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Original Article

Organic Matter Balance of the Sedentary Yam-Based Cropping Systems with Herbaceous Legumes in Guinean Sudan Zone of Benin

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Abstract

In West Africa, yam cultivation is now facing increasing scarcity of fertile soils. With the aim of designing more sustainable yam cropping systems in Central Benin, we compared smallholder farmers' traditional yam-based cropping 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) in a 4-year experiment comprising two-year rotations. The objective of the study was to assess the organic balance of the sedentary yam-based cropping systems with herbaceous legumes and highlight relationship between soil organic matter, biomass dry matter and yam yields. The experiment was conducted with 32 farmers, eight in each site. For each of them, a randomized complete block design with four treatments and four replicates was carried out using a partial nested model with five factors: Year, Replicate, Farmer, Site, and Treatment. Predicted soil organic matter (SOM) was estimated for the time horizon 40 years, i.e. the life cycle of a farm household in the study area. At the beginning of the experiment (2002), the average amount of humus was 37.88 t ha^{-1}. If this rotational dynamic is sustained over time, the amount of soil humus would increase significantly in herbaceous legume systems (44.72 to 92.52 t ha^{-1}) compared to local systems (32.02 to 69.77 t ha^{-1}). This would result in a total net water balance ranging from 6.15 to 44.78 t ha^{-1} in improved systems at -5.27 to 36.85 t ha^{-1} in local systems. The relationship between SOM at (0-10 and 10-20 cm depths) and the total crop biomass incorporated into the soil were significant in improved systems ($P<0.01$) in comparison with the local. The relationship between yam yields and SOM was significantly higher in improved systems at 0-10 cm depth compared with the local ($P<0.01$). No relationship between yam yields and SOM was observed at 10-20 cm depth.

Keywords: Deforestation, Herbaceous legumes, Modelling, Organic matter balance, Soil conservation, Yam

Introduction

Yam (Dioscorea spp.) is a tuber crop widely cultivated in the humid and sub-humid lowland regions of West Africa and the Caribbean. More than 90% of the worldwide production (40 million metric tons of fresh tubers year^{-1}) is produced in West Africa (FAOSTAT, 2011). Yam cultivation in West Africa is now confronted with the scarcity of fertile soil. Until recently yam-based cropping systems involved shifting cultivation, slash-and-burn or short fallow and often resulted in deforestation and soil nutrient depletion (Cornet et al., 2006; Torquebiau, 2007). As long as population pressure was low, the cropping phase was short compared to the fallow period. Three or four years of cultivation followed by a ten year or more fallow allowed for the accumulation of easily degradable organic matter regenerating soil fertility and ensuring an appropriate crop nutrition (Herrmann, 1996; Gaiser et al., 1999; Diby et al., 2009; Srivasta and Gaiser, 2010). The minimum fallow duration to maintain crop production was estimated at 12 years (Hauser, 2006). Where population increases, available land per inhabitant is reduced and fallow periods shorten. Traditional long-fallow shifting cultivation can no longer be found in most of humid sub-Saharan Africa. Fallow periods in most of the humid zone of West and Central Africa are actually between 2 and 5 years (Gockowsky et al., 2002; Cornet et al., 2006). Increasing population densities are posing a serious threat to natural resources and agricultural production. Farmers' response to higher food demand has been an increase in cultivated area as well as a reduction of fallow period. More specifically in the Republic of Benin where data for this paper have been collected, farmers hardly rely on long duration fallow and yam is cultivated in 1 or 2-years herbaceous fallow or maize rotation systems with manual Yam is a demanding crop in terms of organic matter and nutrients. Degras (1986) reported that for a 30-t ha^{-1} yield of fresh yam yield 120 N kg ha^{-1}, 5.1 P kg ha^{-1} and 111 K kg t^{-1} was required. Tropical soils can supply such quantities of nitrogen (N) when it is virgin land which has been newly cleared. Nitrogen is generated by the breakdown of inherent organic matter and needs to be supplemented with other sources of organic materials or mineral fertilizer. Many studies quoted by Balesdent (1996) report that soil organic matter (SOM) decreases in cultivated soils. This decrease is linked to the depth of the cultivated soil layer and is probably exacerbated in yam based-cropping systems. Two fractions of SOM can be distinguished. The first fraction, humus, is the most abundant. It ensures the formation of the clay-humus complex and soil micro-aggregation. The other fraction, which is unstable, consists of young organic carbon and is linked to soil macro-aggregation, the mineralization capacity of the soil and biological activity. When land is used too intensively, and fresh organic matter is insufficient, the SOM is rapidly reduced in the unstable fraction. In the short and medium term, this reduction leads to a decrease in soil biological activity, and affects the aggregation of the soil thus causing a reduction and supply to the crop and in the average diameter of the aggregates, which in turn, contributes to soil degradation and depletion (Quenum et al., 2004). It is possible to stop ongoing soil degradation and the decrease in yield thanks to new farming practices, such as rotations including improved short fallows or intercropping with herbaceous legumes. Most of the research on improved farming practices focused on cereals more than on root and tuber crops, especially yam (Aihou, 1998; Cornet et al., 2006). Studies have been conducted over the past 30 years to find ways to improve soil fertility management and conservation using herbaceous legumes such as Mucuna pruriens var utilis or Aeschynomene histrix (Becker and Johnson, 1998; Carsky et al., 1999). To promote more sustainable yam production in West Africa, we conducted on-farm research on sedentary yam-based cropping systems with herbaceous legumes in the Guinea-Sudan transition zone of Benin. The aim of our study was to assess the organic matter balance of the sedentary yam-based cropping systems with herbaceous legumes in Guinean sudan zone of Benin.

Materials and Methods

Study Sites and Experiment Design:

The study was carried out in Central Benin, in the Guinea-Sudan transition zone (7°45'- 8°40' N, 2°20'- 2°35' E) using four sites (Miniffi, Akpéro, Gbanlin, and Gomè). The climate is tropical transitional Guinea-Sudan with a rainfall distribution gradient from bimodal (Southern Benin) to monomodal (Northern Benin). During the studying period, the average annual rainfall was 1052 mm (2002), 1 386 mm (2003), 983 mm (2004), and 797 mm (2005). The rainfall regime in the study area is variable and unequal distribution (i.e. number of rainy days per month) varies from one site to another. The 2002 and 2003 cropping seasons were wet and had better rainfall distribution with an average annual precipitation of 1200 mm whereas 2004 and 2005 were dry (890 mm) with relatively low rainfall distribution. Most of the soils are tropical ferruginous soils, originally from Precambrian crystalline rocks (granite and gneiss), and classified as plinthosols (Gbanlin and Akpéro), and luvisols (Miniffi and Gomè) (Agossou & Mouïnou, 2002). Miniffi and Akpéro are located on a plateau (well drained soils) while Gomè is on lowland (more poorly drained soils).

Experiment design:

The experiment was conducted with 32 farmers, eight in each site. In each site, traditional yam-based cropping systems with late maturing *Dioscorea rotundata* -'Kokoro' (1-year fallow of *Andropgon gayanus*-yam rotation, Maize+ 100 kg N14P23K14 + 50 kg Urea –yam rotation) with yam-based cropping systems integrating legumes (*Aeschynomene histrix* /maize intercropping + 100 kg N14P23K14 + 50 kg Urea –yam rotation and *Mucuna pruriens* var utilis/maize intercropping + 100 kg N14P23K14 + 50 kg Urea –yam rotation) in a 4-year experiment comprising two year rotations. For each of them, a randomized complete block design with four treatments and four replicates was carried out using a partial nested model with five factors: Year, Replicate, Farmer, Site, and Treatment. The random factors were "Year" and "Replicate" and "Farmer". Farmer was considered as nested within "Site", and "Replicate" nested within "Farmer". The fixed factors were "Treatment" and "Site". Sites were considered as fixed based on certain criteria such as landscape (lowland, plateau), soil type, and initial soil fertility.

Data collection:

Composite soil samples were collected in each field in November 2001 at depths of 0-10 cm and 10-20 cm (32 farm fields × 2 depths = 64 samples). At the end of 2005 after 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). Consequently, the error that may arise from this soil sampling procedures should be soil physical and chemical characteristics from mounds in 2005 reorganized in comparison with soil sampling in 2001 on a flat field. The aboveground and root biomass of maize, A. gayanus and each herbaceous legume were collected separately in October-November 2002 and 2004 in four 1 m² quadrats within each plot. A 100g subsample of each type of biomass was taken in each 100 m² plot. The four subsamples from four replications of each treatment were mixed to form a 400g composite sample for each type of biomass and treatment. In total, for each farm we analyzed six aboveground composite plant samples in 2002 and six in 2004: maize stover TM, A. histrix biomass TMA, maize stover TMA, M. pruriens biomass TMM, maize stover TMM. The biomass samples were dried at 60°C until constant weight and dry weight was determined. At maturity (July), maize grain was harvested in each row in each plot and DM was determined. The fresh weight of the yam tuber was estimated for each plot in December 2003 and 2005 and the DM of yam shoots was determined.

The nutrients contents of the soil samples were performed in the Laboratory of Soil Sciences, Water and Environment (LSSEE) of INRAB (Benin National Research Institute). The plant nutrient content was estimated according to the biomass amount (Maliki et al., 2012; Maliki et al., 2016).

Organic carbon with the Walkley and Black method (Walkley and Black, 1934), soil particles with Robinson method method (Robinson, 1936). The total soil organic matter rate of each site was given by the formula (%SOM = %C×1.72) where %C is the average total carbon rate at a depth of 20 cm.

Calculation of soil organic matter balance:

We used the model of Hénin-Dupuis (1945) in exponential form (Van Dijk, 1980) to estimate the soil organic matter balance. This model calculates the organic matter concentration towards which a soil tends to balance when subjected during an infinite time to a constant mode of organic restitution and a constant technical itinerary. The model equation is as follows:

$$y_t = (K_1 x / K_2) \times \left(1 - e^{-K_2 t}\right) + y_0 e^{-K_2 t} \qquad (1)$$

Where

t = time (year); we considered a maximum time horizon of 40 years (average life cycle of a farm in our study area);

Y_t= quantity of humus at time t (t ha^{-1})

Y_0 = quantity of humus at time t=0 (t ha^{-1})

K_1x = stable organic matter (t ha^{-1}) = $\sum k_1 xi$ (2)

K_1i = isohumic coefficient (%) attributed to each source of organic material = (quantity of humus/quantity of each source of organic matter supplied) ×100 (3)

xi = annual quantity of aboveground parts or roots of each source of organic matter supplied (t ha^{-1})

K_2= Mineralization coefficient (%) = (quantity of mineralized humus/quantity of stored humus) ×100 (4)

K_1 characterizes soil organic matter yield related to organic material supplied. The K_1 coefficient is characteristic of the composition of the organic residues (Mary and Guérif, 1994). A highly fermentable green manure (i.e. green legumes) is mineralized rapidly and supplies little carbon to the soil: its isohumic coefficient (or humification coefficient) is low (5%) (French Ministry of Cooperation, 1993). Incorporated lignified residue (maize stover) supplies much more stable organic matter to the soil: its isohumic coefficient is relatively high, e.g. from 15% to 25% for straw (French Ministry of Cooperation, 1993; Soltner, 1994), and 21% for maize roots (Bolinder, 2003). We considered K1 (5%) for aboveground parts and roots of green manures (A. histrix and M. pruriens) and yam shoots (15%). The isohumic coefficient of straw is lower than that of roots (Serpantié and Ouattara, 2001). For maize stover or Andropogon grass of roots we used 20% and 23% respectively. The coefficient of mineralization K_2 represents the annual rate of destruction of soil organic matter, which mainly depends on the soil and climatic conditions but also on the restitution of organic matter to the soil and K2 increases if restitution is high (Mary and Guérif, 1994). Rémy and Sailor-Laflèche, (1996) used a grid of estimated K_2 ranging from 0.007 to 0.02 depending on the type of the soil (clay and limestone content, pH, etc.). However, the soil typology of their grid does not correspond to the classification of the soils in our study area. Taking into account uncertainty on the values, for the sensitivity analysis in our study, we considered K_2 to range from 0.005 to 0.03. To determine the quantity of initial humus y0 (t ha^{-1}) we used the top 20 cm soil layer and the volumic mass (da) of the soil to calculate the average weight (Pm) of the soil (t ha^{-1}).

$$da = (Pm/ h \times S) \qquad (5)$$

where
da = apparent density (g cm^{-3})
Pm = weight of soil (t ha^{-1})
h = soil depth (20 cm)
S = soil surface (10 000 m²)
We determined average da to be 1.45 g cm^{-3} in the study area. The total soil organic matter rate of each site was given by the formula (%SOM = %C×1.72) where %C is the average total carbon rate at a depth of 20 cm. The first fraction of SOM is humus, which is the most abundant fraction (Quenum et al., 2004). Soil humus was not analyzed in our study. We assumed that the total soil organic matter at each site contained 95% of humus. The quantity of initial humus y0 becomes:

$$Y_0 = SOM \times Pm \times 95/100) \qquad (6)$$

where
SOM = average soil organic matter rate (%) at a soil depth of 20 cm
Pm = weight of soil (t ha^{-1})

Statistical analysis:

Analysis of variance (ANOVA) was applied to yam yield using a randomized block design and a partial nested model with five factors as described above. Analysis of variance (ANOVA) using the general linear model (GLM) procedure (SAS, 1996) was applied to the DM production (tubers, shoots), nutrient contribution to the systems and soil properties at depths (0-10 and 10-20 cm). The GLM was computed to assess the interactions between the factors involved. Least square means and standard error were also computed for factor levels, and the Newman and Keuls test was applied for differences between treatments. Significance was regarded at $p \leq 0.05$.

Results

Soil organic matter contents:

The initial soil fertility status of the study area was poor. Soil organic matter (SOM) contents were low in all fields, ranging from 0.93 to 2.25%, SOM contents were significantly higher in 0-10 cm than in 10-20 cm depth, except at Gbanlin site. The lowest values of g kg^{-1}C, g kg^{-1}N, P (ppm) and organic matter (%) were observed at Gomè (hydromorphic lowland soils) and highest at Akpéro. Calculations of the SOM concentration at the end of the perennial experiment showed that, SOM increased by 0.15% in TMM and TMA.

Table 1: Soil characteristics with the legumes/maize – yam and control rotations 0-10 cm and 10-20 cm soil layers (end of December 2005, 32 farms, Benin)

Soil characteristics	Depth (cm)	T0	TM	TMA	TMM	LSD	SD
C g kg^{-1}	0-10	7.7c	7.6c	8.2b	8.7a	0.05	0.07
	10-20	7.2c	7.0c	7.8b	8.3a	0.05	0.08
SOM%	0-10	1.32c	1.31c	1.41b	1.49a	0.08	0.12
	10-20	1.24c	1.21c	1.34b	1.43a	0.09	0.14

Means with the same letter within row are not significantly different (p > 0.05);

Source: Maliki et al., 2016

Legend: C g kg^{-1}: soil carbon concentration (g kg^{-1}); N g kg^{-1}: soil nitrogen concentration (g kg^{-1}); OM% (= 1.72× C%): soil organic matter content (%); LSD: Least square difference at 5%; SD: Standard deviation; TMA: *Aeschynomene histrix* intercropped with maize-yam rotation; TMM: Mucuna pruriens intercropped with maize-yam rotation; T0 control 1: 1-year fallow with Andropogon-yam rotation; TM control 2: maize-yam rotation.

The total crop biomass (aboveground and root biomass) was significantly higher in TMM and TMA than in T0 and TM (Table 2).

Table 2: Recycled crop biomass in legumes/maize-yam and control rotations 0-10 cm and 10-20 cm soil layers (2002-2003 and 2004-2005 cropping seasons, 32 farms, Benin)

Treatment	Recycled areal biomass (t ha^{-1})	Recycled root biomass (t ha^{-1})	Total recycled biomass (t ha^{-1})
2002-2003 cropping systems			
T0	5.4±0.78 c	0.82±0.15 c	6.22±0.92 c
TM	4.47±0.96 d	0.28±0.26 d	4.75±1.21 d
TMA	11.02±0.87 b	2±0.2 b	13.02±1.07 b
TMM	11.5±0.97 a	2.29±0.27 a	13.78±1.23 a
LSD 5%	0.34	0.08	0.42
SD	1.04	0.26	1.29
2004-2005 cropping systems			
T0	5±0.6 c	0.78±0.11 c	5.79±0.7 c
TM	3.93±0.69 d	0.25±0.19 d	4.18±0.87 d
TM_A	10.34±0.74 b	1.89±0.17 b	12.23±0.9 b
TMM	10.77±0.74 a	2.16±0.21 a	12.93±0.93 a
LSD 5%	0.26	0.07	0.32
SD	0.8	0.2	0.99

Means with the same letter within column are not significantly different ($p > 0.05$); Data are the means ± SD (Standard deviation);

Legend: LSD: Least square difference at 5%; SD: Standard deviation; TMA: *Aeschynomene histrix* intercropped with maize-yam rotation; TMM: *Mucuna pruriens* intercropped with maize-yam rotation; T0 control 1: 1-year fallow with *Andropogon*-yam rotation; TM control 2: maize-yam rotation

The relationship between SOM at (0-10 and 10-20 cm depths) and the total crop biomass incorporated into the soil was significant in TMM and TMA ($P<0.01$) in comparison with T0 and TM (Fig. 1).

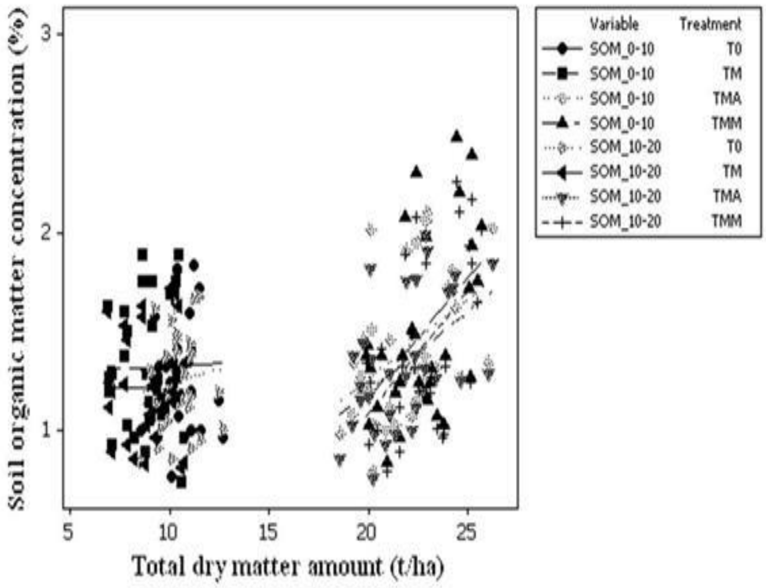

Figure 1: Relationships between soil organic matter at 0-10 and 10-20 cm depths (SOM_0-10 and SOM_10-20) and total organic material dry matter (DM) in the 2002-2003 and 2004-2005 cropping seasons according to treatments

Relationships between soil organic matter on (T0, TM, TMA and TMM) at 0-10 cm depth and total organic material dry matter are as follows: Y (T0) = 1.22 + 0.009 x, R^2 ns; Y (TM) = 1.34 - 0.003 x, R^2 ns; Y (TMA) = -0.33 + 0.08 x, R^2 = 19.5%*; Y (TMM) = -0.92 + 0.11 x, R^2 = 24.2%*

Relationships between soil organic matter on (T0, TM, TMA and TMM) at 10-20 cm depth and total organic material dry matter are as follows: Y (T0) = 0.93 + 0.03 x, R^2 ns; Y (TM) = 1.23 - 0.003 x, R^2 ns; Y (TMA) = -0.43 + 0.08 x, R^2 = 23.6%*; Y (TMM) = -0.92 + 0.11 x; R^2 = 26.2%*

*P < 0.01, ns: not significant

Predicted soil organic matter (SOM) was estimated for the time horizon 40 years, i.e. the life cycle of a farm household in the study area (Figure 2).

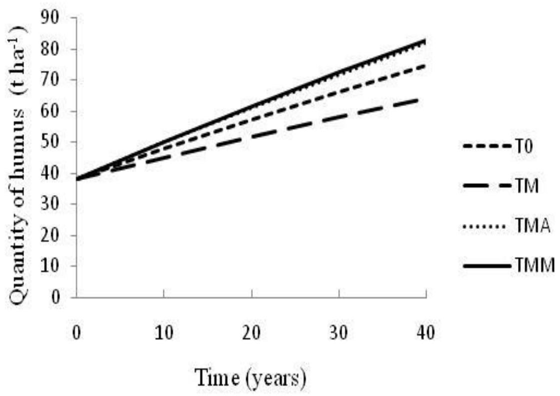

Figure 2a: K2 = 0.005
T0: Y = -203.27$e^{-0.005x}$ + 241.15; R-sq = 0.977
TM: Y = - 144.16$e^{-0.005x}$ + 182.04; R-sq = 0.984
TMA: Y = - 242.21$e^{-0.005x}$ + 280.10; R-sq = 0.973
TMM: Y = - 247.01$e^{-0.005x}$ + 284.89; R-sq = 0.972

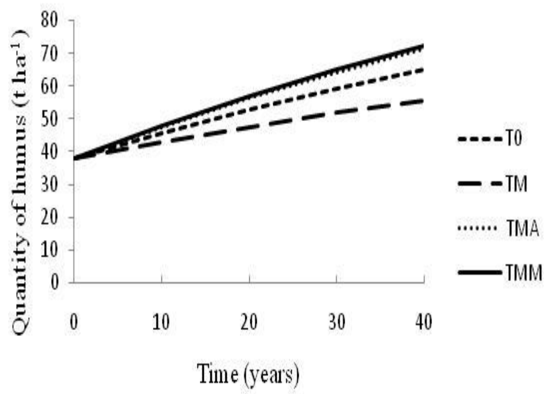

Figure 2b : K2 = 0.01
T0: Y = -82.69$e^{-0.01x}$ + 120.57; R-sq = 0.973
TM: Y = - 53.14$e^{-0.01x}$ + 91.02; R-sq = 0.981
TMA: Y = - 102.17$e^{-0.01x}$ + 140.05; R-sq = 0.969
TMM: Y = - 104.56$e^{-0.01x}$ + 142.45; R-sq = 0.968

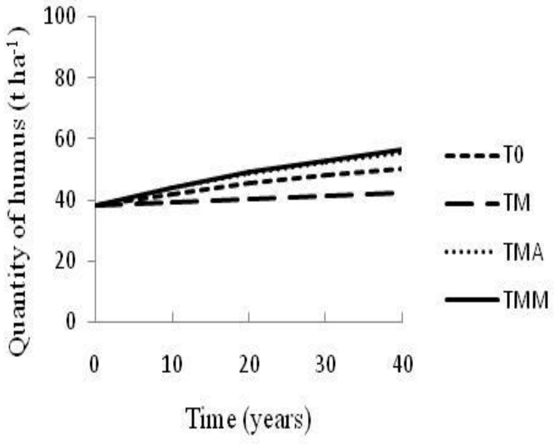

Figure 2c : K2 = 0.02
T0: Y = $-22.41e^{-0.02x} + 60.29$; R-sq = 0.964
TM: Y = $- 7.63e^{-0.02x} + 45.51$; R-sq = 0.974
TMA: Y = $- 32.14e^{-0.02x} + 70.02$; R-sq = 0.958
TMM: Y = $- 33.34e^{-0.02x} + 71.22$; R-sq = 0. 957

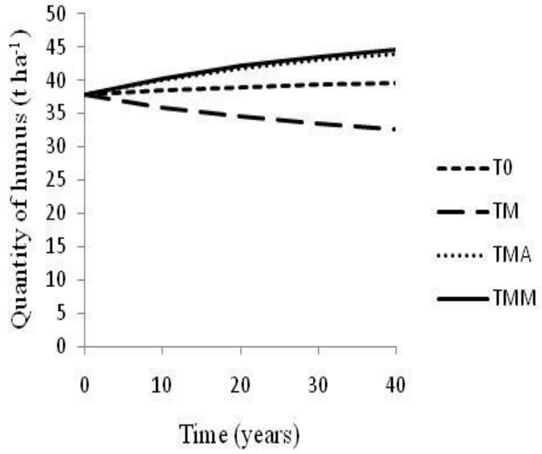

Figure 2d : K2 = 0.03
T0: Y = $-2.31e^{-0.03x} + 40.19$; R-sq = 0.952
TM: Y = $7.54e^{-0.03x} + 30.34$; R-sq = 0.964
TMA: Y = $-8.80e^{-0.03x} + 46.68$; R-sq = 0.945
TMM: Y = $-9.60e^{-0.03x} + 47.48$; R-sq = 0.944

Figure 2. Estimated humus balance significantly increased in TMA: *Aeschynomene histrix* intercropped with maize-yam rotation; TMM: *Mucuna pruriens* intercropped with maize-yam rotation compared with the control rotations (T0 control 1: 1-year fallow with *A. gayanus*-yam rotation; T_M control 2: maize-yam rotation) (4 sites, 32 farmers, Benin): Fig 1a: K2 = 0.005; Fig. 1b: K2 = 0.01; Fig. 1c: K2 = 0.02; Fig. 1d: K2 = 0.03; Legend: R-sq = R square

At the beginning of the experiment (2002), the average amount of humus was 37.88 t ha^{-1}. The amount of humus increased significantly with TMM and TMA ranged (44.72 to 92.52 t ha^{-1}) in comparison with T0 and TM (32.02 to 69.77 t ha^{-1}). This resulted in a total net humic balance ranging from 6.15 to 44.78 t ha^{-1} in TMM and TMA versus -5.27 to 36.85 t ha^{-1} in T0 and TM (Table 3).

Table 3: Net humus balance over a 40-year period (t ha^{-1}) in legumes/maize-yam and control rotations according to predicted mineralization coefficients (0-10 cm and 10-20 cm soil layers, 32 farms, Benin)

Treatment	**Net humus balance over the 40-year period (t ha^{-1})**			
	Predicted mineralization coefficients			
	0.005	0.01	0.02	0.03
T0	36.85±3.49 b	27.26±3.18 b	12.34±2.65 b	1.61±2.24 b
TM	26.13±4.13 c	17.52±3.75 c	4.20±3.14 c	-5.27±2.65 c
TMA	43.91±2.81 a	33.68±2.55 a	17.70±2.13 a	6.15±1.8 a
TMM	44.78±2.98 a	34.47±2.71 a	18.36±2.26 a	6.71±1.92 a
LSD 5%	1.28	1.16	0.97	0.82
SD	3.92	3.56	2.97	2.52

Means with the same letter within column are not significantly different (p>0.05); Data are the means ± SD (Standard deviation).

Legend: LSD: Least square difference at 5%; TMA: Aeschynomene histrix intercropped with maize-yam rotation; TMM: Mucuna pruriens intercropped with maize-yam rotation; T0 control 1: 1-year fallow with Andropogon-yam rotation; TM control 2: maize-yam rotation

The relationship between yam yields and SOM was significantly higher on (TMA and TMM) at 0-10 cm depth compared with the traditional rotations (T0 and TM) (P<0.01). No relationship between yam yields and SOM was observed at 10-20 cm depth (Fig. 3)

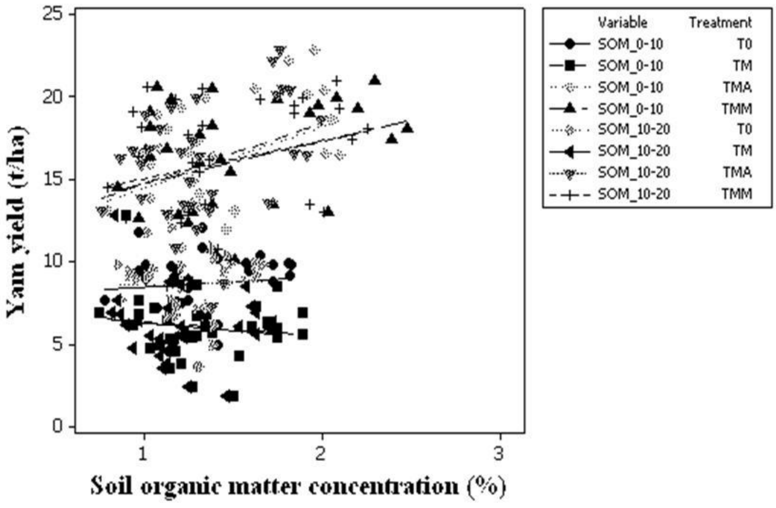

Figure 3: Relationships between ″Kokoro″ yam yield and soil organic matter according to treatments at 0-10 and 10-20 cm depths.

Relationships between ″Kokoro″ yam yield and soil organic matter on treatments (T0, TM, TMA and TMM) at 0-10 cm depth are as follows: Y (T0) = 7.9 + 0.6 x, R_2= 0.9% ns; Y (TM) = 7.3 – 0.9 x, R_2= 1.9% ns; Y (TMA)= 10.8 + 3.7x, R_2= 13.4%* ; Y (TMM) = 12.2 + 2.5 x, R_2= 12.9%*

Relationships between ″Kokoro″ yam yield and soil organic matter on treatments (T0, TM, TMA and TMM) at 10-20 cm depth are as follows: Y (T0) = 8.3 + 0.6 x, R_2 = 0.2% ns; Y (TM) = 7.2 – x, R_2 = 1.7% ns; Y (TMA) = 11.1 + 3.7x, R_2 = 11.2% ns; Y (TMM) = 12.8 + 2.3 x; R_2 = 6.9% ns

*P < 0.01, ns: not significant.

Discussion

Assessing SOM concentration (unstable fraction of humus) in yam-based production systems is indispensable to judge the soil fertility quality and its effect on yield. In our study, these assessments cover short-term changes in SOM with the contribution of organic material used in rotation systems. Therefore, differences in total SOM increase between the treatments were likely related to the total amount of biomass (aboveground and root biomass) in intercropping of herbaceous legumes (fermentable green manure) and lignified maize stover which favors the formation of SOM (Fig. 1). Approximately 26 t ha-1 of organic materials were produced over the 4-year period and restituted to the soil in yam based-cropping systems with legumes (TMA or TMM). This increased SOM by 0.15% in the top 20 cm layer of soil (Table 1). Furthermore, these differences in total SOM increased significantly yam yields on TMA or TMM in comparison with (T0 and TM) (Fig. 3).nCalculations of the humus balance for the 40-year period under yam-based cropping systems showed that SOM increased and ranged from 0.25 to 1.80% in TMM and TMA and from -0.21 to 1.47% in T0 and TM. For example, soil humus in TMM with K2 (0.005) was estimated at 44.78 ha^{-1}. As approximately 25 t ha^{-1} of humus is needed to increase SOM by 1% in the top 20 cm layer of soil (Quenum and al., 2004), according to the prediction of soil humus, SOM should increase by approximately 1.8% (44.78/25). This shows that around 270 tons (TMM and TMA) versus 110 t ha^{-1} (T0 and TM) of organic materials were produced over the 40-year period and restituted to the soil in yam based-cropping systems. Taking into account the average level of the initial soil organic matter, the soil organic matter concentration over the 40-year period should vary from 1.8 to 3.4% in yam based cropping systems with legumes versus 1.3 to 3.0% in traditional systems. However, it is accepted that a rate of 1.5% is the theoretical critical limit, below which the fertility decreases rapidly. It is often desirable to seek to maintain a minimum rate of 2.5% in general and even 3.5-4% in heavy soils (Doucet, 2006). The results of our study in yam-based cropping systems with legumes show a range of rates of SOM in adequacy with the standard required. In General, a rate of 4 to 8% of organic matter corresponds to good productivity and good ability of mineralization. However, high organic matter content may be indicative of poor growing conditions if they are associated with poor drainage conditions. In addition, a high level of organic matter can induce too high-water retention and the development of certain diseases (CRAAQ, 2003). Modeling the humus balance makes it possible to estimate changes in SOM under the crop residues and losses related to microbial mineralization of SOM. However, many factors can influence the calculations, particularly humification coefficients

(K1), and mineralization (K2) of the humus (Soltner, 1994; CRAAQ, 2003). Limits are related to the capacity to obtain valid information on required agronomic parameters such as coefficients of humification of the organic materials supplied to the soil and mineralization of the humus. The predicted humus balance is a good agricultural management tool for researchers, farmers or decision makers as it can help choose the most appropriate rotation and fertilization practices. Our observations are in agreement with those of Bolinder (2003) who reported that cropping systems and organic manures have the most influence on the SOM. These results are in accordance with those of Snapp et al. (1998) who reported that approximately 7 t ha^{-1} $year^{-1}$ dry matter of low quality residues (roots, stems) or 10 t ha^{-1} $year^{-1}$ of high quality residues (green manure leaves) are required to maintain a 1.0% organic C level in a sandy loam soil in the sub-humid tropics (assuming a 0.05 fraction decomposed per year). The authors argued that, it is difficult to produce an adequate amount of organic material under smallholder farm conditions to build or maintain soil organic matter (SOM). Azontondé (1993) showed that the treatment which changes Mucuna every year in association with maize raises the organic matter rate (0.6 to 2.0 %) within five years.

Therefore, the SOM enrichment could be dependent to the boundary conditions (soil type, cropping systems, land use, climate, and cultivation history). However, several factors can influence the calculation of the humic balance, particularly the humification and mineralization coefficients of organic matter or soil humus (Soltner 1994, CRAAQ 2003). These coefficients can vary according to the pedoclimatic zone, the cropping systems, the year, etc. The difficulty of assigning precise values to the humification and mineralization coefficients of the organic matter incorporated in the soil is a limitation of the study. Hence the approach of sensitivity analysis that we proposed.

Conclusion

The objective of the study was to assess the organic balance of the sedentary yam-based cropping systems with herbaceous legumes and highlight relationship between soil organic matter, biomass dry matter and yam yields. At the beginning of the experiment (2002), the average amount of humus was 37.88 t ha^{-1}. The amount of humus increased significantly in yam-based with herbaceous ranged (44.72 to 92.52 t ha^{-1}) in comparison with local systems (32.02 to 69.77 t ha^{-1}). This resulted in a total net humic balance ranging from 6.15 to 44.78 t ha^{-1} in improved systems versus -5.27 to 36.85 t ha^{-1} in the local. The relationship between SOM at (0-10 and 10-20 cm depths) and the total crop biomass incorporated into the soil were significant in improved systems (P<0.01) in comparison with the local. The relationship between yam yields and SOM was significantly higher in improved systems at 0-10 cm depth compared with the local (P<0.01). No relationship between yam yields and SOM was observed at 10-20 cm depth. There is then a need to promote sustainable practices of organic amendments incorporating herbaceous legumes and maize to improve the organic matter levels of our soils.

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