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Cassava-cowpea intercropping system for controlling soil erosion in the Northern mountainous areas of Vietnam

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Abstract

On sloping lands, cassava is a food crop that often promotes severe soil erosion. Moreover, repetitive monocropping of cassava dramatically increases soil erosion and reduces soil fertility. Intercropping, a key agroecological practice, effectively manages soil erosion by increasing soil cover and improving soil fertility. In 2017, a trial was set up in Mau Dong commune, Van Yen district, Yen Bai province, Vietnam, to evaluate the feasibility of intercropping cowpea into a cassava cropping system. The results showed strong feasibility for reducing soil erosion and maintaining cassava yield. In 2018, a follow-up field experiment was undertaken to assess the effects of a cassava-cowpea intercropping on the growth and yield of cassava, and its impact on soil and nutrient losses. A completely randomized design (CRD) was adopted with 3 replications composed of 4 treatments-cassava monocropped on gentle slope, cassava monocropped on steep slope, cassava-cowpea intercropped on gentle slope, and cassava-cowpea intercropped on steep slope. The results showed that intercropping cassava with cowpea on both gentle or steep slope fields significantly improved soil cover levels (2.2 level of cover out of 10 on gentle and 1.7 on steep), reduced soil erosion (40.0% gentle and 58.2% steep) and decreased nutrient losses (15.9-35.6% nitrogen, 0-18.8% phosphorus, and 14.8-22.5% potassium). Regression analysis revealed significant correlation between dry soil erosion, percentage of soil cover, and nutrients losses. The intercropping system enhanced cassava growth, yield, harvest index, and root dry matter. Thus, cassava-cowpea intercropping system shows great potential as a strategy for soil erosion control and sustainable agricultural production.

Keywords: Cassava-cowpea intercropping, Cassava growth and yield, Nutrient losses, Sloping lands, Soil erosion

1. Introduction

Soil erosion is a worldwide threat to fertile soil [1]. Soil erosion is a natural geomorphic process that detaches and removes high fertile topsoil from the surface by water, wind, and mainly by cultivation practices. These events or practices carry away approximately 75 billion tons of fertile topsoil yearly, decrease crop yields (as much as 50%), increase fertilizer input expenses, and greatly reduce biodiversity and soil fertility—total annual economic loss is about 10 billion euros [2]. The world soils are greatly degraded due to intensive agricultural practices such as tilling soil, continuous monocropping systems, excessive use of mineral fertilizers, and burning of crop residues or weeds. After studying the scope of soil loss due to erosion under different cropping systems in upland areas, Phien and Vinh [3] showed that the greatest soil loss occurred in monocropped cassava fields (98.6 tons/ha/year). Howeler et al. [4] determined that continuously monocropping cassava caused severe soil erosion, particularly on sloping lands, mainly due to the wide planting spaces and the slow growth of cassava, resulting in detached soil particles and a greater potential for erosion caused by rainfall and runoff. This risk is even more prevalent in tropical countries where there are heavy rainfalls during the early stages of cassava growth. Moreover, in upland areas, the transition from natural forests to agricultural lands for growing cassava also leads to soil erosion.

In Vietnam, the Northern Mountainous Region (NMR) leads in total cassava crop area and production [5]. In this zone, crop areas with 8-15^{o} slope occupy around 16% of arable land, and the rest are steep sloping lands with greater than 15^{o} slope (about 62% of the total area cultivated) [6]. Cassava is one of the major cash crops for local poor farmers in this region. It is widely planted as a monocrop because of its tolerance to drought and infertile acidic soils and its minimal requirements for land preparation and nutrients [7]. According to Wezel et al. [8], soil and nutrient losses in northern Vietnam result in about 31% decline in production (equivalent to about 200-700 USD/ha).

Intercropping, which is practiced in many tropical countries around the world, is one of the most effective agroecological practices to enhance soil fertility and promote sustainable production [9]. It has various advantages compared to traditional monocropping systems, especially for controlling soil erosion. Intercropping commercial crops and cover crops increases the percentage of soil cover, which in turn inhibits the direct impact of rainfall and sunshine on the soil, consequently maintaining soil fertility, improving soil moisture, and reducing soil erosion and nutrient losses [10,11]. Cassava has a slow initial growth so this crop can be intercropped with crops having a rapid growth and early to medium growth duration, such as cowpea (*Vigna unguiculata*), peanut (*Arachis hypogaea*), mungbean (*Vigna radiata*), and maize [12]. Indeed, Aye and Howeler [12] determined that cassava-cowpea intercropping has the highest land-use efficiency. Trung et al. [13] reported that cassava-peanut intercropping decreased the amount of eroded soil by 63.2%, compared to traditional monocropping. Likewise, Dalton et al. [14] noted that intercropping cassava with peanut, mung bean and soybean resulted in less soil loss, about 25.7 tons/ha/yr, whereas monocropped cassava resulted in about 53.2 tons/ha/yr of soil loss.

Moreover, intercropping with legumes that have the ability of fixing atmospheric nitrogen (N) could contribute higher levels of N to the main crop [15]. Peoples et al. [16] suggested that intercropped cowpea contributed as much as 20 kg N ha/season to the main crop. Additionally, intercropping systems can enhance the organic matter content and the nutrient input to soil due to the biomass residue provided by legume crops [17,18]. Overall, intercropping systems can boost crop production, thereby providing increased economic benefit to smallholders [19,20].

Legume-based intercropping systems can also help to control pests and weeds and decrease the need for greater input of N mineral fertilizer. These advantages mean more efficient use of resources in general by reducing the use (and costs) of chemical inputs by smallholders—which translates into higher economic returns [21,22].

Cowpea is a valuable legume for resource-poor farmers in Vietnam due to its tolerance for sandy soil and low rainfall, little input requirements, atmospheric nitrogen fixation ability, and it is well-suited for intercropping systems with other crops [12]. Limited information exists about the effectiveness of introducing cowpea to a cassava crop. That is, little research has focused specifically on the impact this intercropping system has on soil and nutrient losses in fields with varied degrees of slope, as often encountered in the NMR of Vietnam, and the impact this crop system has on the growth and yield of cassava. We hypothesized that cassava-cowpea intercropping would help control soil erosion on sloping lands because of improved ground cover at critical growth stages and increase soil fertility because of cowpea's ability to fix atmosphere N and biomass residues in soils. Therefore, the aims of this study were to: (1) estimate the changes in soil and nutrient losses in a cassava-cowpea intercropping system, and (2) assess the effects of cassava-cowpea intercropping system on cassava growth and yield.

2. Materials and methods

2.1 Experimental site

The experiments were carried out in Mau Dong commune, Van Yen district, Yen Bai province in March 2018 (Figure 1). This site is located at latitude 21° 50′ to 22° 12' N and longitude 104° 23′ to 104° 39' E. The topography is mostly hilly with a mean altitude of 150 meters above sea level (m.a.s.l.) At this study site, the mean annual temperature was 25.5 °C, mean annual rainfall was 1,860 mm, and average air humidity was 81-

86% during the period of study, 2011-2018. The total area of the district is 138,884 ha, of which 10,890 ha is agricultural land. In this district, cassava is cultivated on about 6,500 ha, mostly on steep sloping land, ranging 15-30° slope.

Cassava variety SA21-12 and cowpea local variety (Dau Den Xanh Long) was used in this study. In 2012, the Root Crop Research and Development Centre (Hanoi, Vietnam) released a new promising line from national trial sets, named SA21-12. This variety has good plant architecture, high root yield (30-35 tons/ha), high starch content (about 28%), high dry biomass (about 39%), and low cyanogenic percentage [5]. The cowpea variety Dau Den Xanh Long is a local variety that has been used by farmers in the study location since 2005. Dau Den Xanh Long seeds can be harvested in about 100-120 days after the planting date. This cowpea variety has a main stem height of about 50-100 cm, and it produces purple flowers with black coat and green entrails. The average seed yield is 300-400 kg/ha [12].

Before setting up the trial, core soil samples were collected at 10 random points from each plot, at a depth of 20 cm; the samples were then thoroughly mixed to make a composite sample that weighed about 0.5 kg. Soil samples were then analyzed to discern main characteristics; the pH H_2O of the soil at this study location was 4.09. The particle characteristics of the soil consisted of sand (52.1%), silt (23.5%), and clay (24.4%). The organic matter content at 0-20 cm depth was 1.43 of soil weight. The soil bulk density was 1.45 g/cm^3. The available nutrients kg/ha were N (240.7), P (107.4), and K (112.8).

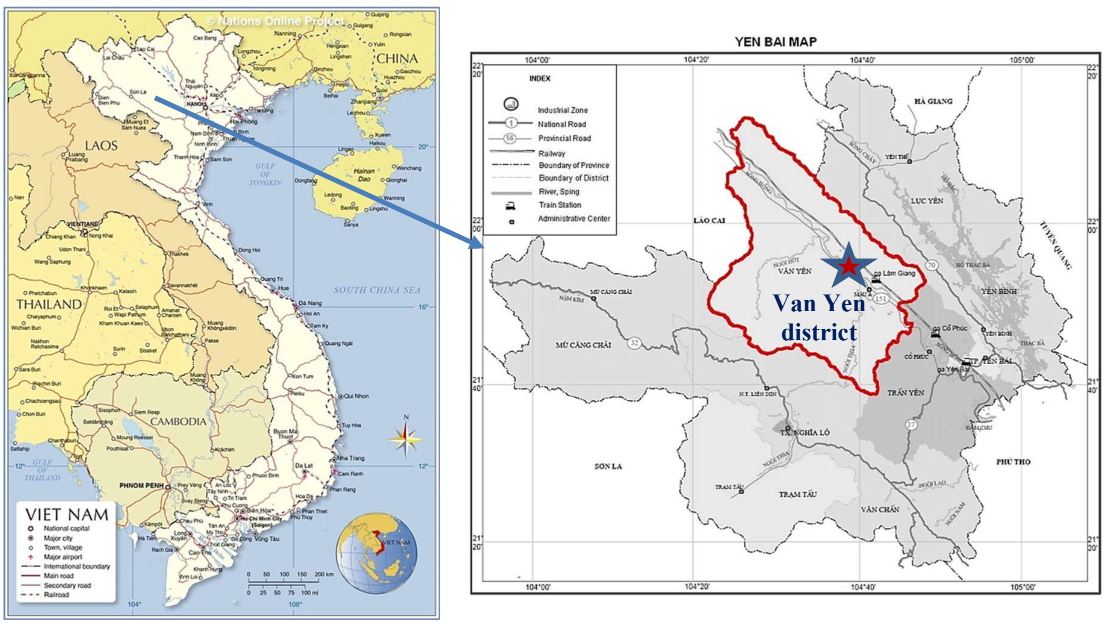

Figure 1 Study location in Van Yen district, Yen Bai province, Vietnam [23].

2.2 Experimental design

In 2017, the trials were conducted at 10 farms (5 farms under gentle slope and another 5 farms under steep slope). The same two cropping systems were tested in all farms—cassava monocropping and cassava-cowpea intercropping. These trials were set up as the preliminary trial to evaluate the feasibility of intercropping cowpea into a cassava plantation to reduce soil erosion under sloping areas, while also considering the maintenance of good cassava yield. During the 2017 trials, soil cover level, dry eroded soil, and cassava yield were collected and analyzed, and results showed high feasibility (Table 1).

The trial was repeated experimentally in March 2018, comprising 4 treatments: cassava monocropped on gentle slope ($\leq 5^o$) (referred to as MG), cassava monocropped on steep slope ($\geq 15^o$) (MS), cassava-cowpea intercropped on gentle slope (IG), and cassava-cowpea intercropped on steep slope (IS). The experiment was laid out in a completely randomized design (CRD) with three replications; each plot area was 80 m^2 (4.0 x 20 m). Due to the actual conditions at the study site (steep sloping lands), only three replications were studied to ensure the uniformity for all the experiment plots. On each plot an erosion trap was dug (dimensions in meters, 4.0 length x 0.5 width x 0.6 depth). Cassava planting density was 10,000 plants/ha (1.0 x 1.0 m). After planting the cassava, 1 row of cowpea was sown between 2 rows of cassava to achieve the intercropping plot treatment. The recommended dose of fertilizer mixture (kg/ha) was applied uniformly to all plots: 100 N, 60 P, and 100 K in the form of NPK+S (5:10:3:8).

2.3 Data collection

Soil cover levels (SCL) were assessed 40 days after sowing (DAS) cowpea. Samples were taken from each plot at 3 random points (within an area of 5 m^2) following the visual method described by Mansuy et al. [24]. A grading scale was used based on the percentage of soil actually covered by plant growth, 1% to 100% of soil covered (recorded as 1 to 9): Soil cover scale 1 (≤ 1%, few residues visible), 2 (≤ 7%, less than 1 crop residue per m^2), 3 (≤ 15%, at least 1 crop residue per m^2); 4 (30% soil cover); 5 (50% soil cover); 6 (70% of soil cover); 7 (85%, at least 1 hole or 10% of soil per m^2); 8 (93%, very few portions of soil visible); 9 (100%, soil fully covered by mulch).

A soil trap was built along the lower edge of each plot and the eroded soil was weighed after each event in the field (after each rainfall that produced runoff). The subsamples were collected and dried at 60 °C until constant weight to measure the dry soil loss. Next, the annual dry soil loss (ton/ha) was calculated from the accumulated dry soil loss from each plot and the contributing area. Each time, after measuring the eroded soil loss that collected in the erosion trap, one soil sample (about 0.5 kg) was collected from five points within the trap and thoroughly mixed. After the last sampling, all the individual soil samples were pooled into one composite soil sample (about 0.5 kg) and the composite sample was analyzed for available N using Kjeldahl methods [25], available P using the Bray II method [26], and available K (NH_4OAc-K) [27].

At harvest time (10 months after planting), ten cassava plants were randomly selected from each plot, and each plant's height (from the ground to the first unexpanded leaf) and stem diameter were measured in centimeters. The number of tubers per plant was counted, the weight of fresh tubers per plant (in grams) was recorded, and cassava tuber yield (ton/ha) were calculated. The weight of individual tubers per plant and the total plant fresh weight (in grams) were also determined. The harvest index was calculated as the proportion of tuber weight to the total plant weight on a fresh weight basis. Root dry matter as a percentage was determined from the weight of samples before and after drying in an oven at 105 °C for 6 h.

2.4 Statistical analysis

Analysis of variance (ANOVA) was calculated using Microsoft Excel for MacOS 2016 and R version 3.4.2 (2017-09-28). For the 2017 trial, a two-way ANOVA was performed to assess the effects of crop system, slope category, and their interaction on soil cover level, soil erosion and yield of cassava. Significance of difference was evaluated at $p<0.05$. For the 2018 experiment, the effects of treatments on the variables were compared using the Tukey's HSD (honestly significant difference) test at $p<0.05$. The correlation between dry soil loss and other parameters were also computed at the significance of $p<0.05$.

3. Results

3.1 Soil covering level, eroded soil, and nutrient losses

Soil cover plays a crucial role in conservation agriculture by protecting soil from erosion processes, maintaining appropriate soil moisture, and by smothering weeds. In 2017, the results from the preliminary trial showed that soil cover level was higher in intercropping systems compared to monocropping systems on both gentle slope and steep slope (8.2 compared to 6.0 gentle, and 7.6 compared to 5.6 steep) (Table 1). There was no significant difference in soil cover level between different slope categories on both monocropping and intercropping fields (Table 1). In the repeated experiment in 2018, there were statistically significant effects of different treatments on SCL at 40 DAS (Table 2). Treatment IG had highest SCL (8.3 out of 10), followed by treatment IS (7.1). Regarding SCL, there was no significant difference between treatment MG (6.1) and MS (5.4).

Table 1 Effects of different treatments on soil cover level, eroded soil and cassava yield in the preliminary trial in 2017.

	Slope					
	Soil cover level		Soil erosion (ton/ha)		Cassava yield (ton/ha)	
	Gentle slope	Steep slope	Gentle slope	Steep slope	Gentle slope	Steep slope
Cassava monocrop	6.0 ± 0.3[b]	5.6 ± 0.4[b]	4.0 ± 0.1[b]	8.9 ± 0.2[a]	21.7 ± 0.2[b]	20.6 ± 0.1[c]
Cassava-cowpea intercropping	8.2 ± 0.4[a]	7.6 ± 0.2[a]	2.4 ± 0.1[c]	3.5 ± 0.2[b]	23.2 ± 0.1[a]	22.1 ± 0.1[b]

[*]Means ± standard errors followed by same lowercase letter(s) of each factor are not significantly different at $p< 0.05$.

As shown in Table 1, in the 2017 preliminary trial, soil erosion from intercropping farms were lower than monocropping farms on either gentle slope or steep slope (2.4 ton/ha compared to 4.0 ton/ha, and 3.5 ton/ha compared to 8.9 ton/ha, respectively). Moreover, on both monocropping and intercropping systems, soil erosion on steep slope was significantly higher than on gentle slope (8.9 ton/ha compared to 4.0 ton/ha steep and 3.5 ton/ ha compared to 2.4 ton/ha gentle) (Table 1).

In 2018, maximum dry soil loss (9.1 tons/ha) was observed in MS while minimum soil loss (2.1 tons/ha) was recorded in cassava-cowpea intercropped on gentle slope (IG) (Table 2). There was no significant difference in dry eroded soil between MG (3.5 tons/ha) and IS (3.8 tons/ha). This revealed that intercropping one row of cowpea between two rows of cassava on gentle and steep slopes reduced dry soil loss: MG 1.4 tons/ha (40.0%) and IS 5.3 tons/ha (58.2%). Notably, MG suffered less soil loss (5.6 tons/ha or 61.5%) compared to MS lands. There is a significant negative correlation (R^2 = 0.63; p = 0.002) between dry soil loss and soil cover levels (Figure 2A).

Table 2 Effects of different treatments on soil cover level, eroded soil, and nutrient losses.

Treatments	Soil cover level	Dry soil loss (ton/ha)	N loss (kg/ha)	P loss (kg/ha)	K loss (kg/ha)
MG	6.1 ± 0.3^{c}	3.5 ± 0.09^{b}	15.1 ± 0.09^{c}	1.2 ± 0.06^{a}	16.9 ± 0.23^{c}
MS	5.4 ± 0.2^{c}	9.1 ± 0.03^{a}	35.4 ± 0.35^{a}	1.6 ± 0.09^{a}	24.3 ± 0.44^{a}
IG	8.3 ± 0.2^{a}	2.1 ± 0.06^{c}	12.7 ± 0.19^{c}	1.2 ± 0.06^{a}	13.1 ± 0.21^{d}
IS	7.1 ± 0.3^{b}	3.8 ± 0.10^{b}	22.8 ± 0.30^{b}	1.3 ± 0.08^{a}	20.7 ± 0.67^{b}
CV%	5.07	2.78	2.03	4.70	3.96

*Means ± standard errors followed by same lowercase letter(s) within the same column of each factor are not significantly different at *p< 0.05* according to Tukey's HSD test.

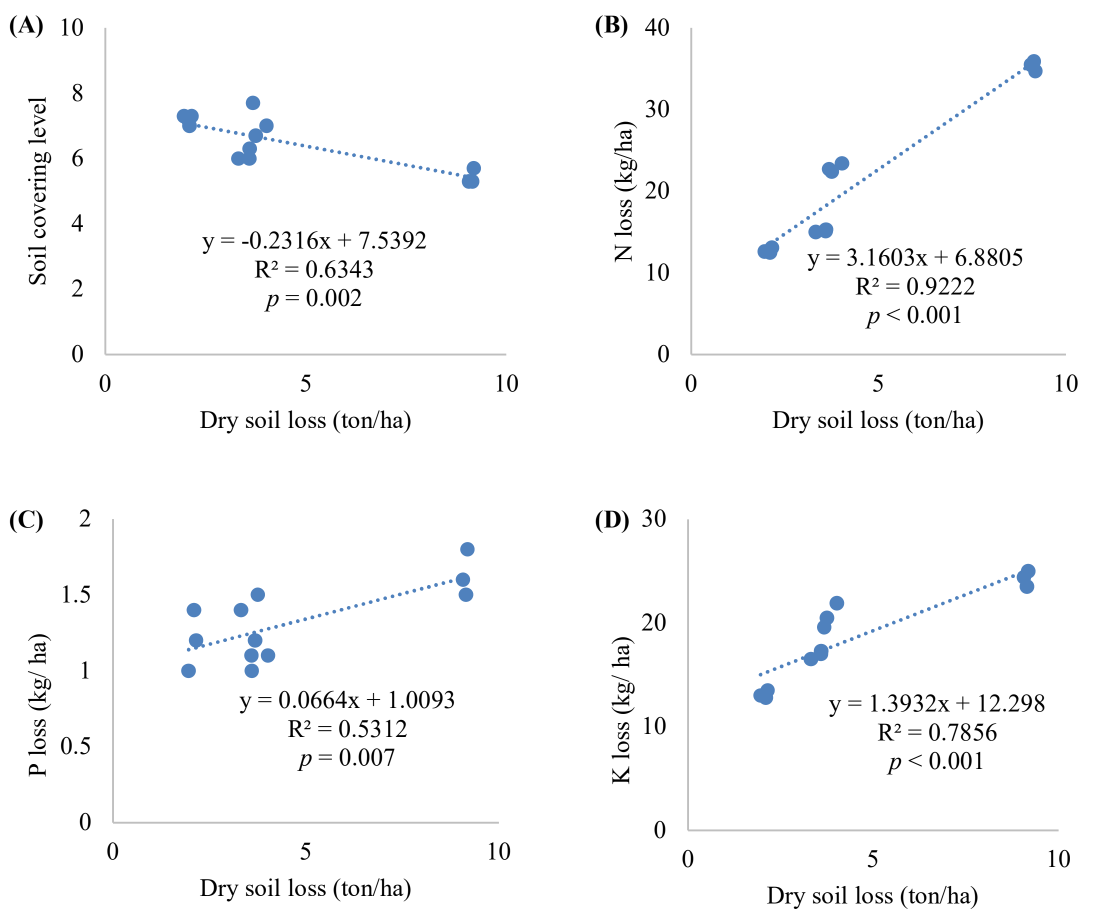

Figure 2 Regression analysis of dry soil loss and: (A) soil covering level, (B) nitrogen (N) loss, (C) phosphorus (P) loss, and (D) potassium (K) loss.

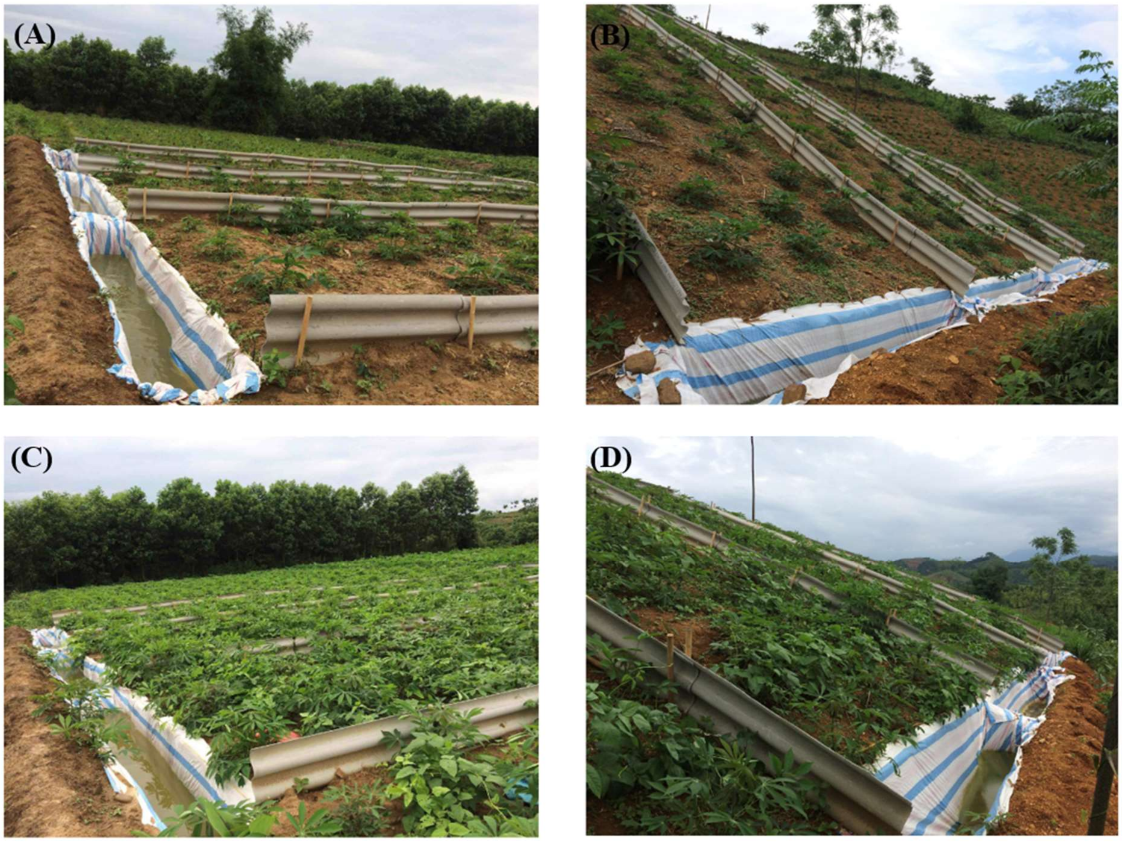

Figure 3 Experimental plots of different treatments; (A) MG- Monocropping on gentle slope, (B) MS- Monocropping on steep slope, (C) IG- Cassava-cowpea intercropping on gentle slope, and (D) IS- Cassava-cowpea intercropping on steep slope.

Rainfall and overland water flow not only thinned the fertile topsoil, but these events also decreased soil organic matter, beneficial microorganisms, and essential nutrients. The highest N loss due to erosion was recorded in treatment MS (35.4 kg/ha), followed by IS (22.8 kg/ha) (Table 2). There was no significant difference between MG (15.1 kg/ha) and IG treatments (12.7 kg/ha). For all treatments, similar levels of P loss were observed (Table 2). K loss varied across different treatments, but the maximum K loss was observed in MS (24.3 kg/ha) and the minimum was recorded in IG (13.1 kg/ha) (Table 2). In IS, the amount of K loss (20.7 kg/ha) was higher than in MG (16.9 kg/ha). There were positive correlations between dry eroded soil and N and K losses (Figure 2B and 2D). There was also a significant correlation (R^2 = 0.53; p = 0.007) between eroded soil and P loss (Figure 2C).

3.2 Cassava growth, yield, and yield components

As shown in Table 3, plants grown in treatment IG had the greatest stem diameter (2.5 cm) and treatment MS produced plants with the lowest stem diameter (2.2 cm). Treatment IG also had the tallest plant height (220.5 cm), while there was no significant difference in plant height among other treatments.

The number of tubers and weight of tubers per plant are the most important cassava yield components. As shown in Table 3, there was no significant difference in the number of tubers per plant among all treatments. The greatest weight of tubers per plant was recorded for treatment IG (2,300 g) and the lowest tuber weight per plant was recorded for treatment MS. There was no significant difference between MG and IS in both weight of tubers per plant and weight of individual tuber. Treatment IG had greatest individual tuber weight (198.9 g) while treatment MS had lowest individual tuber weight (Table 3).

Regarding cassava yield, the 2017 preliminary trial showed that on both gentle slope and steep slope, intercropping systems had higher cassava yield compared to monocropping systems (intercropped gentle 23.2 ton /ha compared to monocropped gentle 21.7 ton/ha and intercropped steep 22.1 ton/ha compared to monocropped steep 20.6 ton/ha) (Table 1). Moreover, cassava yield on gentle slope was significantly higher than on steep slope in both cassava monocropping fields or cassava-cowpea intercropping fields (gentle monocropped 21.7 ton/ha compared to gentle intercropped 20.6 ton/ha, and steep monocropped 23.2 ton/ha compared to steep intercropped 22.1 ton/ha) (Table 1). In the repeated experiment in 2018, significant differences in cassava yield were recorded for the various cropping systems (Table 3). Cassava yield was greatest in treatment IG (23.0 tons/ha), and lowest in MS (20.3 tons/ha). No significant difference was observed between MG treatments (21.5 tons/ha) and IS treatments (21.0 tons/ha). Furthermore, cassava yield on steep sloping lands tended to be lower than on gentle sloping lands.

Table 3 Effects of different treatments on cassava growth, yield, and yield components.

Treatment	Stem diameter (cm)	Plant height (cm)	Number of tubers per plant	Weight of tubers per plant (g)	Weight of individual tuber (g)	Cassava yield (ton/ha)
MG	2.4 ± 0.06^{ab}	215.9 ± 1.5^{b}	11.6 ± 0.2^{a}	2,154 ± 62^{ab}	185.8 ± 5.3^{ab}	21.5 ± 0.6^{ab}
MS	2.2 ± 0.03^{b}	214.6 ± 1.7^{b}	11.2 ± 0.2^{a}	2,033 ± 43^{b}	181.5 ± 5.6^{b}	20.3 ± 0.4^{b}
IG	2.5 ± 0.07^{a}	220.5 ± 1.2^{a}	11.6 ± 0.3^{a}	2,300 ± 55^{a}	198.9 ± 2.0^{a}	23.0 ± 0.6^{a}
IS	2.4 ± 0.09^{ab}	216.5 ± 1.3^{b}	11.3 ± 0.5^{a}	2,104 ± 58^{ab}	187.1 ± 4.5^{ab}	21.0 ± 0.6^{ab}
CV%	3.63	3.54	4.89	4.44	3.34	2.92

*Means followed by same lowercase letter(s) within the same column of each factor are not significantly different at $p < 0.05$ according to Tukey's HSD test.

3.3 Cassava total plant biomass, harvest index and root dry matter

Table 4 Effects of different treatments on total plant fresh weight, harvest index and root dry matter of cassava.

Treatment	Total plant fresh weight (g)	Harvest index	Root dry matter (%)
MG	4,923 ± 40^{a}	0.44 ± 0.02^{b}	38.3 ± 0.2^{ab}
MS	4,832 ± 11^{a}	0.42 ± 0.01^{b}	38.1 ± 0.2^{b}
IG	4,941 ± 51^{a}	0.47 ± 0.01^{a}	38.5 ± 0.2^{a}
IS	4,837 ± 54^{a}	0.44 ± 0.01^{b}	38.5 ± 0.1^{a}
CV%	1.51	4.69	2.88

*Means followed by the same lowercase letter(s) within the same column of each factor are not significantly different at $p < 0.05$ according to Tukey's HSD test.

Regarding total plant fresh biomass, no significant difference was noted between the various treatments (ranging from 4,832 to 4,941 g) (Table 4). The greatest harvest index was recorded in treatment IG (0.47), and the harvest index for each of the other treatments was similar. These results suggest that intercropping cassava with cowpea on gentle slope fields produces the highest harvest index. The root dry matter was greatest in treatment IG and IS (both 38.5%) and the lowest was recorded in MS (38.1%) (Table 4).

4. Discussion

The soil cover levels data collected revealed that intercropping cassava with cowpea can significantly improve the percentage of canopy cover, consequently decreasing the erosive influence of rainfall and overland flow, particularly on sloping lands. These findings are consistent with the study by Silva et al. [28] who reported that cassava intercropping systems provided higher crop canopy cover than monocropping systems, thus significantly reducing the soil erosion rate. In that study, the highest soil cover level was found in a cassava-bean intercropping system. The higher SCL value found in intercropped treatments compared to monocropped confirms there are benefits gained in terms of soil conservation by intercropping, regardless of slope degrees. The finding from this study is in line with previous studies which concluded that monocropped cassava often causes severe erosion when grown on sloping lands as compared to other commercial crops such as maize, wheat, or potato [11,29]. It is clear that intercropping is one of the most effective agroecological practices because this crop management system can considerably reduce runoff and soil loss [1,13]. This study confirmed the effectiveness of intercropping practices in reducing runoff and soil loss; the data demonstrated a significant negative correlation ($R^2 = 0.63$; $p = 0.002$) between dry soil loss and soil cover levels (Figure 2A). Improving the crop canopy and developing greater root structures decreases the impacts of rainfall and surface water flux, which otherwise results in the destruction of soil particles and the loss of fertile surface soils [30,31].

At the study location, during the high rainfall period (typically starting late April or early May), cassava plants are still in their early stage of growth and the canopy is not yet closed; therefore, providing better crop canopy cover is valuable as it reduces runoff and soil erosion. According to Sharma et al. [20], the root systems of cover crops improve infiltration of water into the soil and reduce the speed of surface water flow, which provides induced water infiltration, decreases surface erosion, and increases soil moisture. Well-developed cassava canopy at later stages of growth only protects topsoil from rainfall impact and does not effectively inhibit overland and down-slope water flow, which is even more injurious on steep slopes to topsoil. After harvesting cowpea, the residue mulch of cowpea left on the ground also helps to control soil erosion by improving soil aggregation and water infiltration, which decreases the velocity of water flow and reduces runoff [32]. Regarding soil loss amount, the effectiveness of intercropping cowpea with cassava found in this study (2.1-3.8 ton/ha) is similar to the results found by Trung et al. [13] which intercropped peanut with cassava (2.1-3.9 ton/ha). In other research that explored different cassava intercropping systems, Iijima et al. [33] determined that soil erosion under monocropped cassava was about 36 ton/ha/yrs, but much lower levels of soil erosion were found in the intercropped systems studied: cassava/(maize+rice) (18 ton/ha/yrs), cassava/maize-soybean-cowpea (21 ton/ha/yrs) and cassava/(maize+rice)-soybean-cowpea (24 ton/ha/yrs).

The impact that the degree of slope has on soil loss, as determined by this study, is consistent with research conducted by Koulouri and Giourga [34] and El Kateb et al. [35], who reported that soil loss was greater on steep slopes than on gentle slopes. These findings support the conclusion that cassava-cowpea intercropping is an effective, appropriate agricultural crop management system, because it substantially reduces soil erosion, particularly on sites that are commonplace in the NMR of Vietnam. However, additional studies are needed to determine whether the degree of slope is nonlinearly related to the amount of soil loss. Zhang et al. [36] revealed that the soil loss rate only shows an increasing trend when slope length increases. This might be due to the complicated relationship between soil erosion rate and soil moisture, soil surface roughness, rock outcrops, and climatic characteristics [37,38].

The result from this study indicates that there is a uniform trend between eroded soil and nutrient N and K losses, across all treatments (Figure 2B and 2D). The nutrient N and K losses, as well as soil loss, were highest in the monocropped cassava; in contrast, N and K nutrient losses were lowest in the cassava-cowpea intercropped system, particularly on gentle slopes which suffered the least soil erosion. Notably, there is a direct, positive correlation between the amounts of eroded soil and N and K losses (Figure 2B and 2D). These findings are consistent with previous studies showing that greater soil loss leads to the higher levels of nutrient loss [20,39]. Even though there was no significant difference in P loss across all treatments, there was a significant correlation ($R^2 = 0.53$; $p = 0.007$) between the amount of soil erosion and P loss (Figure 2C). These findings again show the direct, positive correlation between nutrient loss and dry soil loss. Thus, this study suggests that controlling runoff and reducing soil loss by using a cassava-cowpea intercropping system, farmers growing crops on slope fields can effectively reduce nutrient losses.

Interestingly, intercropping cassava with cowpea did not affect cassava growth, yield components, and yield, however this system did result in the highest productivity, compared to other treatments. This might be due to the growing characteristics of the two crops—which do not compete for natural resources during their stages of growth. According to Aye and Howeler [12], cowpea has a different root architecture and different growth habits (growth stages occur for different durations), which makes it well-suited for cassava-based intercropping. Specifically, cassava has a slow initial growth, while cowpea grows quickly, and for a shorter duration. That is, cowpea is harvested early (about 65 DAS), which means the slower growing cassava (about 75 days after planting (DAP)) gains space to grow and has a longer period of time to utilize the natural resources, which aids its development and results in higher total yields [12].

Moreover, cowpea is a legume crop with biological N fixation (BNF) ability and with various advantages, including improving soil fertility and soil moisture, and stimulating microbial growth and activities [20,21]. Tang et al. [40] revealed that intercropping cassava with peanut significantly increased available nitrogen and abundance of beneficial bacteria/fungi (*DA101*, *Pilimelia*, and *Ramlibacter*) in soil, compared to monocropped cassava. The BNF contributions made by this legume includes the biomass residue left on the ground for mulching, which also benefits cassava crops. Thus, cassava benefits by intercropping with this legume, including greater productivity of the cassava. The findings in studies that examined the productivity yields of monocropped cassava compared to yields from legume-based intercropping are not consistent—some studies showed higher yields from monocropped cassava [27,41]. The possible explanation may be the competition between cassava and other, unsuitable legume species used in the intercropped systems studies; that is, it may be that some legumes will compete with the cassava for the required natural resources during critical stages of growth [4,19]. In this study, the lower yield of cassava on steep slopes compared to gentle slopes is explained by the low soil fertility and higher amounts of nutrient losses on steep sloping fields, especially when severe erosion left bare soil [42].

5. Conclusion

In conclusion, intercropping cassava with cowpea was effective in reducing soil and nutrient losses and in maintaining cassava growth and yield on both gentle and steep slope fields. Thus, this study indicates that using a cassava-cowpea intercropping system in the NMR of Vietnam has the potential to better control soil erosion and support more sustainable cassava production. Findings of this study also contribute to global research on conservation agriculture, particularly in hillside or slope areas of developing countries (specifically in tropical regions that experience heavy rainfall) and provides genuine benefits to sustainable development of hillside or slope rural communities. Further experimentation pursued over longer durations (such as covering multiple crop cycles) would enhance the findings of this study. Furthermore, future research should assess the diversity of soil organisms to discover the impacts of intercropping systems on soil organism population and activities.

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7. Conflict of interests

The authors declare that there are no conflicts of interest.

8. References

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