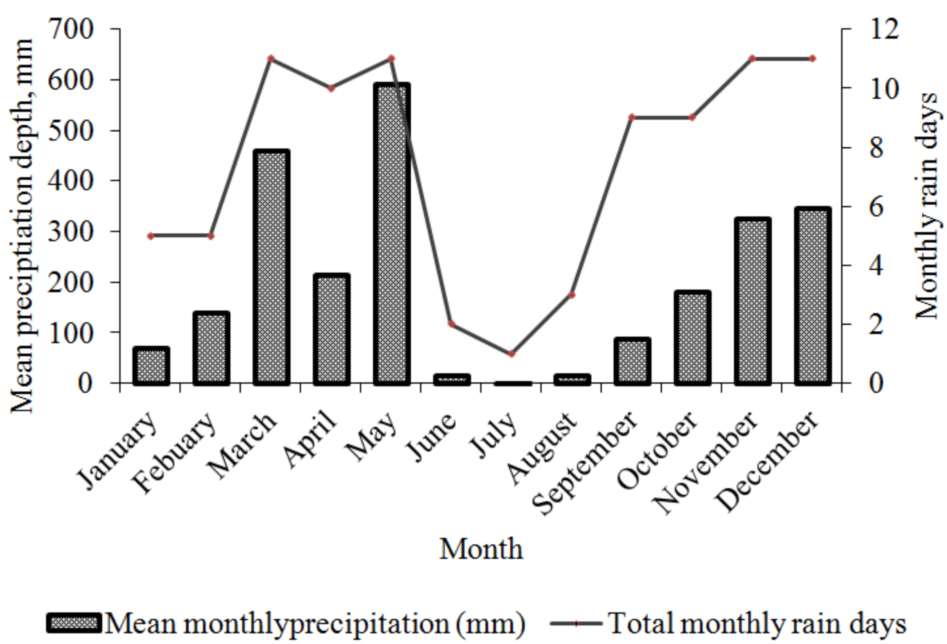

Fig. 3. Mean monthly precipitation and total rain days in the sub-catchment in 2012

Table 1. Chemical properties of soils under climbing and bush beans

Depth (cm)	Bean type	pH	N	SOM	Av. P	Exch. K	Ca	Mg	Na
			%		mg/kg	cmol(+)/kg			
0-15 top	Climbing beans	5.30	0.18	3.80	20.30	0.62	4.27	2.04	0.05
	Bush beans	5.20	0.15	3.60	16.90	0.50	4.18	2.20	0.05
15-30	Climbing beans	5.20	0.15	3.39	16.60	0.56	3.96	2.00	0.05
	Bush beans	5.00	0.15	2.84	9.10	0.42	3.68	1.90	0.05
Bean type ($LSD_{0.05}$)		ns	ns	ns	ns	0.12	ns	ns	ns
Depth ($LSD_{0.05}$)		ns	ns	0.58	ns	ns	ns	ns	ns

ns = mean not significant at $P \geq 0.05$. SOM= Soil Organic Matter; Av. P= Available Phosphorus; Exch. K= Exchangeable Potassium

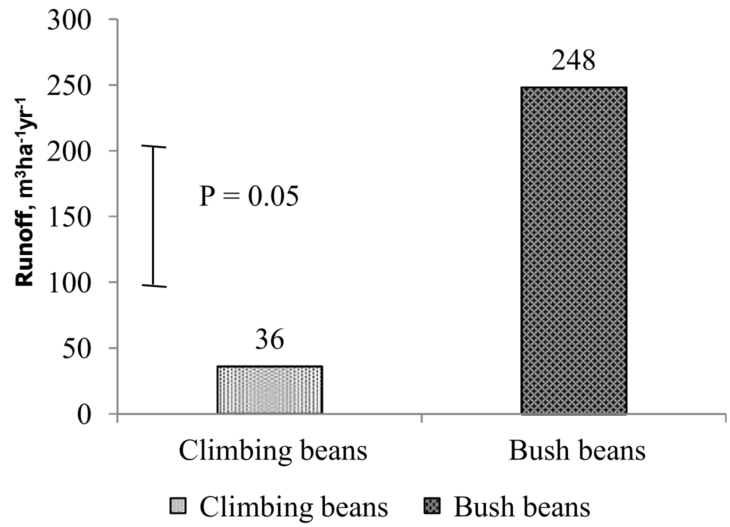

Fig. 4. Annual runoff from terraced slopes cropped with climbing and bush beans

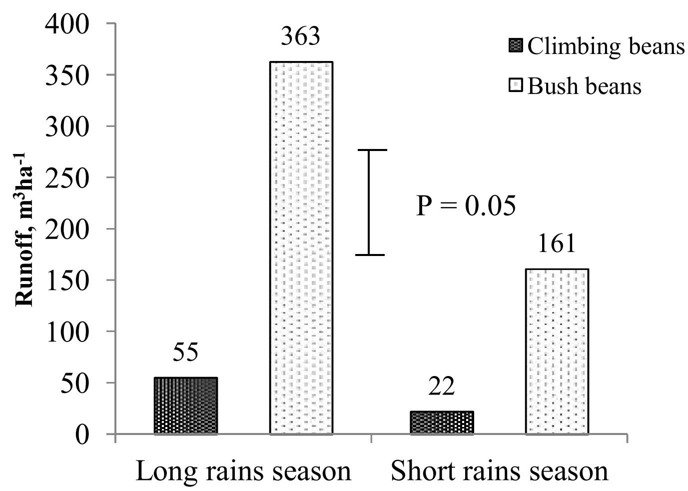

Fig. 5. Runoff from the different rain seasons during the study period

Annual soil loss varied significantly (P<0.05) from 121 kg ha^{-1} yr^{-1} in climbing beans to 548 kg ha^{-1} yr^{-1} in bush beans (Fig. 7). Seasonal soil loss also varied significantly between the two bean types (P<0.05). Bush beans contributed the highest amounts of soil loss in each bean cultivation season: 1008 kg soil loss ha^{-1} $season^{-1}$ for long rainy season period and 311 kg soil loss ha^{-1} $season^{-1}$ for short rainy season period as compared to climbing beans which registered 413 kg soil loss ha^{-1} $season^{-1}$ for long rainy season period and 29 kg soil loss ha^{-1} $season^{-1}$ for short rainy season period (Fig. 8).

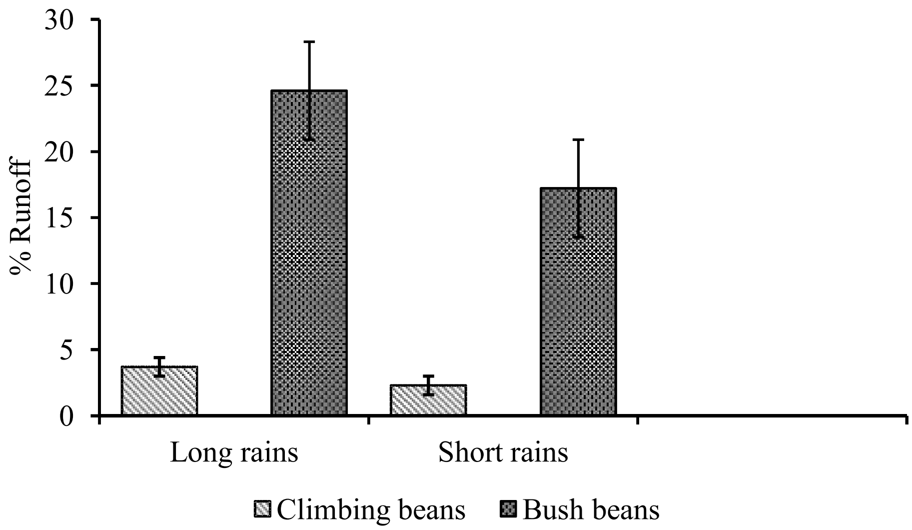

Fig. 6. Percentage runoff to rainfall

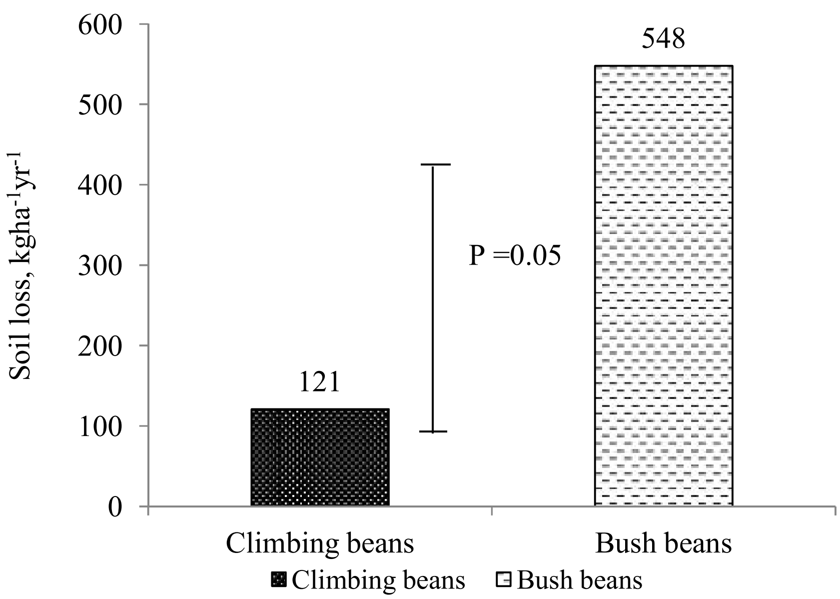

Fig. 7. Annual soil loss from terraced slopes cropped with climbing and bush beans

Table 2. Interactions of soil physic-chemical properties with sites, bean types and soil depths

Depth (cm)	Bean type	Site	Clay	Sand	SOM	N	Av.P	BD	Ksat	Ca	Mg	Na	K	pH
0-15			**%**				**Mg/kg**	**g/cm³**	**cm/hr.**	**Cmol(+)/kg**				
	Climbing	1	22.0	48.0	2.83	0.11	2.2	1.41	4.33	2.30	1.17	0.04	0.24	4.81
	beans	2	20.7	45.7	3.89	0.19	23.0	1.42	11.03	3.80	1.68	0.03	0.53	5.23
		3	28.7	35.3	4.07	0.17	35.6	1.34	7.33	6.72	3.28	0.07	1.10	5.86
	Bush	1	22.0	46.0	2.29	0.15	4.5	1.41	2.84	2.70	1.39	0.05	0.41	4.74
	beans	2	18.7	57.3	3.81	0.19	30.9	1.45	8.23	4.14	2.22	0.04	0.61	4.96
		3	27.7	34.7	5.29	0.21	15.3	1.35	10.52	5.70	3.08	0.06	0.47	5.82
15-30	Climbing	1	22.0	49.7	2.67	0.12	3.4	1.42	3.85	2.50	1.27	0.04	0.28	5.03
	beans	2	23.7	52.0	3.87	0.14	18.8	1.41	6.89	3.19	1.72	0.04	0.45	4.86
		3	27.3	33.7	3.64	0.20	27.6	1.35	6.05	6.18	3.01	0.06	0.96	5.82
	Bush	1	24.0	45.7	1.26	0.13	1.8	1.39	0.32	2.37	1.18	0.04	0.39	4.72
	beans	2	20.7	55.7	3.59	0.15	15.0	1.43	6.28	3.25	1.95	0.06	0.42	4.72
		3	27.7	37.7	3.66	0.18	10.4	1.35	5.65	5.45	2.58	0.05	0.45	5.57
Bean type (*P* <.05)			ns	ns	ns	ns	ns	ns	<0.05	ns	ns	ns	<0.001	<0.001
Site (*P* <.05)			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ns	<.001	<0.001
Depth (*P* <.05)			ns	ns	<0.001	ns	ns	ns	<0.001	<0.05	<0.001	ns	<0.001	<0.05
Bean type*Site (*P* <.05)			<0.05	<0.05	<0.001	ns	ns	<0.05	<0.001	0.05	<0.001	ns	<0.001	ns
Bean type*depth (*P* <.05)			ns	ns	ns	ns	ns	ns	ns	ns	<0.05	ns	ns	ns
Bean type*depth*site (*P* <.05)			ns	ns	ns	ns	ns	ns	<0.001	ns	ns	ns	ns	ns

ns = mean not significant at $P \geq 0.05$. SOM= Soil Organic Matter; BD= Bulk density; Ksat =Saturated hydraulic conductivity; Ca =Calcium; Mg = Magnesium; Na= Sodium

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Table 3 shows the annual nutrient losses from climbing and bush beans from the study area. Bush beans contributed significantly to the highest annual N and P losses from both runoff and sediment losses than climbing beans. Potassium loss did not vary significantly from both bean types; however, bush beans had the highest losses than climbing beans. The annual N, P and K losses for the study area were 0.49, 0.1, 0.03 kg ha^{-1} yr^{-1} and 1.87, 0.6 and 0.2 kg ha^{-1} yr^{-1} from climbing and bush beans, respectively.

Economic valuation for the imposition of monetary value was based on the nutrients losses within the transported soil materials and the calculation was adopted from [54]. The calculation of economic value is the total loss of nutrients (N, P and K) in transported soil material and is converted into the economic value based on the local price of urea, tri super phosphate (TSP), and potassium chloride (KCl). Bush beans had the highest value as compared to climbing beans (Table 4).

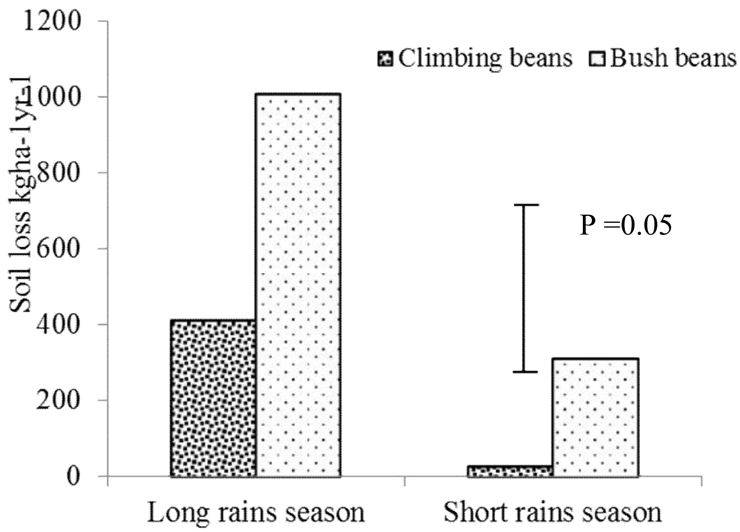

Fig. 8. Soil losses for the different rainy seasons during the study period

Table 3. Annual nutrient losses from cultivated climbing beans and bush beans

	Bean type	Nutrient loss (kgha-1)		
		N	P	K
Runoff/water	Climbing beans	0.001	0.32	0.24
	Bush beans	0.09	2.09	0.37
Soil/sediment	Climbing beans	0.49	0.10	0.03
	Bush beans	1.87	0.60	0.20
P<0.05 (runoff/water)		<0.05	<0.001	ns
P<0.05 (soil/sediment)		<0.001	ns	ns

ns = mean not significant at P>0.05

Table 4. Total economic value of soil erosion in the catchment

Nutrients	Nutrients losses (kg/ha/yr.)	
	Climbing beans	Bush beans
Nitrogen	0.49	1.96
Phosphorus	0.42	2.69
Potassium	0.27	0.57
Economic value (Ug shilling/ha) of nutrient losses based on price of:		
Urea (46% N)	5337	21304
TSP(0:20:0)	7560	48420
KCL (48% K)	2700	5700
Total economic value (Ug shillings/ha)	15597	75424

Economic value of bush beans is higher than that of climbing beans

4. DISCUSSION OF THE RESULTS

4.1 Soil Physic-chemical Characteristics

The low bulk density and high saturated hydraulic conductivity (Ksat) at the top soil is due to the modification by the rich organic matter at the surface due to littering effect of bean plants. This is in agreement with the earlier findings of [55-58,59] who reported a low bulk density in rich organic soils. The high bulk density in the sub soil is due to the relatively more developed soil structure of mineral soils than organic soils. Climbing beans had lower bulk density and higher Ksat than the bush beans due to the high level of littering from the high vegetation cover and the extensive rooting system characteristic of climbing over the bush beans [27]. This leads to the formation of macro pores as result of decaying effects of the leaves [60] and hence increased infiltration thus leading to a reduction of runoff in the catchment. These changes increase crop yield and environmental protection due to nutrient retention in the long rainy season.

4.2 Runoff, Soil and Nutrient Losses from Climbing and Bush Beans

The relatively high runoff from bush beans could be attributed to the low hydraulic conductivity observed and the limited surface vegetation cover which takes a shorter period than climbing beans whose vegetation cover takes 200 days to stand before maturity [30,34]. That could have acted as runoff breakers hence reducing the impact of rainfall energy to the soil surface [61,62]. According to [63], climbing beans have extensive root systems with greater exploration and mechanical support as well as better ability at binding the soil particles than the bush beans. Thus the climbing beans have better capacity in improving the soil structure and hence reducing the runoff and soil losses than bush beans. The climbing beans have a growth height of 2 m high compared with the 30 cm of bush beans. As well as possessing a well and higher aerated surface cover, the green canopy cover which takes longer (about 6 weeks) before flowering as compared with bush beans which retain a green cover for up to 2 – 3 weeks before flowering [34]. These characteristics aid climbing beans to intercept rainfall and increases infiltration on the soil surface [64] and as a result, reduced runoff and soil losses down the catchment. High runoff from bush beans with limited vegetation cover over climbing beans is in agreement with observations from [51,65,66] under the agricultural lands.

The runoff values from both bean types tallied within the range reported by [67,68] and contrasted with [69,70] who reported high values. However, all these runoff values are very low to the tropical African context under the mountainous agricultural lands due to low rainfall erosivity and high infiltration rates.

The high soil loss from bush beans was due to the high runoff registered by these bean types translating into increased soil losses as also reported by [51,71]. The lower vegetation cover in bush beans than climbing beans [30,34] also caused increased soil losses from bush beans due to the fact that soil particles under bush beans' stands were more exposed to detachment by rain drops, and further transportation along with runoff as also observed by [46,72,73]. The annual soil loss from bush beans and climbing beans are within the range of those reported by [67] and in contrast with [74,75] on mountaneous environments.

The factors that favored runoff could have attributed to the trend in soil loss from these two types of beans. As also reported by [22], low bulk density and high organic matter content resulting into high saturated hydraulic conductivity could have favored low runoff and soil losses from climbing beans. The annual soil loss values in the study area were generally too small as compared to those reported by [70] and below the proxy tolerable limit of 5 t ha^{-1} yr^{-1} used in Uganda. Hence the observed plot scale soil loss values indicated that the situation in catchment has not yet reached the critical levels, as also reported by [72,76,77] under the agricultural crop lands. Appraisals by [78] on erosion in the highland regions of Uganda concluded that soil erosion rates are much less than would be expected even in steep slopes due to the low rainfall erosivity, rainfall intensity, high infiltration rates and low soil erodibility due to favorable soil mineralogy and a stable soil structure as reported by [70]. However, if the soil losses are not curbed, they can lead to economic losses in terms of reconstructing terraces, draining streams/channels and replenishing the soil fertility especially if bush beans are continuously cultivated.

The nutrient losses are generally very low for all bean types, in agreement with those reported by [70,79,80,81]. The smaller vegetation cover under bush beans compared with climbing beans, in agreement with the study of [30] caused higher nutrient losses from bush beans.

This also confirms the observations [82] in Tihany Peninsula who reported that higher vegetation cover caused low nutrient losses. The [83,84] studies indicated that increase in vegetation cover reduced nutrient losses. Therefore, N, P, K losses from runoff and sediment are very detrimental to agricultural production in terms of soil fertility loss and water resources degradation down the catchment. Hence management options have to be devised to reduce on the runoff and soil losses in the study area.

5. CONCLUSION

The soils in the study area had a moderate to rapid Ksat which allows an easy water movement within the soil. There were generally low soil runoff and nutrient losses from both climbing and bush beans compared with those reported in similar highlands. However, bush beans experienced significantly more runoff and soil loss than climbing beans. Therefore, climbing beans if grown in the highlands can serve a dual purpose: of providing food and controlling soil erosion. This will help to reduce the rate of land degradation in the high intensive agricultural highlands of southwestern Uganda. If traditional bush beans are cultivated, then other soil and water conservation practices must be considered in order to reduce the runoff and soil losses. Water infiltration and nutrient leaching studies should be carried out in order to further explain the low level of runoff and soil loss on the steep slopes in the highlands of southwestern Uganda.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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