

Incorporation of Leguminous Cover Crops in Smallholder Cassava-Based Production System in Western Tanzania

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Abstract

Small-scale crop production in many parts of Tanzania is constrained by many problems among which soil fertility degradation is a major problem. Over 80% of cassava (*Manihot esculenta*) production in Tanzania is done by the small-scale farmers who continuously cultivate their fields, but use limited inputs to restore depleted plant nutrients. The objective of this study was to examine the best legume species that could be incorporated in cassava (*Manihot esculenta*) production systems under farmers' conditions and result in increase in soil fertility and crop yields. *Mucuna pruriens* and *Canavalia ensiformis* were either incorporated with cassava (*Manihot esculenta*) or planted as sole crop in rotation with cassava. *Mucuna pruriens* and *Canavalia ensiformis* were found to produce almost similar amount of biomass. The two legumes, however, produced higher biomass in rotation than intercropping system. The amount of biomass produced by *Mucuna pruriens* and *Canavalia ensiformis* in rotation system was 6.28 t·ha⁻¹ and 5.31 t·ha⁻¹, respectively. The *Mucuna* use represents an input of nitrogen into the soil which simulates a saving cost of 181.42 and 141.96 US\$ ha⁻¹. In the first year, cassava root yields were significantly increased ($p < 0.05$) over control (continuous sole cassava) (1.44 t·ha⁻¹) by the use of intercropping of cassava (*Manihot esculenta*) with *Mucuna pruriens* (2.41 t·ha⁻¹) and or *Canavalia ensiformis* (2.25 t·ha⁻¹). Intercropping and rotation of cassava with legumes increase cassava yield and represent a sustainable alternative to reduce the farms' dependence on external inputs and to enhance inherent soil fertility.

Keywords

Mucuna pruriens, *Canavalia ensiformis*, Intercropping, Rotation, Climate Change

1. Introduction

Low soil fertility is widely recognized as a major obstacle to improving agricultural productivity in sub-Saharan Africa [1]. Given the strong linkage between soil fertility and food insecurity, addressing the decline in soil fertility remains an important challenge for those faced with formulating Africa's development policy agenda [2]. The rapid growth of population in developing countries and the intensive cultivation of agricultural land are causing widespread soil degradation.

The low and declining productivity of many tropical soils are the major constraints limiting the realization of improved genetic potential of crops that is now available [3]. Depletion of soil fertility contributes to low per capital food production and is one factor of poverty in sub-Saharan Africa. The need to take appropriate measures to avoid this decline in soil productivity is urgent as the rate of deterioration is on increase and if not checked will have serious implications for future food demands of the increasing human population [3].

One alternative to restore soil fertility is the use of high-soluble fertilizers; however, the ratio of the price of inorganic fertilizers is unfavorable to most of the smallholder farmers because of the high price. These situations create food insecurity and low income to resource poor farmers. Other alternative is to intercrop or rotate crops with legumes as a low-cost approach to adding nitrogen in the soil [4].

In Southern Africa, increased yield of subsequent cereal crops after leguminous plants has been demonstrated [5]. Brazilian experiences have shown positive effects using legumes as *Canavalia ensiformis*, *Chamaecrista rotundifolia*, *Acacia mangium*, *Inga edulis* and *Cajanus cajan* for soil reclamation [6] [7] [8], improving maize [9] and cassava (*Manihot esculenta*) productivity [10]. However, farmers grow crops solely or as intercrop. There are many crop combinations, and the combinations range from simple to complex (especially near homesteads). The predominant ones are simple and usually combine cereals with legumes. Whatever the combination, intercropping is an intensive and sustainable land use system evolved over the years through the farmers experiments [11]. To further mention, more than 80% of farmers in Africa practice intercropping. Biomass using fertilizer-shrub species is shown as a sustainable means for maintaining nutrient balances in maize and vegetables-based production systems. The leaf materials are able to supply Nitrogen to the soil [12]. There is therefore increased dependence on the use of organic waste such as Farmyard Manure (FYM), compost and crop residues.

These are highly valued because of their contribution to soil productivity.

The relationship between Soil Organic Matter (SOM) and productivity is ascribed to the role of SOM in supplying plant nutrients, enhancing water holding capacity, improving soil aggregation and hence water holding capacity, improving soil pH, supporting soil biological activity, consequently giving higher crop yield compared to treatments from which the crop residue had been removed [1]. Research efforts at Tanzania have been focused in some regions on alternatives, cost effective and locally available nutrient sources that can improve crop yields through improved soil fertility and water conservation. Green manure from *Mucuna* and lab and N-fixing legumes are some of the important organic nutrient sources—poor farmers could use for soil fertility replacement [13] [14].

In some villages of western Tanzania, most farmers use neither fertilizers nor farm yard manure [15]. Green manure, farm yard manure and N-fixing legumes are some of the important organic nutrient sources that resource-poor farmers could use for soil fertility replenishment [16]. The growing of leguminous plants and shrubs is increasingly being recommended and adopted for integration in smallholder farming systems as a source of nutrients (green manure and mulch) for crop production and fodder for livestock in the dry season. Preliminary studies to screen some leguminous pastures and shrubs for use in soil nitrogen replenishment in Kenya and Tanzania [17] [18] have reported positive results from use of *Mucuna pruriens* and *Centrosema pubescences* in cassava-legume cropping systems. Both species produce a large biomass with high concentration of Nitrogen [19].

Although many studies emphasize the use of legumes, little has been reported in Tanzania on the use of *Mucuna pruriens* and *Canavalia ensiformis* for improving soil fertility of small scale farmers. This paper aimed to evaluate the influence of *Mucuna pruriens* and *Canavalia ensiformis* to improve soil fertility and cassava root yield in Western Tanzania.

2. Methods and Materials

Kigoma region is located on shores of Lake Tanganyika at the North-West corner of Tanzania. The region is situated between longitude 29.5 and 31.5 East and latitude 3.5 and 6.5 South of the equator. The region is characterized by a unimodal rainfall regime with annual total rainfall between 500 - 1500 mm. The region is divided into four agroeconomical zones, namely the lake shore zone, the miombo forest zone, the intermediate zone and the highlands zones [20]. The main economic activity in Kigoma is farming cereal crop such as maize, beans and cassava. Besides that sale of surplus harvests, farmers earn incomes from cash crops such as oilpalm.

The experiment was carried out in Kasulu district in Kigoma Region in areas low in N and P. The study involved Fifty (50) farmers in the district. The farmers were randomly selected at the region. Rainfall and potential evapotranspiration

were measured by satellite imagens gathered data of two years (2015 and 2016) in the experimental fields region [21] (**Figure 1**).

Before initiation of the trials, composite soil samples were collected from each farmer's field for initial fertility determination using soil auger at 0 - 15, 15 - 30 cm depth from 4 randomly selected spots within the plots. The samples were analysed for pH, organic carbon, available phosphorus and exchangeable cations (Na, K, Ca and Mg) and total nitrogen (**Table 1**).

Organic carbon was determined using the Walkey and Black wet oxidation method using concentrated sulphuric acid and aqueous potassium dichromate [22]. Electrical conductivity and pH were determined in 1:2.5 ratios: distilled water paste [14] using electrical conductivity and pH meter respectively. Total Nitrogen was analysed using the semi-micro Kjeldahl procedure after digesting samples in concentrated sulphuric acid and hydrogen peroxide as an oxidizing agent.

The trial design was randomized complete randomized block (RCBD) with individual farmer field plots as replicates. Plot size was 10 × 10 m and the net plot 8 × 8 m separated by 1m distance, in which 10 rows of cassava were planted at a spacing of 1 × 1 m, within and between rows spacing respectively.

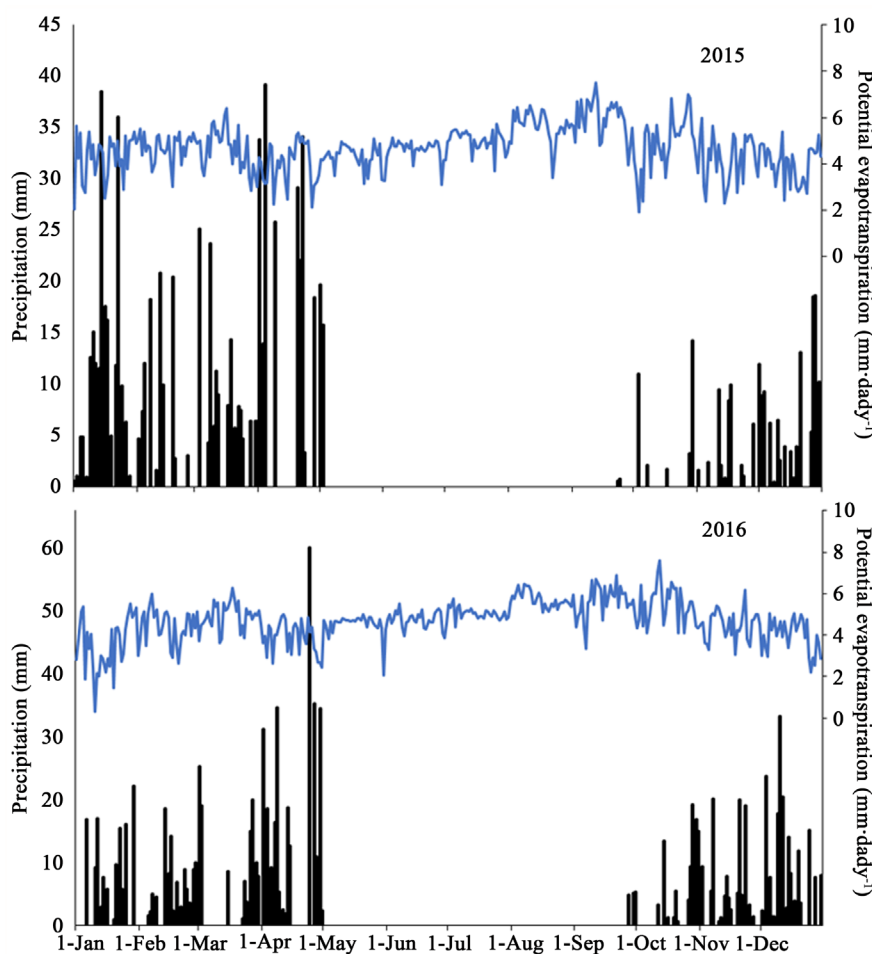


Figure 1. Precipitation in the experimental period in the region.

Table 1. Soil physical and chemical properties before planting of cover crops and cassava in February 2015.

Properties	Soil depth (cm)	Medium value
Organic C ($\text{g}\cdot\text{kg}^{-1}$)	0 to 15	3.21
Total N ($\text{g}\cdot\text{kg}^{-1}$)	0 to 15	0.29
Available P ($\text{mg}\cdot\text{kg}^{-1}$)	0 to 15	6.09
Exchangeable Ca ($\text{cmol}\cdot\text{kg}^{-1}$)	0 to 15	4.05
Exchangeable Mg ($\text{cmol}\cdot\text{kg}^{-1}$)	0 to 15	1.25
Exchangeable K ($\text{cmol}\cdot\text{kg}^{-1}$)	0 to 15	0.15
pH (in water 1:2.5)	0 to 15	6.30
	15 to 30	5.88
Bulk density ($\text{g}\cdot\text{cm}^{-3}$)	0 to 15	1.151
	15 to 30	11.358
Sand (%)	0 to 15	57.8
Silt (%)		14.2
Clay (%)		38.5

Treatments were as followed: 1) Cassava without legumes (Control); 2) Cassava with recommended mineral-fertilizer applied at the time of planting (50 kg N ha^{-1}) applied to cassava in both seasons; 3) *Mucuna pruriens* sole crop (rotation system); 4) Cassava intercropped with *Mucuna pruriens* planted two weeks after planting cassava; 5) *Canavalia ensiformis* sole crop (rotation system); 6) Cassava intercropped with *Canavalia ensiformis* planted two weeks after planting cassava. The used cassava variety from IITA was Mkombozi with 125 days to maturity. Sole cassava was grown in the first season 2015 and 2016 in order to test the residual value of *Mucuna pruriens* and *Canavalia ensiformis*.

Phosphorus was applied to all treatments at a rate of $45 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ to one season. Legumes-*Mucuna* and *Canavalia ensiformis* intercropped in between cassava row 30 cm apart, while *Mucuna* and *Canavalia ensiformis* sole crop-75 cm between rows, 0.3 m within rows. At harvesting, all cassava in the eight middle rows was harvested. From the middle eight rows, root of the cassava plants were harvested and weighted. Subsamples were taken to laboratory to oven dry to 65°C for estimation of harvested dry weight.

Cover plants samples were ground to 0.5 mm and digested according to [23] in order to determine the nutrients accumulation on shoot. Total N was determined with ammonium sensitive electrode. Ca, Mg, and K were analyzed by atomic absorption spectrophotometer. Total P was determined by the malachite green colorimetric procedure [24]. A corresponding value cost of the nitrogen accumulated by the green manure plants shoot, using the urea chemical fertilizer, was calculated to each cropping system. The local price of US500 per tonne of urea (45% nitrogen concentration) was used.

Mean cassava yield data of two years (2015 and 2016) were used in the partial budget analysis [25]. The gross benefit was calculated as average adjusted cassava yield ($\text{kg}\cdot\text{ha}^{-1} \times \text{field price}$) that farmers receive for the sale of the crop. Total variable cost was calculated as the sum of all cost that is variable or specific to a treatment against control.

$$\text{TVC} = a + b + c + d \quad (1)$$

where:

TVC: Total variable cost ($\text{US\$ ha}^{-1}$);

a: cassava cuttings ($\text{US\$ ha}^{-1}$);

b: legume seeds ($\text{US\$ ha}^{-1}$);

c: fertilizers ($\text{US\$ ha}^{-1}$);

d: labour ($\text{US\$ ha}^{-1}$).

Net benefit was calculated by subtracting total variable cost from gross benefit.

$$\text{NB} = \text{GB} - \text{TVC} \quad (2)$$

where:

NB: net benefit ($\text{US\$ ha}^{-1}$);

GB: gross benefit ($\text{US\$ ha}^{-1}$);

TVC: total variable cost ($\text{US\$ ha}^{-1}$).

The marginal rate of return (MRR) was calculated as the ratio of differences between net benefits to successive treatments to the difference between total variable costs of successive treatments.

$$\text{MRR} = \frac{\text{RL}}{\text{CT}_v}$$

where:

MRR: marginal rate of return;

NB: net benefit;

TVC: Total variable cost.

Data from the trials were organized and analysed using the GENSTAT statistical programme. Significant differences at $p < 0.05$ are indicated by DMRT. Production costs for economic analysis were analysed through partial budget analysis.

3. Results and Discussion

Mucuna and *Canavalia ensiformis* were found to produce almost similar amount of biomass. The two legumes, however, produced higher biomass in rotation than intercropping system (Table 2). The amount of biomass produced by *Mucuna* and *Canavalia ensiformis* in rotation system was $6.28 \text{ t}\cdot\text{ha}^{-1}$ and $5.31 \text{ t}\cdot\text{ha}^{-1}$, respectively. In intercropping system, amount of biomass produced by the two legumes was 5.31 and $3.82 \text{ t}\cdot\text{ha}^{-1}$, respectively. The lower biomass production in intercropping system was probably attributed to the shading effect from the cassava crop. Through observation, the weed density was slightly lower in *Mucuna pruriens* plots than in *Canavalia ensiformis*, but all were far less than in control.

Table 2. Mean dry matter (biomass) yield, Nitrogen content, Nitrogen yield and simulated cost of replacement by urea of cover crops during the 2015 and 2016 growth seasons.

Cropping systems	Biomass (t·ha ⁻¹)	Nitrogen content (%)	Nitrogen (kg·ha ⁻¹)	Cost saving (US\$ ha ⁻¹)
Mucuna cassava rotation	6.28	2.60	163.28	181.42
Cassava Mucuna intercropping	5.05	2.53	127.77	141.96
Canavalia cassava rotation	5.31	2.40	127.44	141.60
Cassava Canavalia intercropping	3.82	2.34	89.39	99.32

Effect of rotation and intercropping of cassava with *Mucuna* and *Canavalia ensiformis* on cassava yield. Legume incorporation and N fertilizer significantly affected cassava yield in the two seasons 2015 and 2016 seasons (**Table 3**). Cassava yield was significantly higher with incorporation of legumes than the control for the two seasons. Rotation and intercropping of cassava with *Mucuna* and or *Canavalia ensiformis* increased cassava yield significantly over control (Continuous sole cassava) during the second season (**Table 3**). Mean separation of the responses showed that more cassava yield was obtained under rotation system of the legumes. The difference recorded between legumes could be attributed to their quality and quantity of biomass produced [26].

In general, on average they increased cassava yield over the control treatment by 118% and 56% under rotation and intercropping systems respectively. Jarvis *et.al*, 2012, reported that cassava yield was more than doubled by incorporation of three month old *Mucuna* and *Crotalaria* grown in alluvial soil on the island of Java, Indonesia. These results showed that the two legumes did not differ significantly on their effects on cassava yield under the different cropping systems, meaning that the two legumes have almost equal potential as source of nitrogen for soil fertility replenishment. The higher effect of the legumes on cassava yield observed under rotation over intercropping system could be due to a higher biomass produced and incorporated into the soil.

Comparison of the mineral fertilizer treatment (50 kg N ha⁻¹) with two legumes under the two cropping systems showed that mineral nitrogen fertilizer was not statically different from the two legumes under the two cropping systems. However, the mean cassava yield of the mineral fertilizer was slightly lower but higher than the mean cassava yield under rotation and intercropping systems, respectively. The inferior effect of the mineral nitrogen fertilizer over the green manure under rotation system could probably be attributed to excessive leaching effect as a result of high rainfall during the second season. Increase in cassava yield with the incorporation of forage legumes had been reported by several researchers [27].

In the present study we have shown that nitrogen content of the two legumes was high (*Mucuna* 2.60% and *Canavalia* 2.40%) and there was no much difference in nitrogen content of the biomass harvested from the two different cropping systems (**Table 4**). The high nitrogen content of the two legumes indicated

Table 3. Effect of legume incorporation after two years of growth and N fertilizer on cassava yield.

Treatment	Cassava yield (t·ha ⁻¹)		Yield increase (%)
	2015	2016	
Control	1.44c	2.00c	0
Cassava + 50 kg N ha ⁻¹	2.76ab	2.83b	88
Mucuna rotation	3.14a	3.79a	118
Cassava Mucuna intercropping	2.41b	2.80b	62
Canavalia rotation	3.03ab	3.28ab	120
Cassava Canavalia intercropping	2.25b	2.39b	56
Mean	2.51	2.85	
CV (%)	3.8	8.4	

Means followed by the same letter are not significantly different according to DMRT ($P > 0.05$).

Table 4. Nutrient uptake (kg·ha⁻¹) of cassava planted after *Mucuna pruriens* and *Canavalia ensiformis* and control in 2015 and 2016.

Cropping systems	Nitrogen		Phosphorus		Potassium		Calcium		Magnesium	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Mucuna pruriens	102.4a	63.2a	18.6ab	13.2ab	115.0ab	68.2a	22.2a	13.0bc	9.7ab	9.7ab
Canavalia	57.8b	45.6b	14.7bc	11.9ab	86.1bc	50.0bc	14.4bc	11.0c	8.1bc	8.1bc
Control (no fertilizers)	40.4c	29.0c	6.5c	4.8b	40.7c	37.0c	6.4c	5.6c	5.2c	6.0c

Means followed by the same letter are not significantly different according to DMRT ($P > 0.05$).

that they can be used as source of nitrogen for soil fertility replenishment [28] have also reported similar levels of nitrogen content from the two legumes.

The total N uptake of cassava was quite different between treatments. More was taken up in *Mucuna pruriens* followed by *Canavalia ensiformis* than after control in both years (Table 4). The same pattern was found for K, Ca, and Mg. The P uptake of cassava after *Mucuna pruriens* was higher than after *Canavalia ensiformis* and control. The N amounts taken up were consistently lower in 2016 than 2015. The uptake of other nutrients did not differ between years. [29] found an equivalent of 119 kg·ha⁻¹ for *Mucuna* spp. in the Rwanda Highlands leading to cassava yield of 3.13 kg·ha⁻¹. *Mucuna* produced 22.3 kg·ha⁻¹ of fresh matter biomass in their trials.

Economic analysis (Table 5) following partial budget analysis showed that intercropping cassava with *Mucuna pruriens* and *Canavalia ensiformis* gave higher net benefit than when the two legumes are grown under rotation system. In rotation system cassava crop is forgone in the first season and the only benefit that the farmer could get is improved soil fertility.

Comparison of the mineral nitrogen treatment with the two legumes as a source of nitrogen indicated that a higher net benefit was obtained from use of

Table 5. Total variable cost (TVC), net benefit (NB) and marginal rate of return (MRR) of cassava cropping systems¹.

Cropping systems	TVC ²	NB ³	MRR ⁴
	US\$ ha ⁻¹	US\$ ha ⁻¹	
Control	38.83	69.35	1.79
Mucuna-Cassava rotation	29.69	64.59	2.18
Cassava-Mucuna intercropping	30.84	107.31	3.48
Canavalia-rotation	29.69	65.33	2.20
Cassava-Canavalia ensiformis intercropping	30.84	109.50	3.55

1. = Price of cassava crop, cassava cuttings, and legume seeds = 3.65 \$, 45.68 and 45.68 \$-kg⁻¹, respectively.

the two legumes than mineral fertilizer. Reasons for the lower net benefit recorded from the mineral N treatment versus the legumes could be attributed to high price ratio of mineral fertilizers to price ratio of cassava crop. Price of mineral fertilizers has been going up over the years whereas that cassava remained constant or even went down.

However, farmer's evaluation of the treatments showed that Mucuna was chosen as first priority for soil fertility and cassava yield improvement. However, its habit of coiling on cassava, made Mucuna suitable in rotation system. *Canavalia ensiformis* was chosen as best-bet because it can be used both in rotation as well as in intercropping system as it does not coil on cassava. Mucuna was considered to be equally useful as *Canavalia ensiformis* in terms of cassava yield improvement, however, its habit of coiling on cassava and strangle it, made it to be suitable only in rotation systems. But acceptability of the farmers to use the two legumes for soil fertility improvement under rotation system was low because the legumes do not have other economic benefit(s) other than soil fertility improvement.

4. Conclusions

Use of nitrogen fertilizers in the study area is important for improving cassava yields. Farmers who can afford to apply mineral nitrogen fertilizers (50 kg-ha⁻¹) or above can expect cassava yield improvement of about 88% than farmers who do not use mineral fertilizer. However, farmers that can use Mucuna and *Canavalia ensiformis* legumes as source of nitrogen with cassava can get higher cassava about 118% than those farmers who do not use Nitrogen fertilizers. Also, farmers who could intercrop cassava with either of the two legumes can expect cassava yields of about 56% than those farmers who do not use mineral nitrogen fertilizers.

Based on economic analysis, higher net benefit was obtained from intercropping than rotation system either of the two legumes. Rotation system had lower net benefits because of cassava crop that was forgone during the first season, thus making net return for this treatment low.

It was concluded that both Mucuna and *Canavalia ensiformis* legumes have

high potential as organic nitrogen source for soil fertility restoration, and hence cassava yield improvement.

More studies are needed in future to study on; amount of nitrogen contributes to the soil by the two legumes through biological fixation and effect of the two legumes as cover crop for soil moisture conservation and weed suppression.

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