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ORIGINAL ARTICLE

Productivity of yam-based systems with herbaceous legumes and short fallows in the Guinea-Sudan transition zone of Benin

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Abstract The principal driving force in agricultural research is to increase the yield of food crops. For farming to remain productive, it will be necessary to replenish the nutrients removed or lost from the soil. The objective of this study was to determine the impact of yam-based systems on soil productivity (dry matter production, nutrients recycled or removed, profitability and soil fertility changes). We compared smallholders' traditional systems (1-year fallow of *Andropogonon gayanus* -yam rotation; maize-yam rotation) with yam-based systems with legumes (intercropped *Aeschynomene histrix* with maize-yam rotation; intercropped *Mucuna pruriens* with maize-yam rotation). The production of dry matter (tubers, shoots), nutrients removed or recycled, and soil properties were significantly improved on yam-based systems with legumes in comparison with traditional systems. Year × Treatment interactions influenced significantly the tuber dry matter production. Site × Treatment and Treatment × Farmer interactions affected significantly nutrients removed or recycled. The amount of nutrients recycled or removed was dependent on the dry matter production that, in turn, depended on soil fertility, rainfall and farmers' effect. Yam-based systems with legumes brought a higher present value than traditional systems in the first 4 years and appeared attractive for land, labour and cash productivities.

Keywords *Dioscorea rotundata* · Crop rotation · Nutrient recycling · Herbaceous legumes · Net present value

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Introduction

Yam (*Dioscorea* spp.) is a tuber crop widely cultivated in the humid and sub-humid lowland regions of West Africa and the Caribbean (Onwueme and Haverkort 1991). More than 90% of the worldwide production (40 million metric tons of fresh tubers year^{-1}) comes from West Africa (FAOSTAT 2009). Yam is grown in traditional cropping systems as the first crop after virgin forest or after a long fallow period yielding about 10 t of fresh tubers ha^{-1} $year^{-1}$ (Carsky et al. 2001). But when the soil fertility is high, the potential yield of species *Dioscorea rotundata* (*D. rotundata*) can easily reach 25–30 t ha^{-1} (Vernier and Dossou 2000). The increase in yam production has been due more to land expansion than to crop improvement potential (FAO 2003). For example, the yield increase of 7.6% in West Africa was mainly due to an increase in area of 7.2% and only 0.4% was due to an improvement in crop productivity itself (FAO 2003).

Yam is a demanding crop in terms of organic matter and soil fertility, especially the most appreciated and market-valued cultivars (early maturing *D. rotundata*) used for the popular dish called *Fufu* (pounded yam) (Vernier and Dossou 2003). Yam tubers are indeed known to export from the soil large quantities of nitrogen (N) and potassium (K) (O'Sullivan and Ernest 2008). According to Degras (1986), the harvest of 30 t ha^{-1} of fresh yam yield takes up 120 N kg ha^{-1}, 5.1 P kg ha^{-1}, and 111 K kg ha^{-1}.

Yam cultivation in West Africa is now confronted with the scarcity of fertile soil available for clearing (Cornet et al. 2006). In Benin nowadays, farmers hardly have the possibility to rely on long duration fallow and yam is being cultivated in 1 or 2-year herbaceous fallow–yam or maize-yam rotation systems with manual incorporation of residue into the soil (Doumbia 2005; Maliki 2006). Smallholder farmers removed important quantities of nutrient from their soil without applying a sufficient quantity of manure or fertilizer to replenish the soil (Saidou 2006).

The decline in yam yields under continuous cultivation has led to the largely accepted conclusion that yam requires a high level of natural soil fertility (organic matter and nutrient) (O'Sullivan and Ernest 2008). Since the demand for yam keeps increasing due to the continued population growth, reserves of arable land are diminishing, and fallow duration is decreasing. It is becoming necessary to sustainably increase yam productivity in sedentary cropping systems (O'Sullivan and Ernest 2008). There is a dire need therefore to assess in farmers' conditions the economic performance of sustainable cultivation techniques. Ongoing soil degradation could be reduced by the adoption of new farming techniques such as improved fallows of herbaceous legumes (Carsky et al. 1998; Becker et al. 1999).

Studies on improved fallow practices are generally grain-oriented (cereals, such as maize), whereas very little has been done on root and tuber crops, especially yam. Comparative studies are lacking that assess the effects of yam-based technologies with herbaceous legumes intercrops and short fallows on yam production and soil properties in the savannah transition agro-ecological zone of Benin. We compared in a perennial experiment for 4 years, with 2-year rotations, smallholder farmers' traditional rotations maize-yam or 1-year *Andropogonon gayanus* fallow–yam, with rotations intercropped *Aeschynomene histrix* with maize-yam or intercropped *Mucuna pruriens* with maize-yam. The amount of nutrients recycled or removed in yam-based cropping systems could be dependent on plant dry matter production that, in turn, depend on climate (rainfall) and soil fertility conditions. The objective of this study was to determine the impact of yam-based systems on soil productivity (dry matter production, nutrients recycled or removed, profitability and soil fertility changes).

Materials and methods

Study sites

The study was carried out in the Guinea-Sudan transition zone of Benin (centre of Benin) in four sites: Miniffi (District of Dassa-Zoumè), Gomè (Glazoué), Akpéro, and Gbanlin (Ouessè) within latitudes 7°45′ and 8°40′ North and longitudes 2°20′ and 2°35′ East. The climate is tropical with a bimodal rainfall pattern. The average annual rainfall levels during the study period were 1,052 mm (2002), 1,386 mm (2003), 983 mm (2004) and 797 mm (2005) with a variable tendency from one site to another (Fig. 1). The soils are plinthosols (Gbanlin and Akpéro), and luvisols (Miniffi and Gomè) (Agossou and Mouïnou 2002). Miniffi, Akpéro and Gbanlin are located on a plateau while Gomè is on lowland. Akpéro is close to forest while Gbanlin, Miniffi and Gomè are far. There is a rising gradient of fertility from the continuous cropping system on degraded soils towards the forests. This degradation is related to soil organic matter decrease, which leads to nutrient depletion (nutrients removed in the crop harvest, leaching and erosion). Vegetation is a degraded woody savannah type. Maize, yam, cassava and groundnut are annual cropping systems and the cash crops are cotton and soybean. Mineral fertilizer application appears to be

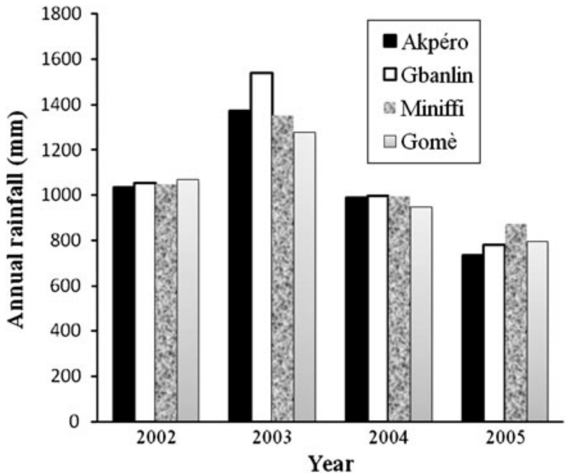

Fig. 1 Annual rainfall distribution in the four village sites (Akpéro, Gbanlin, Miniffi, Gomè) in the 2002–2005 cropping seasons, in the Guinea-Sudan transition zone of Benin

essential. Smallholder farmers use fertilizers on maize on depleted soils depending on cash and inputs availability. Cotton is not grown in mixed cropping, but as pure crop in rotation with other crops (maize or sorghum). In this cropping pattern the subsequent cereals benefit from the residual effect of inorganic fertilizer applied to cotton (150 kg ha^{-1} of NPK-SB 14-23-14-5-1 plus 50 kg ha^{-1} of urea).

On-farm experiment

The concept of the experiment was to produce residue biomass followed by planting yam in rotation cropping systems.

We carried out two-year rotations experiment of yam-based cropping systems repeated twice (2002–2005) on-farm with single-harvest late maturing variety of yam "Kokoro" (*Dioscorea rotundata*). This is one of the most cultivated species in the study area due to its good aptitude for conservation and processing into dried tubers (the so-called chips), flour, and starchy paste (locally called *amala*) (Vernier and Dossou 2003). We conducted the experiment with 32 farmers, eight in each site (Miniffi, Gomè, Akpéro, and Gbanlin). For each of them, we used a randomized block design with four replications and four levels of treatment. Plot size was 10 m × 10 m (total of 1,600 m^2 per farm). The four treatments were as follows (Table 1):

- T0 (Control 1): 1-year fallow-yam rotation, which is a common practice in the area. A natural fallow of *Andropogon gayanus* grass was grown in the first year.
- TM (Control 2): maize-yam rotation, which is also a common practice in the area. Maize was planted (at 80 cm × 40 cm) in April of the first year.
- TMA: Intercropped *Aeschynomene histrix* with maize-yam rotation: Maize was planted (at 80 cm × 40 cm) in April of the first year. *A. histrix* seeds (7 kg ha^{-1}) were mixed with dry sand (3/4 sand–1/4 seeds) and sown 2 weeks after the maize.
- TMM: Intercropped *Mucuna pruriens* with maize-yam rotation. Maize was planted (at 80 cm × 40 cm) in April of the first year. *M. pruriens* seeds (25 kg ha^{-1}) were sown at spacing 80 cm × 40 cm in May 6 weeks after the maize.

On treatments TM, TMA and TMM, 100 kg ha^{-1} NPK fertilizer (14% N, 10% P, 11.7% K) was applied to maize in April and 50 kg ha^{-1} urea (46% N) in June. The maize was harvested in July. The grainless *M. pruriens* and *A. histrix* crops were mowed 140 and 180 days respectively after planting. Organic matter was incorporated in mounds and left on the surface as mulch in October, and then yam was planted directly on these mounds, without mineral fertilization.

With recurring drought stress exacerbated by highly variable and unpredictable rains in the study area, some farmers grow a second crop, which often fail. This corroborates the great interest of the maize/leguminous crop when no second crop is planned.

Data collection

Composite soil samples were collected in each field before the beginning of the experiment along plot transects at soil depths of 0–10 cm and 10–20 cm (32 farm fields × 2 depths = 64 samples) in order to determine soil characteristics. At the end of 2005 before yam harvesting, composite soil samples were collected at the same depths in the mounds along plot transects (32 farm fields × 4 treatments × 2 depths = 256 samples).

Prior to ridging, in four 1 m^2 quadrats within each plot the aboveground biomass of herbaceous legumes and fallow was collected in October 2002 and 2004. The biomass samples were dried at 60°C until constant weight and then dry weight was determined. At maturity, maize grain and stover were harvested per row on each plot and DM determined. The fresh yam

Table 1 Design of yam-based cropping systems with 1-year fallow of *Andropgon gayanus*-yam rotation, Maize + 100 kg $N_{14}P_{23}K_{14}$ + 50 kg Urea-yam rotation, *Aeschynomene histrix*/maize intercropping + 100 kg $N_{14}P_{23}K_{14}$ + 50 kg Urea-yam rotation and *Mucuna pruriens* var *utilis*/maize intercropping + 100 kg $N_{14}P_{23}K_{14}$ + 50 kg Urea-yam rotation in the 2002–2003 and 2004–2005 cropping seasons in four villages in Benin

Treatment
T0 (control 1): (1-year fallow of *Andropogon gayanus*) − yam rotation
TM (control 2): (Maize + 100 kg $N_{14}P_{23}K_{14}$ + 50 kg Urea) − yam rotation
TMA: (*Aeschynomene histrix*/maize intercropping + 100 kg $N_{14}P_{23}K_{14}$ + 50 kg Urea) − yam rotation
TMM: (*Mucuna pruriens* var *utilis*/maize intercropping + 100 kg $N_{14}P_{23}K_{14}$ + 50 kg Urea) − yam rotation

tuber weight and DM of yam tubers and shoots were estimated on each plot in December 2003 and 2005.

Soil and plant nutrients content

The plant nutrient content was estimated according to the biomass amount.

Soil and plant macronutrients content (N, P, and K) were analyzed. Nitrogen (N) content was analyzed using the Kjeldahl method, available phosphorus with the Bray 1 method, potassium with the FAO method, organic carbon with the Walkley and Black method, soil fractionation with Robinson method and pH (H2O) (using a glass electrode in 1:2.5 v/v soil solution). Only yam tuber and maize grain were removed, and all other plants parts were recycled (*A. gayanus*, maize stover, yam shoot, *A. histrix* and *M. pruriens*). Yam or *M. pruriens* shoot included leaves. Nutrient removed or recycled was calculated as a summation of nutrient concentration time dry matter of the respective plant parts. Dry matter removed or recycled was calculated as a summation of dry matter of the respective plant parts.

Statistical analysis

Analysis of variance (ANOVA) was applied to the DM production (tubers, shoots), nutrient contribution to the systems and soil properties at depths (0–10 and 10–20 cm) using a randomized block design and a partial nested model with five factors: Year, Replication, Farmer, Site, and Treatment. The random factors were "Year" and "Replication"; "Farmer" was also considered as nested within "Site". The fixed factors were "Treatment" and "Site". Sites were considered as fixed, based on certain criteria such as landscape (lowland, plateau), soil type, population density and initial soil fertility. The general linear model (GLM) (SAS 1996) was computed to assess the interactions between the factors involved. When there were significant interactions between the main factors, interaction diagrams were drawn to describe the effect of each factor. Least square means and standard error were also computed for factor levels. Treatment effects were determined by analysis of variance using computer package SPSS version 11 (SPS Sinc. ©2002, Chicago, Illinois, USA). Significance was regarded at $P \leq 0.05$.

Economic analysis

A simple financial analysis was performed to evaluate the profitability of each yam-based cropping system. We considered the time horizon 2002–2005 (4 years) and a discount rate of 10%, World Bank standard, not too far from bank interest rates. The choice of discount rate is always an object of controversy among economists (Stern 2006). We considered discount rates ranging from 0 to 50% for sensitivity analysis.

The net present value is as follows:

$$NPV = (TPR - TPC)$$

or

$$NPV = \sum_{i=1}^{n} \frac{R_n}{(1+r)^n} - \sum_{i=1}^{n} \frac{D_n}{(1+r)^n} = \sum_{i=1}^{n} \frac{R_n - D_n}{(1+r)^n} \quad (1)$$

NPV = Net Present Value (US$), TPR = Total Present Revenue (US$), TPC = Total Present Cost (US$), R_n = Revenue in the year n (US$), D_n = Cost in the year n (US$), r = Discount rate (%).

Returns on investment (RI %) were also computed through the formula:

Table 2 Initial soil characteristics at the beginning of the experiment at 0–10 and 10–20 cm layers in four villages in Benin

Depth (cm)	Akpéro		Gbanlin		Miniffi		Gomè	
	0–10 "Plinthosols"	10–20	0–10 "Plinthosols"	10–20	0–10 "Luvisols ferriques"	10–20	0–10 "Luvisols ferriques"	10–20
Clay%	6.6 ± 0.3	7.3 ± 0.3	5.8 ± 0.3	5.7 ± 0.3	6.8 ± 0.3	6.5 ± 0.3	6.8 ± 0.3	7.9 ± 0.4
Silt%	11.7 ± 0.6	11.8 ± 0.6	5.8 ± 0.3	5.6 ± 0.3	6.8 ± 0.3	7.1 ± 0.3	16.1 ± 0.8	17.4 ± 0.8
Sand%	81.7 ± 0.9	80.9 ± 0.9	88.4 ± 0.5	88.7 ± 0.5	86.4 ± 0.6	86.4 ± 0.6	77.1 ± 1.1	74.7 ± 1.2
C%	1.31 ± 0.1	1.05 ± 0.1	0.69 ± 0.0	0.79 ± 0.0	0.80 ± 0.0	0.64 ± 0.0	0.65 ± 0.0	0.54 ± 0.0
N%	0.112 ± 0.0	0.092 ± 0.0	0.060 ± 0.0	0.080 ± 0.0	0.081 ± 0.0	0.056 ± 0.0	0.073 ± 0.0	0.062 ± 0.0
C:N ratio	11.7 ± 0.0	11.4 ± 0.1	11.7 ± 0.0	9.7 ± 0.0	9.8 ± 0.3	11.4 ± 0.1	8.9 ± 0.0	8.7 ± 0.0
OM%	2.25 ± 0.1	1.81 ± 0.1	1.19 ± 0.0	1.36 ± 0.0	1.37 ± 0.1	1.10 ± 0.1	1.12 ± 0.1	0.93 ± 0.0
PH water	6.7 ± 0.3	6.7 ± 0.3	6.6 ± 0.3	6.3 ± 0.3	6.7 ± 0.3	6.8 ± 0.3	6.6 ± 0.3	6.6 ± 0.3
Bray P	20.1 ± 1.1	14.9 ± 0.6	7.0 ± 0.3	4.0 ± 0.2	11.0 ± 0.5	3.0 ± 0.2	8.0 ± 0.4	4.0 ± 0.2

Data are the means ± SD (standard deviation)

$$RI = 100 \times (NPV/TPC), \quad (2)$$

with RI > interest rate on capital, profitability is implied (2).

Labour productivity US$ per man-day (LP) was given by:

$$LP = NPV/L, \quad (3)$$

where L (man day) is the total labour requirement (3).

Economic yields for maize were based on 15% moisture content while that of yam was based on fresh weight. Costs of production were divided into land (hired land cost US$ ha^{-1} $year^{-1}$), inputs (maize, yam and legume seeds, fertilizers costs) and labour (farm activities costs for yam-based cropping systems establishment and management). Land, inputs and labour costs were determined based on local prices in the 2002–2005 cropping seasons. We considered the average annual prices for food crops (maize and yam) based on the prevailing market price (Glazoué market in the central Benin). All amounts of money are expressed in US dollars (501.8 FCFA to US$ 1, 1 December 2010).

Results

Soil chemical properties

The initial soil organic matter (SOM) contents were low in all fields, ranging from 0.93 and 2.25%, and the C:N ratio ranged from 8.7 to 11.7 (Table 2). Available P levels were very low and varied from 3.0 to 20.1 ppm. Soil N concentration ranged from 0.056 to 0.112%. N, P and SOM contents were significantly higher in 0-10 cm than in 10–20 cm depth, except at Gbanlin site for N and SOM. Gomè site showed for both soil depths, the lowest values of carbon (C%), N%, P (ppm), and organic matter (%) whereas Akpéro had the highest values. The end of study soil analysis showed soil chemical properties (SMO%, N %, P (ppm), K^+ cmol kg^{-1}, and PH water) significantly higher in TMA and TMM than in traditional systems T0 and TM ($P < 0.001$). Soil clay contents were significantly higher in TMA, TMM and T0 than in TM ($P < 0.001$) (Table 3). SOM, N, P, K, and pH increased by 10, 22, 19, 29 and 10% respectively for both soil depths in TMA and TMM whereas soil clay contents increased by 8%.

DM production and nutrient contribution to the systems

Table 4 shows the average nutrient composition in different sources of biomass dry matter (DM). Intercropped *M. pruriens* with maize-yam rotation (TMM) gave more DM and nutrient recycled or removed than the intercropped *A. histrix* with maize-yam rotation (TMA). The ANOVA partial nested model on DM production (tubers, shoots) showed significant differences between treatments ($P < 0.001$) (Table 5). Year × Treatment interactions influenced significantly the tuber dry matter production ($P < 0.01$).

Table 3 End of study soil characteristics at 0–10 cm and 10–20 cm soil layers in four villages in Benin

Soil characteristics	Depth (cm)	T0	TM	TMA	TMM	LSD
Clay%	0–10	5.82a	5.52b	5.94a	5.96a	0.30
	10–20	5.93a	5.61b	6.01a	6.05a	0.32
Silt%	0–10	9.55a	9.68a	9.52a	9.53a	ns
	10–20	9.71a	9.81a	9.67a	9.65a	ns
Sand%	0–10	84.63a	84.80a	84.54a	84.51a	ns
	10–20	84.36a	84.58a	84.32a	84.30a	ns
C%	0–10	0.77c	0.76c	0.82b	0.87a	0.05
	10–20	0.72c	0.70c	0.78b	0.83a	0.05
N %	0–10	0.06d	0.08c	0.09b	0.10a	0.01
	10–20	0.07c	0.09b	0.10a	0.10a	0.01
C:N ratio	0–10	12.0a	10.1b	9.3c	9.0c	0.7
	10–20	11.1a	8.3b	8.3b	8.3b	0.7
MO%	0–10	1.32c	1.31c	1.41b	1.49a	0.08
	10–20	1.24c	1.21c	1.34b	1.43a	0.09
Bray P mg kg^{-1}	0–10	10.21c	11.84b	13.43a	14.35a	1.23
	10–20	8.75c	10.66b	11.41ab	12.29a	1.36
K^+ cmol kg^{-1}	0–10	0.33d	0.42c	0.50b	0.54a	0.04
	10–20	0.27d	0.33c	0.41b	0.45a	0.04
PH water	0–10	6.0c	6.7b	7.1a	7.0a	0.17
	10–20	6.0c	6.6b	7.1a	7.0a	0.18

Means with the same letter within row are not significantly different ($P < 0.05$)

SD standard deviation, *LSD* least square difference at 5%, *ns* no significant

Amounts of N, P, and K removed in yam tuber and those recycled in yam shoot were significantly higher in TMA and TMM than in traditional systems T0 and TM (Table 6). Site × Treatment and Treatment × Farmers' interactions were significant ($P < 0.001$).

Relative profitability of yam-based cropping systems

Table 7 shows the estimated total present production cost (TPC), the net present value (NPV) (U$$ ha^{-1} $year^{-1}$) and labour productivity (LP) (U$$ man-day^{-1}) and return on investment (RI) (%) of yam-based cropping systems with a discount rate of 10%. The yam-based cropping systems with herbaceous legumes (TMA and TMM) resulted in the highest NPV (US$757 and US$822) and corresponded to a return on investment (RI) that ranged from 145 to 152% respectively. The traditional yam-based systems (T0 and TM) showed the lowest NPV (US$301 and US$178) and RI ranged from 62 to 29%. TMM or TMA showed the highest labour productivity (US$7 man-$day^{-1}$) whereas T0 and TM had the lowest (US$5 and US$2 man-day^{-1}) respectively.

Figure 2 depicts the NPVs of yam-based cropping systems with herbaceous legumes (TMA and TMM) in comparison with controls (T0 and TM) with a time horizon of 4 years (2002–2005) according to various discount rates (0–50%). The discount rates reflect the alternative of the investment opportunities and the diverse farmers' preference for investments rather than an immediate income. For various discount rates, TMA and TMM would bring a significantly higher present value than T0 and TM in the first 4 years.

Discussion

Impact of yam-based cropping systems on soil properties

Soil clay contents improvement in T0, TMA and TMM at the end of the perennial experiment could be related

Table 4 Nutrient composition in different sources of biomass dry matter (*A. gayanus*, maize, *A. histrix*, *M. pruriens,* yam shoot, yam tuber, maize grain) in the 2003 and 2005 cropping seasons in four villages in Benin

	Source of biomass	N (%)	P (%)	K (%)
2003 cropping season	*A. gayanus* stover	1.16 ± 0.28	0.13 ± 0.09	0.49 ± 0.16
	Maize stover	0.91 ± 0.16	0.13 ± 0.03	0.50 ± 0.12
	Maize grain	2.17 ± 0.22	0.33 ± 0.10	0.27 ± 0.08
	A. histrix stover	2.02 ± 0.31	0.14 ± 0.05	0.63 ± 0.03
	M. pruriens stover	2.21 ± 0.59	0.18 ± 0.08	0.63 ± 0.02
	Yam shoot	1.10 ± 0.24	0.15 ± 0.03	1.38 ± 0.20
	Yam tuber	0.38 ± 0.10	0.04 ± 0.02	0.42 ± 0.05
2005 cropping season	*A. gayanus* stover	1.20 ± 0.37	0.13 ± 0.10	0.50 ± 0.16
	Maize stover	1.05 ± 0.30	0.15 ± 0.05	0.55 ± 0.14
	Maize grain	2.15 ± 0.23	0.32 ± 0.11	0.25 ± 0.08
	A. histrix stover	2.02 ± 0.73	0.14 ± 0.08	0.63 ± 0.20
	M. pruriens stover	2.20 ± 0.40	0.18 ± 0.08	0.65 ± 0.10
	Yam shoot	1.08 ± 0.24	0.12 ± 0.04	1.35 ± 0.17
	Yam tuber	0.37 ± 0.10	0.04 ± 0.01	0.41 ± 0.06

Data are the means ± SD (standard deviation)

Table 5 Dry matter (t ha^{-1}) of yam tubers removed at harvest and yam shoots recycled in the 2002–2003 and 2004–2005 cropping seasons in four villages in Benin

	2002–2003 cropping seasons					2004–2005 cropping seasons				
	T0	TM	TMA	TMM	LSD	T0	TM	TMA	TMM	LSD
DM removed (t ha^{-1})										
Yam tubers	5.09b	3.83c	7.20a	7.33a	0.51	4.34b	3.02c	8.00a	8.02a	0.55
DM recycled (t ha^{-1})										
Yam shoots	1.27b	0.96c	1.80a	1.83a	0.13	1.09b	0.76c	2.00a	2.00a	0.14

Means with the same letter within row are not significantly different ($P < 0.05$)

DM dry matter, *LSD* least square difference at 5%

to the increase of mounds humidity in these plots contributing to the enhancement of the earthworms' activity. Indeed, smallholders mulched the mounds to protect seed yam from solar radiations. The Earthworm casts were not measured. In general, smallholders perceived earthworms' casts as an indicator of soil fertility. Earthworm casts on the mounds could regulate soil porosity, as a volume of voids equivalent to that of casts is created inside the soil (Birang 2004). Earthworms could increase the clay content of surface soil by selectively bringing up soil richer in clay (Birang 2004). Furthermore, soil chemical characteristics were higher in (TMA, TMM) than in (T0, TM). Organic materials supplied could contribute directly to the building of soil organic matter (SOM), which itself performs diverse functionary roles in improving the physical, chemical and biological composition of the soil (Sanginga and Woomer 2009).

DM production

DM of yam tubers removed and shoots recycled on TMA and TMM were significantly higher in the 2005 (dry year) than in the 2003 (rainy year). In our study, rainfall distribution varied among years and sites, particularly from January to May, i.e. 20 weeks after yam was planted. The production of yam yield mainly depends on the effective duration of the transition to autotrophy, i.e. the stage of vegetative development of the crop without the supply of reserves from the mother tuber (Degras 1986). The beginning of autotrophy, which occurs when real leaves grow, is determined by

Table 6 Nitrogen, Phosphorus and Potassium content (kg ha^{-1}) removed in yam tubers at the crop harvest and those recycled in yam shoots in the 2002–2003 and 2004–2005 cropping seasons in four villages in Benin

	2002–2003 cropping seasons					2004–2005 cropping seasons				
	T0	TM	TMA	TMM	LSD	T0	TM	TMA	TMM	LSD
Plant nutrients removed (kg ha^{-1})										
Yam tubers										
N	19.35b	14.57c	27.37a	27.84a	1.95	16.49b	11.48c	30.41a	30.47a	2.08
P	1.99b	1.49c	2.81a	2.86a	0.20	1.69b	1.18c	3.12a	3.13a	0.21
K	21.39b	16.10c	30.25a	30.77a	2.16	18.23b	12.70c	33.61a	33.68a	2.30
Plant nutrients recycled (kg ha^{-1})										
Yam shoots										
N	14.01b	10.54c	19.81a	20.15a	1.41	11.72b	8.16c	21.60a	21.65a	1.48
P	1.91b	1.44c	2.70a	2.75a	0.19	1.30b	0.91c	2.40a	2.41a	0.16
K	17.57b	13.22c	24.85a	25.28a	1.77	14.65b	10.20c	27.01a	27.06a	1.85

Means with the same letter within row are not significantly different ($P < 0.05$)

LSD least square difference at 5%

Table 7 Estimated annual present production cost, net present value (US$ ha^{-1}), labour productivity (US$ man-day^{-1}) and return on investment (%) in the 2002–2003 and 2004–2005 cropping seasons in four villages in Benin: time horizon 4 years and discount rate (10%)

	T0	TM	TMA	TMM
Economic yield (t ha^{-1})				
Yam	9.43	6.85	15.20	15.34
Maize	–	1.80	1.68	1.63
Total present revenue (US$ ha^{-1})	775	763	1,380	1,457
Production cost (US$ ha^{-1})				
Land	10	10	10	10
Input	349	382	385	390
Labour	219	335	381	392
Total present cost (US$ ha^{-1})	474	585	623	635
Net present value (US$ ha^{-1})	301	178	757	822
Return on investment (%)	62	29	145	152
Labour (man-day^{-1})	63	96	111	112
Labour productivity (US$ man-day^{-1})	5	2	7	7

Inputs costs: Yam seeds (US$ 697.5 ha^{-1}); Maize grains (US$ 6.0 ha^{-1}); *Mucuna* grains (US$ 15.9 ha^{-1}); *Aeschynomene* grains (US$ 7.0 ha^{-1}); Fertilizers (NPK + Urea) (US$ 59.8 ha^{-1})

Labour cost: Land clearing (US$ 29.9 ha^{-1}); Tillage (US$ 79.7 ha^{-1}); Maize planting (US$ 5.0 ha^{-1}); NPK spreading (US$ 27.9 ha^{-1}); Urea spreading (US$ 19.9 ha^{-1}); *Aeschynomene* planting (US$ 10.0 ha^{-1}); *Mucuna* planting (US$ 7.0 ha^{-1}); Weeding (US$ 39.9–47.8 ha^{-1}); Maize harvesting + Transport (US$ 59.8 ha^{-1}); Ridging (US$ 124.6–149.5 ha^{-1}); Seed yam planting (US$ 39.9 ha^{-1}); Yam harvesting (US$ 79.7 ha^{-1})

the beginning of the rainy season. Consequently, a delayed rainy season could be prejudicial to crop growth and yam production. In 2005, even though there was a drought, the favorable early rainfall distribution after yam planting can have positively affected yam DM production. Furthermore, the chemical fertilizers applied and the above biomass DM of intercropping maize and herbaceous legume recycled and accumulated in 2002, 2003 and 2004 could have resulted in a combined beneficial effect of water, nutrient use and

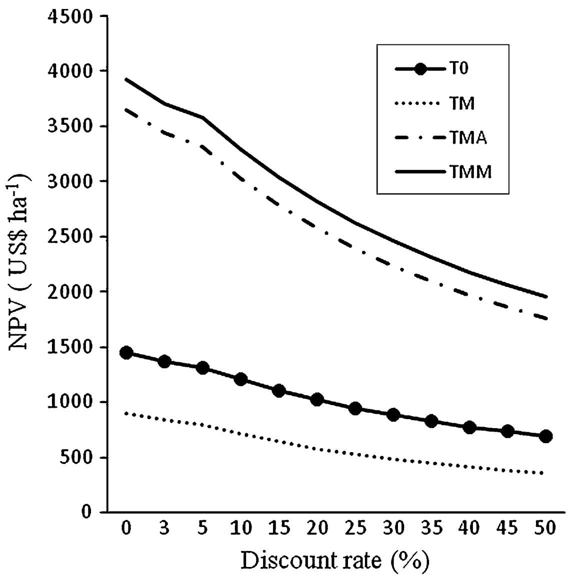

Fig. 2 Profitability of yam-based cropping systems with herbaceous legumes in comparison with traditional systems (time horizon: 4 years) in the transition zone of Benin. *NPV* net present value

plant growth in 2005. Table 5 shows that in 2005 tubers and shoots of yam are less on T0 and TM and more on TMA and TMM: this is in good accordance with the hypothesis that the accumulation of nutrients in the soil is the main cause of the differences of yield between 2003 and 2005.

DM amounts of *M. pruriens*, *A. histrix* and maize stover recycled or maize grain removed were higher in the 2002–2003 (humid year) than in 2004–2005 (dry year). In fact, plant yields and agronomic productivity were constrained by recurring drought stress exacerbated by highly variable and unpredictable rains. *M. pruriens* stover showed the highest DM amount followed by *A. histrix* whatever the year and this could reach 10 t ha^{-1} (Carsky et al. 1998). Indeed, *M. Pruriens,* compared with *A. histrix,* grows more rapidly and close.

Plant nutrients contribution to the systems

The nutrient (N, P, and K) levels removed or recycled fit the DM production (tubers, shoots) and then varied according to treatment and cropping season. The significantly higher nitrogen (N) contributions to the systems in 2002–2003 and 2004–2005 cropping seasons were recorded in intercropped *M. pruriens* with maize-yam rotation (TMM) followed by the intercropped *A. histrix* with maize– yam rotation (TMA). All N requirements in the 1-year fallow—yam rotation (T0) and the maize—yam rotation (TM) were obtained respectively from fertilizers and soil whereas in TMA and TMM, N was derived from biological nitrogen fixation (BNF), soil and fertilizer. The levels of nitrogen content in TMM and TMA were significantly higher in the 2002–2003 (rainy year) than in 2004–2005 (dry year). Generally, studies revealed that the incorporation of the biomass gets more nitrogen to the succeeding crop than the mulch application on the soil because the decomposition of organic matter is more rapid after incorporation (Hulugalle et al. 1985; Franzen et al. 1994; Ibewiro et al. 2000).

TMA and TMM removed significantly more P than T0 (Table 6). The high nutrient removal is due to the high yield observed in those treatments. Our results showed that *M. pruriens* improved soil P. Legumes fallows with *M. pruriens,* are known especially for improving the quantity of available P fractions in the soil for subsequent crops (Salako and Tian 2003). Nevertheless, it depends on the inherent P levels in the soils. *M. pruriens* root exudates could solubilize P increasing its availability.

As far as K is concerned, the quantity recycled with maize stover, yam shoots and *M. pruriens* or *A. histrix* stover was twice as high as that which was removed with maize grain and yam tubers from the systems. The soil K concentrations were low in our study. Indeed in this type of soil, there is no K response of the crops for many years without K fertilization. Igué (2000) showed the soil K concentration of 0.82 cmol kg^{-1} at 0–20 cm depth and decreased significantly with cultivation.

Profitability of cropping systems

The yam-based systems (TMM and TMA) showed highest land and cash productivities with net present value levels significantly higher than the other systems (T0 and TM). However, TMM and TMA demand an additional labour compared with local yam-based systems but allowed for a better labour productivity.

These results agree the work of Adjei-Nsiah et al. (2007) that revealed the highest net revenue and returns on investment (62%) in the cropping sequences M. *pruriens*-maize with N fertilizer application to maize in Ghana. Furthermore, former work reported the profitability of intensification technologies with a positive effect on farm household income (Olarinde

2006). Annual farm incomes were higher under the repeated leguminous cover crops method (RLCC) in southwestern Nigeria for food crops, mainly with yam and cassava (Olarinde 2006). This also was obtained where the use of repeated leguminous cover crops comes into play to enhance soil fertility and to prevent degradation which is the bane of production in the study area.

Conclusion

The study highlights how smallholder farmers who practice *Mucuna pruriens* var *utilis* or *Aeschynomene histrix* in yam-based cropping systems can meet their immediate food security and cash needs while maintaining soil fertility. The production of yam on marginal land where the biomass of herbaceous legumes is available and incorporated into the soil can serve as a means of allowing smallholder farmers with limited access to finance to improve the fertility of their soils. The production of dry matter (tubers, shoots), nutrients removed or recycled, soil properties were significantly improved on yam-based systems with legumes in comparison with traditional systems. The amount of nutrients recycled or removed was dependent on the dry matter production that, in turn, depended on soil fertility, rainfall and farmers' effect. Yam-based systems with legumes appeared attractive for land, labour and cash productivities.

Therefore, yam yield increase in the Guinea-Sudan transition zone of Benin will depend on the capacity to restore the soil fertility (organic matter, nutrients) and make water available at least 20 weeks after yam was planted for a better tuber performance. The study thus suggests that these yam-based cropping systems with herbaceous legumes could be an alternative to the traditional continuous cropping systems and long-duration fallow.

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