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DIVERSITY OF YAM-BASED PRODUCTION SYSTEMS AND SUSTAINABLE SOIL MANAGEMENT: THE CASE OF TIÉNINGBOUÉ IN IVORY COAST

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Abstract

Yams are cultivated by almost every household in Tiéningboué in the northern center of Ivory Coast. The steady increase in production by increasing the areas of cultivation leads to a scarcity of land, which commands for more sustainable management practices regarding soil fertility. This study establishes the baseline for more effective interventions of a research for development project 'YAMSYS', aiming to develop more sustainable yams production systems. To assess the accumulation of natural and social capital that are essential factors in sustainable production systems, a typology combining qualitative and quantitative approach is developed. Then, stakeholder analysis is carried out for soil fertility management. Six yam-based production systems are identified: 'yam specialists' (1%), 'cotton growers' (15%), 'smallholders' (47%), 'very large indigenous farms' (3%), 'large indigenous farms' (27%), 'large allochthonous and allogeneic non-cotton farms' (7%). Results show both similarities and differences in production system, as well as predictions of reaction of the groups to Integrated Soil Fertility Management (ISFM) technologies developed by YAMSYS. For 'Smallholders', facing low resource endowments, the potential for ISFM techniques adoption is the highest when their cropping system become permanent. Ultimately, the study highlights the stakeholders making up an innovation platform whose objective is to have "champions" along the yam value chains acting as "agents of change" allowing farmers to adapt new technologies for better management of soil fertility.

Key words: *crop production systems, soil fertility management, family farm, innovation platform, yam*

INTRODUCTION

Yam, consumed as staple food by about 155 million people, is cultivated as cash crop and medicinal plant, mainly in Africa [42]. In addition, it has an important cultural value for producing communities [10]. The most important species are *Dioscorea alata*, *Dioscorea rotundata*, *Dioscorea cayenensis* and *Dioscorea esculenta* [1]. The yam belt, formed mainly by West African countries, extends from the humid forest, where yam is grown for food security, to the Sudanian savannah, where yam is also grown as cash crop [2]. In fact, West Africa produces 92% of the world's supply of yam tubers [19]. Consumed in daily diets in both cities and rural areas, the cultivation of yam has expanded drastically over the last three decades. The cultivated area increased from 2.1 million hectares in 1994 to 8.1 million hectares in 2018, and led to an increase in production of 36.5 million tonnes in these 24 years. During this period, the average tuber yield fell from 11.9 tha^{-1} to 8.25 tha^{-1} [19]. Thus, farmers' yields are far below yield potentials of 50 and 40 tha^{-1} that have been reported by research for *D. alata* and *D. rotundata*, respectively [13, 3].

Ivory Coast, located on the yam belt, is the third largest yam producer in the world with 7.2 million tonnes of tubers harvested from 1.3 million hectares. Yield average is even lower, with 5.5 tha^{-1} in 2018 [19]. Several factors were reported to explain this gap, such as: inadequate crop fertilisation, poor seed quality, high pest pressure, and limited production potential of traditional varieties [43]. [15] identified quality seed being the main constraining factor, in terms of availability and its cost. For [44], increased land pressure reduces the availability of 'virgin' land sought by yam farmers, making them grow yam on less fertile soils. For [25], the lower yam yields result from production practices that relate to a steadily declining soil fertility.

In fact, the common practice of farmers to use newly deforested land, i.e. soils rich in organic matter, and to grow yam at the head of a crop rotation based has become rare. Therefore, the concern of various rural development and research actors is to develop and disseminate appropriate intensification methods that aim to ensure both a certain degree of food security and the conservation of natural resources. This involves providing farmers with technologies adapted to their constraints and priorities. To address the constraint of decline in soil fertility, the project "Biophysical, institutional and economic determinants of sustainable land use in yam production systems (YAMSYS)" was set up. The main objective of the project is to develop innovations for sustainable soil management in yam production systems in West Africa to sustainably improve food security, farmer income and environmental quality. The project is conducted on two pilot sites in Burkina Faso and two pilot sites in Ivory Coast. Tiéningboué is one of the sites in Ivory Coast. This study aims to develop a typology for different yam-based or –related production systems in Ivory Coast, as the basis to analyse the potential and pathways to make yam production more sustainable in varying production systems. Thereby, its analysis will make it possible to identify the constraints and priorities that influence the adoption or rejection of a change in agricultural practices. In order to develop adapted technologies, the characterisation of farms is necessary and refers to farms typology establishment. A "typology" divides entities into groups according to interest subject and makes it possible to characterise each group according to observed criteria that present variability [34]. It makes it possible to define target groups for more effective interventions. It can improve knowledge of the dynamics change in regional agriculture [14] and serve as a basis for local policies technical support. The study of yam-based peasant production systems was therefore a necessary step in the YAMSYS technology improvement project.

Integrated soil fertility management as part of sustainable land use

In Sub-Saharan Africa, the severity of land degradation is well documented, ranging from physical degradation due to wind and water erosion, compaction and formation of impermeable layers, soil compaction, waterlogging and reduced infiltration, to chemical degradation resulting from acidification, nutrient depletion, pollution due to the pesticides or fertilisers misuse, or biological degradation produced by organic matter levels reduction in the soil, the burning of biomass and the depletion of plant cover and soil fauna [17]. In the case of yam-based production systems, researchers have mainly emphasised the chemical and biological impoverishment of the soil caused by crop succession without appropriate organo-mineral restitutions, the consequences of opening up new land through deforestation [29]. The degradation also relates to the loss of traditional yam varieties, as wild yam domestication practices disappear and the cultivation of improved varieties expand [20]. Faced with the risks of land degradation and gaps between actual and potential yields, the YAMSYS project has developed technology packages that need to be analysed for their relevance and effectiveness for the different production systems in important yam production areas. These technological packages consist of a combination of innovations, relating to the use of improved varieties, healthy seed, low disturbance tillage techniques, organo-mineral fertilisation, improved crop rotation and improved staking in yam production [23]. All these aspects are part of an integrated soil fertility management (ISFM) approach that build on a combined use of organic and inorganic nutrient sources to ensure an adequate fertilization in agricultural production. ISFM combines different methods of soil and water amendment and conservation and is based on the following three (3) principles: maximising the use of different sources of organic matter; minimising nutrient losses; and using mineral fertilisers judiciously according to economic needs and availability [18]. In practice, the endorsement of ISFM translates into a wide variety of techniques depending on production systems and regions [18].

From a sustainability point of view, a farm is only sustainable when it at least maintains the productive natural capital of its land over time. According to the model of sustainable agriculture developed by [39], sustainable systems are those that ensure renewal and promote the accumulation of a stock of both natural and socio-economic capital. Yam being a nutrient-demanding crop of great cultural relevance, it is indeed essential to broaden the analysis by considering also environment-related and social capital, i.e. assessing under what circumstances stocks of these capitals are accumulated or eroded in yam-based production systems, respectively to study possible substitution effects between one and the other. Natural capital corresponds to the stock of goods (plants, animals, minerals, etc.) and services provided (e.g. waste absorption cycle) by ecosystems to satisfy human needs. [16] propose a framework for analysing natural capital, structured by four environmental elements: air, water, soil and habitats. Social capital is "the sum of the actual and potential integrated resources available through or arising from the network of relations that an individual or social unit possesses" [35].

We hypothesize that according to [39] model, current production systems based on yam do not ensure an accumulation of at least one natural capital (i.e. soil fertility) and one social capital (i.e. farmers' organization).

This article aims to assess how the use of the technological packages developed by YAMSYS affect the renewal and accumulation of natural capital and social capital in Ivory Coast central northern. Firstly, the article characterises current yam-based production systems and identifies some principles of their functioning. Secondly, it analyses which ISFM practices are already at least partially integrated into these systems and compares them with the technologies developed by YAMSYS. Finally, the limits to the adoption of widespread ISFM practices are discussed and ways to overcome them.

MATERIALS AND METHODS

Favourable characteristics for yam cropping

The region selected for the study is the sub-prefecture of Tiéningboué in north-central Ivory Coast. Tiéningboué (Fig.1) is a yam production area that supplies not only Bouaké (the city where the wholesale yam market is located) at about 101 km, but also Abidjan (the economic capital, the largest consumer city in the country) at 343 km. According to the latest general population and housing census of 2014, the population of Tiéningboué, which is predominantly agricultural, is estimated at 40,000 inhabitants. It is made up of indigenous people (Koro), allochthonous people (Sénoufo, Lobi, Baoulé) and allogeneic people (Economic Community of West African States 'ECOWAS' nationals, particularly Malians, Burkinabes, Guineans). Koro and Baoulé have yam as their staple food. The other communities mainly produce yam as a cash crop. It was expected that this ethnic diversity would result in a diversity of yam-based production systems. The natural characteristics of Tiéningboué are favourable to yam. The tropical climate at the edge of the southern forest zone and the savannah region are suitable to yam, and the vegetation found in the area is of the "forest meadow" type; it is made up of forests and savannah which give way to numerous fallow lands, and cashew tree. Tiéningboué was also selected because of the presence of the YAMSYS project. It has set up an experimentation site under the management of researchers and disseminated the innovative techniques of the technological packages tested through "baby trials" managed by interested farmers. Also, a multi-stakeholder platform was set in place to facilitate exchanges between farmers, traders and service providers in the yam sector, and this lead to analyse it.

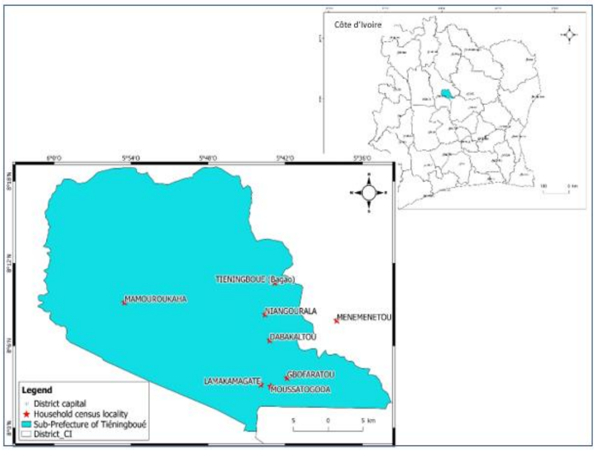

Fig. 2. Map of Ivory Coast highlighting the Tiéningboué sub-prefecture (the study area)
Source: Authors, 2020.

Iterative approach for data collection and analysis

The study was conducted in two phases. The holistic approach combines exploratory studies and surveys of a sample of farm households. A rapid diagnosis was carried out in July 2015 in the sub-prefecture of Tiéningboué and in March 2017, a socio-economic monograph was conducted on 3 villages in the sub-prefecture, which differ in their population density and ethnic structure, factors that influence yam-based production systems and yam marketing. Following a household census from December 2017 to February 2018, a survey of a sample of households was conducted between April and May 2018.

Then, according to the formula of [24], the formula for calculating an exhaustive sample:

$$n^2 = \frac{t^2 p(1-p)}{e^2} * \frac{N-n}{N-1}$$

with t= 1.96; p= 0.898; e= 5%; N= 410;

n = $\frac{t^2\, p\,(1-p)}{e^2}$; n= 140.75, so n^2= 92.66.

where:

N: mother population size;

n: sample size for a very large (infinite) parent population;

n^2:sample size for a limited parent population;

s: Confidence threshold ;

t: Margin coefficient deduced from the Confidence rate "s";

e: Margin of error ;

p: Proportion of the elements of the mother population that have a given property.

(When p is unknown, we use p = 0.5);

q = 1-p: Probability of failure.

We also define: The sampling rate R = n/N; The Uncertainty Range I = 2e).

Thus, the minimum sample size for the survey is 93 farm households. However, the questionnaire was administered to 230 households that constituted the sample for the statistical typology.

The actor-oriented approach starts with the assumption that different farmers define and operationalize their objectives and farm management practices based on different criteria, interests, experiences, and perspectives [11]. The approach was intended to be iterative, with each step making it possible to identify relevant factors differentiating operating systems and to verify or refine them during the next step based on assumptions [8]. The diagnosis in the exploratory phase used interactive tools of the Accelerated Method of Participative Research (MARP) documented by [7].

On the one hand, the monographs allowed the typologies built by farmers to identify discriminating criteria and explanatory factors and to question representatives of each type about their practices. Based on this, a standardised questionnaire was developed for household survey to establish the statistical typology.

The statistical typology was constructed based on structural (resource endowment) and functional (production objectives) characteristics [30].

Six groups of variables (Table 1) were identified during the exploratory phase and validated by the bibliographical analysis: yam production experience, socio economic variables (autochthony), marketing (or consumption) objectives pursued, yam species cultivated, land allocation and cropping system features, and the level of mechanization.

Multiple variables required a multidimensional analysis. Depending on the nature of quantitative or qualitative variables, multiple factor analysis (MFA) reduces the complexity of the variables before grouping the individuals into classes using a hierarchical bottom-up classification (HLC)

method. For the characterisation of the classes obtained, a chi 2 significance test was carried out. The significance of the test was evaluated at the 5% threshold. Thus, the chi2 test makes it possible to know if the class variable is related to the qualitative variables [27].
Multiple Factor Analysis (MFA) first plan explains more than 50% of the variability. Hierarchical bottom-up classification (HLC) carried out with 5 dimensions of MFA, i.e. at least 90% of the inertia, has led to the formation of six (6) classes.
The multivariate analyses were carried out with the FactoMineR package of software R version 3.5.3.

Stakeholder analysis

On the other hand, stakeholder analysis has been seen in policy research as a way of generating information on the ‘‘relevant actors’’ to understand their behaviour, interests, agendas, and influence on decision-making processes [5]. Many definitions of stakeholders build on [21] seminal work on stakeholder theory that distinguished between those who affect or are affected by a decision or action. Indeed, stakeholder analysis is used in development and the natural resources management. By understanding who has a stake in an initiative, and through understanding the nature of their claims and inter-relationships with each other, can the appropriate stakeholders be effectively involved in environmental decision-making [41]. Therefore, the monographs identified stakeholders for soil fertility management issue. Then, a focus is put on the innovation platform (IP) set up by YAMSYS as a tool to develop collaboration between stakeholders [22]. Indeed, "Innovation platforms (IPs) are a way of organizing multi-stakeholder interactions, marshalling ideas, people and resources to address challenges and opportunities embedded in complex settings" (Davies et al., in press). Often, IPs are organized around a farm product, such as, yam [4]. Therefore, it is a question of identifying the axes of IP analysis to improve its actions.

RESULTS AND DISCUSSIONS

Yam cropping as a farm household activity

The census of households and their agricultural production units took place in eight (8) localities of Tiéningboué. Out of 410 households surveyed, 397 are agricultural households and 368 consist of at least one yam-producing unit, representing 89.8% of the total number of households.
The heads of yam production units (PUs) also engage in non-agricultural or para-agricultural activities (trade in agricultural and other products, crafts). 92.3% of the heads of PUs who cultivate yams are also heads of households and all are men. Women are heads of production units when the head of household is very old and has no sons, or when they are widows. Yam cultivation is practised by men.

Common characteristics of production systems in the Tiéningboué region

The quantitative typology differentiates six clusters relating to different classes. Although they have different characteristics, it is worth noting the common elements that they share.

Cropping and production systems

Most farms in the study site involve 10 to 30 ha of UAA (Utilized Agricultural Area) and grow mainly cashew, rice and yam (Table 1). International demand has made cashew cropping become a major source of income in the zone. New plantations are established every year, sometimes as soon as land is cleared and new fallow land is developed, and sometimes after a few years of production when the plots run out. Only 37% of the area in cropping relates to annual crops, including yams, which is not planted within cashew plantations. It is possible to combine annual crops with young cashew trees for 2 to 3 years, but then the plantations have a high coverage rate.
In the cropping systems, yam is head of rotation for 97.8% of all farms. According to farmers, this crop is demanding in terms of soil fertility and new clearings meet this demand. The other 2.2% of the farms put rice at the head of the crop rotation. In this case, farmers argue that rice helps to increase soil fertility before cropping yam the coming year.

Table 1. Retained variables for statistical typology

	Quantitative variables Mean +/- standard deviation								
	Name	Unit	**Class 1**	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Class 6**	**Total sample**
1	*D.alata*	ha	0.79± 0.36 *	0.74± 0.33 *	2.0± 0.71 *	0.66± 0.67*	2.35± 0.78*	5± 1*	1.18± 0.9
	D.rotundata	ha	0.19 ± 0.30 *	0.43 ± 0.55	0.21 ± 0.33 *	2 ± 0.8 *	0.72± 0.63	5 ± 1 *	0.41 ± 0.8
2	Cotton	ha	0.32 ± 0.93 *	6.69 ± 2.16 *	0.12 ± 0.63 *	1.25± 2.01	0.43± 1.05	3 ± 3	1.33 ± 2.6
	Fallow land	ha	1.19 ± 1.96 *	2.73 ± 3.48	3.88 ± 3.28	2.94± 2.84	20± 9.63*	2.5 ± 2.5	2.78 ± 4.5
	Cashew tree	ha	3.81 ± 3.09 *	12.06± 7.18*	7.42 ± 4.45	6.62± 5.08	20.29± 13.38*	7.5± 7.5	6.99± 6.3
3	Farmers'age	years	46.95± 13.61	50.17 ± 9.85	47.23± 11.57	43 ± 10.37	46 ± 12.92	45 ± 13	47.3 ± 12.5
	Experience in Yam	years	15.33± 11.07*	19.71± 10.72	19.93± 9.49	19.5± 8.28	23 ± 11.35	23 ± 11	17.81 ± 10.7
	Qualitative variables Proportion (%)								
	Variables	**Modality**	**Class 1**	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Class 6**	Global (%)
4	Rotation head	Yam	97	100	95.1	100	100	100	97.8
		Rice	3	0	4.9	0	0	0	2.2
	Rotation with Cotton	No	98.17	80	100 *	100	100	50	95.7
		Yes	1.83	20 *	0	0	0	50	4.3
	Rotation with return to fallow land	With fallow land	6.42	8.57	6.56	18.75	0	0	7.4
		Continuous in annual crop	33.03	51.43 *	14.75	18.75	14.29	50	29.6
		Non	60.55	40	78.69 *	62.5	85.71	50	63.0
	First Year of Cashew tree Association	Year1 after fallow	52.3	37.14	70.49 *	50	71.43	0	54.8
		2 years of annual crop rotation.	8.25	2.86	8.2	12.5	14.28	50	8.2
		Without Cashew	39.45	60 *	21.31	37.5	14.29	50	37.0
5	*D.alata_* majority destination	own consumption	47.71 *	42.86	27.87	37.5	14.29	50	38.7
		no production	15.59	0	0	37.5	0	0	14.8
		sale	36.7	57.14	72.13 *	25	85.71 *	50	46.5
	*D.rotundata_* majority destination	own consumption	10.1	25.71 *	19.67	12.5	14.29	0	11.7
		no production	69.72 *	40	62.3	0	14.29	0	60.4
		sale	20.18	38.28	18.03	87.5 *	71.42	100	27.8
	Autochthony	No	39.45	100 *	11.48	68.75	28.57	100	43.5
		Yes	60.55	0	88.52 *	31.25	71.43	0	56.5
	Yam species	*D.alata(a)*	62.38 *	40	62.3	0	14.29	0	52.6
		a&r	33.03	60 *	37.7	62.5	85.71 *	100	42.6
		D.rotundata (r)	4.59	0	0	37.5 *	0	0	4.8
6	Utilized Agricultural Area (UAA or in French SAU) (ha)	S1(0,5≤UAA<5)	20.94 *	0	0	6.25	0	0	11.3
		S2 (5 ≤ UAA <10)	50.46 *	0	8.2	6.25	0	0	26.5
		S3(10≤ UAA <30)	26.6	60	91.8 *	87.5*	0	50	52.6
		S4(30≤ UAA <70)	0	40 *	0	0	100 *	50	9.6
	Mechani-zation of ploughing	No	97.25*	74.29	93.44	85.7	85.71	0	90.9
		yes	2.75	25.71*	6.56	14.3	14.29	100 *	9.1

*significant variable at 5% threshold

Variables groups: **1**.Species of yam; **2.**Other Allocation of land; **3.**Experience; **4.**Cropping system; **5.**Socio-economic; **6.** Mechanization

Source: Authors' results, 2020.

According to the agricultural seasons and considering their food availability and need, all farms grow rice, maize, groundnuts and cowpeas, being part of the yam-based crop rotation. In terms of biomass management, most of the crop residues are exported from the plot, except for the roots. Thus, the tubers for yam, the ears for maize and other plant parts are taken out of the plot when the time comes to prepare the land for the next crop. On the other hand, for rice, except for the panicles which are exported, all the other organs are left on the plot and will be incorporated into the yam mounds. Farmers never grow yam after yam.

Mechanization and fertilisation

Cropping yam is essentially done manually. Even those farms with cattle, being in the position to do semi-mechanized soil work, do not systematically practice mechanised ploughing before making the mounds. To prepare the mounds for yam copping, plots are mostly cleaned by burning, or more rarely with total herbicides. Commonly, both yam species, i.e. *D. alata* and *D. rotundata*, undergo herbicide treatments after planting. No mineral or organic fertiliser is applied. Even cotton growers, who have the greatest experience with mineral fertilisers application, believe that all type of fertilisation is detrimental to the quality of the tubers and their preservation.

Yam species and seed management

Overall, cropping *D. alata* dominates. A comparison of the technical itineraries of these two species shows that *D. alata*, reputed to be hardier, is more often associated with perennials (mainly cashew trees) and receives less care than *D. rotundata*, whose mounds are more often protected from sunlight by straw pads and stakes. Seeds of *D. rotundata*, which account for a considerable part of the harvest, are expensive and are therefore more often treated before planting with insecticides and acaricides (used for cotton). Farmers commonly produce their own seed. One (1) cultivar is mainly found for the species *D.rotundata* in the zone, the "krènglè", whereas for the species *D.alata*, four (4) cultivars: Bètè-bètè, Cameroun (C18), woroba, Florido.

Place of animal husbandry

The traditional goats, sheep and poultry breeding is practiced, but in relatively small numbers (2 cattle, 1 sheep, 1 goat, 7 poultry on average) and essentially for self-consumption. The farms are managed by leaving the animals free to roam freely. This makes it difficult to collect manure or compost. There are also a few cattle farms managed by Peulhs, but their natural pastures in savannah areas are increasingly bordering farmers' fields, resulting in recurrent farmer-herder conflicts. Thus, the availability of organic manure, whether from traditional livestock farming or rare night pens for cattle, is low and rarely used for crop production.

Link with ethnicity

An important diversification factor identified is linked to farmers' ethnic origin. Cotton is only produced by non-native Senoufo people, who mainly grow the species *D. rotundata* for the market. They have migrated decades ago from areas where these two practices are common, also using cattle for soil work and mineral fertilisation in cotton. Their relatively old migration has enabled them to develop and thus appropriate areas at least as large as their indigenous Koro neighbours. The more recent migrants have no own land and cultivate the land of indigenous people; after some time, they tend to obtain plots from their landowners, but their land rights are limited and precarious, especially their cashew tree planting rights.

Diversity of yam-based production systems

The farming system typology shows that there are few farms that involve large areas in cropping yam. Only 1% of the farms (Class 6 in Fig. 2) produce yam on 10 ha or more, half of which are in *D. rotundata*. The vast majority of grow little yam, partly for own consumption, mainly *D. alata*. This is the case of Class 1, which includes 47% farmers, and Class 2, which includes 15%. These two large groups are essentially distinguished by the fact that Class 1 is made up of natives following cashew settlement pattern and Class 2 is made up of non-natives who grow cotton. Classes 4 and 5 are distinguished from the others by their larger size, which allows them to both establish large cashew plantations and clear fallow land to grow yam on areas smaller than those implemented by Class 6, but larger than the other classes. These two classes are distinguished by the relative importance of *D.rotundata*.

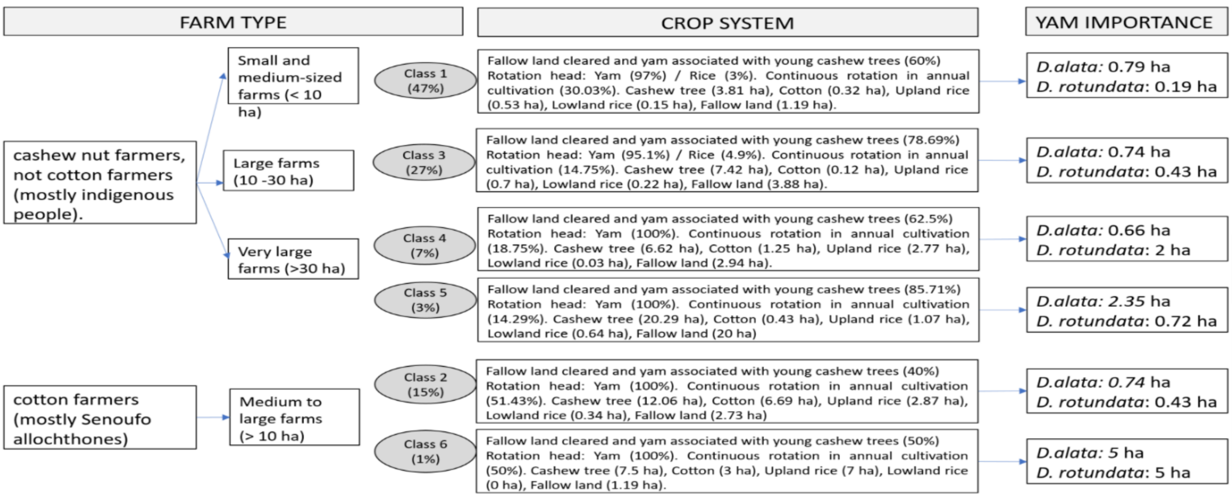

Fig. 3. Characteristics of the six (6) types of production systems
Source: Authors' results, 2020.

Differences in fertility soil management

Three types of yam cropping systems can be counted and classified in descending order of importance: (1) yam at the head of rotation in permanent crop rotations that often include cotton; (2) yam at the head of the rotation after clearing and more or less rapid transformation of the plots into cashew groves and (3) yam at the head of rotation after clearing in a system that allows return of overexploited land to fallow after a few years. This last system has become residual (8.57% of farmers). Despite this, only specialised farmers in yam cropping, being part of Class 6, consider limited by the fertility of their land. The land under yam crop appreciation (Table 2) shows that more than 57% of each Classes 1, 2, 3 and 5 consider their land to be fertile; 44% of Class 4 as well as 100% of Class 6 consider the land to be not very fertile. Based on this farmers' perception about soil fertility, how relevant is for them fertilization? In fact, farmers consider fertilisation only of marginal importance in yam production. Organic fertilisation is only very important for about 1% of the farms in each of Classes 1 and 3. Mineral fertilisation is only very important for about 2% and 3% of Class 1 and Class 2 respectively (Table 2).

In farmers' opinion (Table 2), when yam is not grown on forest or fallow land cleared, the best precedent is rice. Yam specialists from Class 6 grow 100% of their yam after rice. In the other classes, the best precedent with an improving effect is groundnuts in 69% of Class 1, cotton in 62.5% of Class 2, and rice or maize in Classes 3 and 4 in almost identical proportions. It can be deduced that by playing on the previous ones, farmers are satisfied with their fertility management methods. They also do not attach importance to production sites choice; for example, they have no preference for cattle pens or lowlands, although 28-37% of farmers in each class feel that the length of the drought period is increasing. In fact, they attribute more importance to other constraints than the fertility of their land. For instance, between 42 and 56% farmers, depending on the class, consider seed size and more than 50% of the farms in each class, the health of the seed, for being important. Finally, certain farming practices that *a priori* allow for improved yields are not considered important. This is the case of the use of straw pads on the top of the mounds, which is only considered relevant by a very small minority. Some farmers rely on crop associations to improve the productivity of their plots. Overall, the last five years, farmers feel that there has been no change in cropping practices, except for weed control through herbicides use. This change is seen as positive because the tedious task of weed control is reduced. It is particularly relevant for Class 2 cotton growers, who have easier access to herbicide supplies from the cotton purchasing companies.

As yam is a cultural crop, 20 to 44% farmers (depending on the class) give a very important place to spiritual forces to obtain good production. Only the few specialised producers in Class 6 do not refer to these as being important.

Table 2. Assessment of the fertility of yam crops and farmers' perceptions

		Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Appreciation of the land sown to yams	Fertile	70.64	71.43	73.77	50	57.14	
	Poor	1.83		1.64	6.25		
	Not very fertile	27.52	28.57	22.95	43.75	28.57	100
	Very fertile			1.64		14.29	
Perception of organic manure	Quite important	0.92	2.86	1.64			
	Not used so no opinion	98.17	97.14	96.72	100	85.71	100
	Very important	0.92		1.64			
	not important					14.29	
Perception of mineral fertilisation	Quite important	0.92	2.86	1.64			
	Not used so no opinion	97.25	97.14	93.44	100	85.71	100
	Very important	1.83		3.28			
	not important			1.64		14.29	
Good cropping precedent for yam	Groundnut	68.75	12.5	15.38			
	Cotton	12.5	62.5				100
	Maize		12.5	30.77	50		
	Maize & Rice			7.69			
	Rice	18.75	12.5	46.15	50		

Source: Authors' results, 2020.

Adequacy of agronomists' proposals to fertility management problems

Importance of marketing and credit

Most farmers state that the interest in producing yams for the market has become an important incentive to increase production. Yet, non-cotton farmers, i.e. farmers with less land and financial resources, are often limited by their cash flow. 41% of all farmers use loans from buyers (pre-harvest sales) to finance their campaign. In fact, these loans also often cover other expenses, such as children's schooling, being of greatest importance for farmers with limited resources. Between 75% and 100% of the farmers in Classes 1,3,5 and 6 obtain loans from a yam buyer. The use of a loan from a yam buyer implies an agreement on a unit price for yam set by the buyer before harvest, which is lower than the current market price at harvest. Other growers restrict their yam area to what they can financially afford. Only cotton farmers have facilities to obtain input credits from their marketing companies, and 50% use them.

Requirements of ISFM

The ISFM technology package offered by YAMSYS targets the decline in soil productivity quite specifically without paying too much attention to increased demand for labour and cash. It consists of integrated practices set. These technologies include different crop rotations, fertilizer inputs and fallow management and use crop cultivars requested by farmers, clean yam planting material and a planting density of one plant m^2. Mineral fertiliser has a specific composition suitable for tuber exports. The recommended organic manure is in the form of manure or compost.

Probable reaction to ISFM

Small indigenous class 1 farms with low resource endowment are a priori ideal candidates for the adoption of ISFM techniques to be proposed by the Yamsys project, as this class needs to intensify its cultivation system that has become permanent. But their cash flow could limit them because they sell their yams to traders via unloyalized relationships (buyers are numerous and change from one transaction to another for 44% of farmers and the relationship is loyal with only one buyer for only 14%); they have little chance of receiving credit from their buyers to obtain inputs. Often the family workforce is also small and they will prefer techniques that reduce the demand for labour.

Medium-sized cotton farms in Class 2 have long experience with mineral fertilisation. Thus, these farmers might be inclined to experiment with mineral fertilisation on yam, especially since they can easily obtain inputs from their cotton buying company, provided they are convinced that a direct effect of this fertilisation is superior to an indirect effect of fertilisation on yam. This has not been studied. They might also be able to switch to semi-mechanised yam cropping on slight raising of earth bounded by furrows with the help of a plough, since they use cattle for tillage. Nevertheless, there is very little interest in this technique because for the same yield, the tubers are more numerous and smaller. However, the large size of the tubers is still perceived as a local indicator of productivity. However, it should be remembered that yam is not an essential crop for them and that the adoption of new practices will rather interest those who will develop a market-oriented activity, such as the yam farmers currently in the minority in class 6.

Class 6 large farms specialising produce for the market and have sufficient labour and expertise to produce as much *D. rotundata* as the hardier *D. alata*. These growers will be interested in testing new techniques and will only keep those techniques for which the differences in performance are highly significant. In other words, they will only adopt techniques if and only if their financial and labour investment can be profitable. Cotton farmers in classes 2 and 6 would deserve special targeting and school fields.

Farmers in classes 3, 4 and 5 still have fallow land and are oriented towards processing them into cashew trees. In this process, they grow yams. They may be interested in techniques that improve labour productivity and the return on their investment in yam. The need to adopt ISFM techniques will become apparent in the longer term for the descendants of these farmers, when a large part of these large farms will be occupied by cashew tree and will have been broken up between heirs.

Stakeholders for soil fertility management

To understand the issue of integrated soil fertility management, it is first necessary to identify the actors involved or to be involved (Fig. 3) to determine the actions to be taken.

The implementation of YAMSYS' ISFM techniques will depend on producers' access to recommended inputs and technical information. Certainly, cotton buying companies in some way contribute partially to ISFM as cotton farmers are supplied with fertiliser to be paid back at harvest time and are assisted in the acquisition of production equipment such as cattle plough. Yam traders are not opposed to techniques that increase agricultural production. However, they believe that mineral fertilisation in yam cropping accelerates yam tubers rotting speed during storage and consumers complain of organoleptic properties of yam degradation when it is fertilised. Consequently, it is unlikely that traders will mobilise for loans to farmers for yam fertilisation, and even less likely to organise a supply of specific inputs as long as they are not convinced that it is in their interest to do so. The question of the combination of mineral and organic fertilisation has not been resolved. Recurrent conflicts between farmers and cattle breeders have dissolved traditional exchange links and the use of cattle dung to produce manure or, failing that, to grow on cattle pens has become minimal.

Agricultural extension in the zone is mainly focused on export crops. And there is an insufficient agent’s number, with only one agent from the Agence Nationale d'Appui au Développement Agricole (ANADER) for the entire sub-prefecture of Tiéningboué. This agent directs his advice mainly towards cashew tree. The cotton buying companies have agents who follow their farmers. Overall, the agricultural advisers in the zone do not carry out activities oriented towards ISFM or other crops, especially yam. Faced with this situation, the project YAMSYS has attempted to initiate a melting pot of exchanges in the form of an innovation platform bringing together the various stakeholders in the sector and agricultural support organisations.YAMSYS' technologies need champions, both at the level of farmers and other stakeholders in the system.

Indeed, the innovation platform (IP) in Tiéningboué, “Djiguissême”, is composed of direct and indirect value chains actors. The composition of the IP board describes its structure. On the one hand, six (6) producers, one (1) wholesale trader, one (1) supplier of phytosanitary products, who constitute the representatives of the direct actors. On the other hand, one (1) extension agent, one (1) researcher, one (1) modern administration authority, one (1) advisory service agent (social centre), one (1) agent of a microfinance institution (COOPEC), one (1) agent of the Water and Forestry Department, one (1) customary authority constitute the representatives of indirect actors. In addition, there is a facilitator for activities coordination.

The functioning of the IP can be described by the conduct activities, the decision-making process, monitoring and evaluation of the activities. First, the activities carried out are the frameworks for stakeholder consultation, workshops for planning and reporting on activities, training sessions, guided visits, farmer exchange trips, promotional and/or agricultural days, radio and television programmes. Then, IP decisions are taken by the board members during meetings. Finally, the project coordination ensures the monitoring and evaluation of activities by monitoring indicators such as the rates of implementation of activities and participation in activities. Ad hoc consultations are held during the year to diagnose the reasons in the event of a drop in these indicators.

IP will need to be analysed as a key institution for this process of agricultural technical innovation.

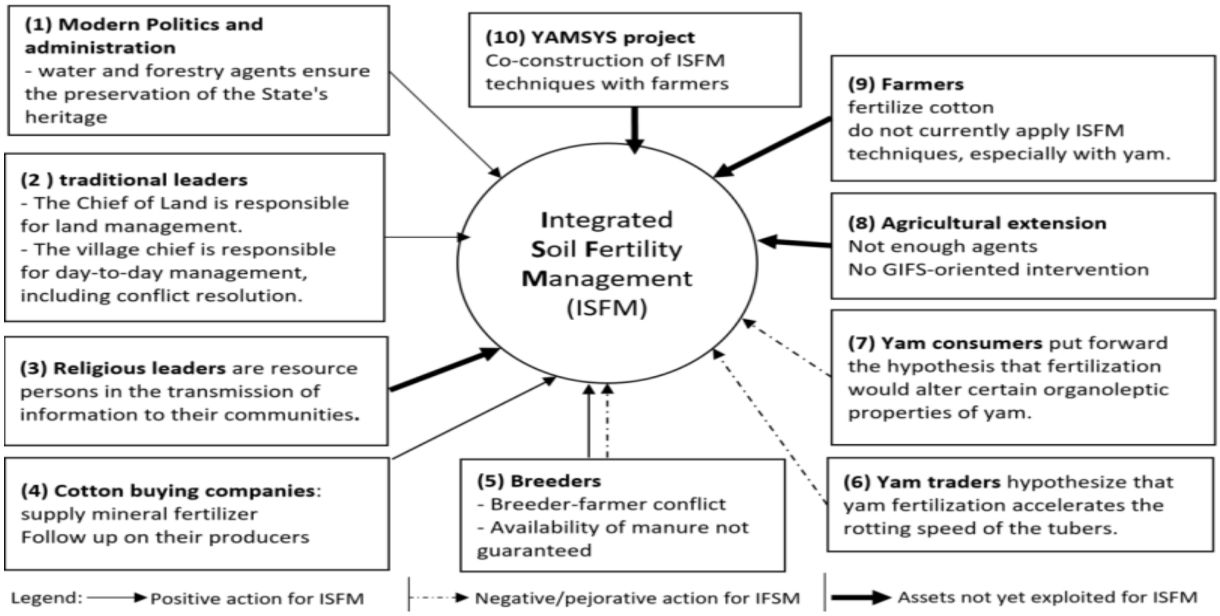

Fig. 4. Stakeholders for integrated soil fertility management
Source: Author's results, 2020.

Discrepancy between the perceptions of farmers and experts

According to the model of sustainable agriculture developed by [39], sustainable systems are those that ensure renewal and promote the accumulation of a stock of capital (natural and social). In traditional long fallow cropping systems, yam was traditionally planted as a first crop because it is considered demanding in terms of soil fertility [6]. In subsequent years, the field was sown with other crops and after one or more cycles, when yields declined or weeds required too much work, the field was returned to fallow.

Yam is usually grown without any external inputs using its own tubers as planting material. In areas where land is scarce, farmers produce yam after only one year of fallow or no fallow [32]. [31] reports that farmers perceive declining soil fertility as a key constraint to yam production in areas with low agricultural intensification. In current contexts, in the opinion of experts, yam-based production systems do not ensure the renewal of natural capital (soil fertility) and these ecosystems will be less and less able to satisfy human needs [16]. In fact, the export of macronutrients by yam crop is high and, regarding technical itineraries without the use of fertilisers, the mineral balance of the rotation is unbalanced [22]. Consequently, the natural capital 'soil fertility' is not renewed.

As for social capital, it is "the sum of actual and potential integrated resources, available through or resulting from the network of relations that an individual or a social unit possesses" [35]. Social capital mainly has two dimensions: a structural dimension, which refers to the structure of the network of relations between actors, and a relational dimension, corresponding to the content of relations in terms of norms and trust that result from the network of relations. Two types of links are identified as important in networks of relationships: strong links within the group of actors (bonding, according to [40]) and weak links with actors outside the group (bridging). However, ISFM does not mobilise the actors to any great extent. Membership in a cooperative and access to credit facilitate yam marketing [37]. However, these conditions are not yet a reality for the farmers of Tiéningboué. The potential for the creation of social capital exists, but its exploitation remains sub-optimal. Neither farmers nor the other yam actors seem to be able to dialogue with the researchers to readjust the technical proposals to their constraints and improve their relevance, efficiency and feasibility.

Why this discrepancy between the perceptions of experts and farmers?

In fact, the majority of Tiéningboué yam farmers no longer have large areas of fallow land, but most of them still have some that they are clearing and transforming into cashew fields. The effects of these processes on available area reduction for seasonal crops and on yield of fields cropping of continuously cultivated, are only gradually emerging. Most farmers continue to depend only on forest fallow or on *Chromolaena odorata*, a pioneer plant, as yam crop precedent, and are not yet under pressure to develop other strategies. "Cotton can be produced for a long time with fertiliser-medicine; however, no fertiliser-medicine for yam is known, so we only depend on fallow land", said one non-native famer during the exploratory phase. *Chromolanea* is recognised as a species with a high capacity for rapid biomass production and capable of slowing the decrease in soil organic matter [28]. When the alternative to natural fallow is no longer available and farmers switch to continuous cropping systems, rice cultivation has a moderating effect. Most of this crop biomass is reincorporated into the plot. We should also mention the effects of the increasingly frequent use of herbicides, which certainly disrupts the development of spontaneous flora and fauna, but also makes it less necessary to use burns to prepare a new plot of land. Thus, the rotations of the indigenous non-cotton farmers are lengthened with yam alternating with rice and sometimes groundnuts before installing cashew trees that will take over the plot when it becomes exhausted. Then some deforestation negative effects are counterbalanced by the plant cover provided by the cashew trees. The negative effects of unbalanced mineral balances will eventually make themselves felt, but not as quickly as researchers anticipate. Finally, land scarcity is only felt by a minority in this region, which still receives flows of migrants to compensate for the labour shortages of agriculture mainly manual, even if the land rights of these new arrivals are increasingly precarious or their obligations regarding monitoring and maintenance their landowner’s cashew crop are becoming stricter.

Land scarcity is felt when agricultural intensity and population density are higher [33]. In such situations, local farming practices develop to grow yam in permanent crop rotations or short fallow. Common rotations with legumes (soybean, groundnut, cowpea, etc.) or cereals (rice, maize and sorghum) or fertilised cotton are part of ISFM farming strategies in the yam zone. Thus, for yam production systems in the Sudano-Guinean zone of Benin, [20] point out that in areas where there is little or no forest fallow, yam production has been sharply reduced but has not disappeared, and that some of these crops are planted in rotations after cereals whose stalks serve as yam stakes, after improving crop or after cattle have been parked on an area. This sedentarisation is accompanied by an evolution of cultivars for greater hardiness and production of small tubers that will be largely transformed into cossettes [47]. Another strategy observed is to concentrate *D. rotundata* fields in lowland areas where the plots benefit from the nutrient concentrations caused by runoff and where farmers grow early yams with high market value. In Nigeria and Benin, researchers then proposed fallows planted with fast-growing shrub species, to be managed in rotation or in association in yam rotations, but their management requires a lot of additional work. Easier to set up, various cover leguminous plants were tested as a precedent for yam. These promising systems are particularly suitable for use in permanent agriculture with minimum tillage [9]. However, these systems have not been widely adopted, having been promoted only by small research teams.

The transition towards permanent farming systems requires a major change in the logic of farmers' actions: from logic focused solely on enhancement of soil fertility naturally recreated, they are moving towards a recursive dynamic of enhancement, preservation and active creation of resources. The current yam-based systems of farms compared to the model of sustainable agriculture developed by [39] are not sustainable. In this model, capital (natural and social) has an important collective dimension, and its accumulation and use are based on forms of cooperation and coordination of actors [38] that contribute to sustainable management. The other capitals (physical, financial, commercial and human capital) are specific to an individual and are mainly the subject of individual strategies. For this reason, the YAMSYS team promote innovation platforms as a tool to develop collaboration between stakeholders [22]: they are called upon to design innovations and strengthen sustainable soil management in their yam-based production systems based on capital (natural and social). Despite the associated difficulties that must be overcome, researchers are aware of the need for improved collaboration, and with farmers and their organisations and between farmers and their organisations [46]. The levels adopting by YAMSYS include : the field where the actual crop management is implemented, the household where the decision for a given crop management technique will be taken, the yam value chain that provides the incentive for production, and the surrounding environment that also strongly affects the decision-making at the household level [23]. In fact, the innovation platforms function is to induce institutional changes that allow farmers who are under strong pressure to adopt innovations that are relevant to them (and therefore also relevant to downstream actors in the value chains).Currently, Tiéningboué IP vision is to develop cropping systems that preserve the environment and increase yam yields. Therefore, the IP members discussed the technologies that are developed by researchers and made available to farmers. Crop rotations and associations and increased planting density of 10,000 plants/ha are considered as a solution to land scarcity. The application of mineral and/or organic fertilizers is as a solution to soil fertility decline. For the importance of healthy seed, researchers proposed to select plants tubers with no visible disease symptoms as seeds for the next cropping season, to use a mixture of a fungicide and an insecticide to treat seeds just before planting and to improve tuber storage in order to keep the tubers healthy until the next cropping season [29]. One remark is that IP focused on production should be part of a dynamic that allows expression and consideration from other stakeholder groups expectations. Thus, actors in each field develop a common vision and are led to initiate major institutional and systemic changes that promote technical changes to which they adhere. A change of scale from niche to socio-technological regime is targeted in the long term [26]. The IP is an appropriate tool for stimulating dialogue among local stakeholders allowing co-development of technologies, but it has shown weaknesses when not appropriately managed [29]. Indeed, there is a risk of discrepancies between decisions and actions of IP and the real needs of stakeholder groups. A major risk is that, as stakeholders in the IPs, researchers often dominate discussions and influence the decision [29]. Concerning IP board, there was no guarantee that the representatives were the right persons who would work primarily for the interest of the group and not their own [12].

Nevertheless, the Tiéningboué platform does not yet have its champions among the actors of the yam sector, and the technologies only generate interest when they are accompanied by donations of inputs. Shouldn't we then return to basic principles such as "areas of recommendation" where technologies are knitted for particular types of farmers, in good knowledge of their internal constraints [36], but taking into account the requirements of their marketing? Such design of technical options requires strong interaction of researchers with farmers, their buyers and other stakeholders. Indeed, inevitably, behaviour will be linked to structural features of the economy within which any given farmer operates, especially agricultural policy, market configurations, and technology design [11]. Therefore, the transdisciplinary approach requires time and patience to make a relevant diagnostic and to co-develop solutions [29]. In such processes, failures in technology adoption are as important as successes if lessons are learned. Starting from local innovations to improve them is also an often-attractive entry point for stakeholders to articulate technical and socio-institutional innovations as well [45].

CONCLUSIONS

The choice of yam by the YAMSYS project is confirmed as this activity is practiced by 89.9% of households in the Tiéningboué area. Thus, six (6) yam-based production systems (PS) and their proportion in the sample are identified: yam specialists in class 6 (1%), cotton farmers in class 2 (15%), smallholders in class 1 (47%), very large autochthonous farms in class 5 (3%), large autochthonous farms in class 3 (27%), and large allochthonous and allogeneic non-cotton farms in class 4 (7%).

As a similarity, current soil fertility management strategies are based not only on rotations (with yam leading in 97.8% of the farms) although the best precedent for yam is not yet stabilised, but also on natural fallows which are only available in large areas for class 5, i.e. 3% of the sample. Current yam production is carried out without any external input of organic or mineral fertilisers, because traditional livestock farming makes it difficult to collect manure, and recurrent farmer-breeder conflicts reduce the chances of collaboration in the valorisation of cattle manure from the Peulh-managed farms.

In addition, the typology of yam-based SP assumes that the specific characteristics of the groups will affect the interest that each type would give to the different technical packages on soil fertility management proposed by the "Yamsys". Indeed, the producers' perception of fertilisation reveals a discrepancy with that of the researcher. This therefore raises the problem of the adequacy of agronomists' proposals to the problems of fertility management of yam farmers. In fact, the YAMSYS technology package targets quite specifically the decline in soil productivity without much concern for the additional demand for labour and cash. Small indigenous class 1 farms with low resource endowment are a priori ideal candidates for the adoption of ISFM techniques proposed by the Yamsys, as this class needs to intensify its production's system that has become permanent. But their cash flow could limit them because they sell yams to traders through non-loyalty relationships.

Finally, this study highlighted not only a segmentation of the target of the Yamsys project, but also pointed out the key factors to be exploited to have "champions" at the level of the actors of the yam sector in order to boost a change in farmers adaptive behaviour for the sustainable management of soil fertility by taking into account in particular the natural and social capital and to avoid the occurrence of critical levels of degradation.

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REFERENCES

[1]Arnau, G., Abraham, K., Sheela, M., Chair, H., Sartie, A., Asiedu, R., 2010, Yams, In: Root and Tuber Crops. Handbook of Plant Breeding, Vol. 7, ed. J. Bradshaw (New York, NY: Springer Science + Business Media), p. 127–148.

[2]Asiedu, R., Sartie, A., 2010, Crops that feed the World 1. Yams. Yams for income and food security. Food Secur. 2: 305–315. DOI: 10.1007/s12571-010-0085-0, Accessed on 27.03.2017.

[3]Bassey, E.E., Akpan, U.S., 2015, Evaluation of guinea white yam (*Dioscorea rotundata Poir*.) for yield and yield components in Nigeria. Am. J. Exp. Agric. 8: 216–233. DOI: 10.9734/AJEA/2015/16496, Accessed on 11.07.2018.

[4]Bonfoh, B., Todje, A., Gbakenou, K.I., 2016, Status of Agricultural Innovations, Innovation Platforms, and Innovations Investment. 2015 PARI project country report, Republic of Togo, Forum for Agricultural Research in Africa (FARA), Accra.

[5]Brugha, R., Varvasovsky, Z., 2000, Stakeholder analysis: a review. Health Policy and Planning 15, 239–246.

[6]Carsky, R.J., Asiedu, R., Cornet, D., 2010, Review of soil fertility management for yam-based systems in West Africa. Afr. J. Root Tuber Crops 8: 1–17.

[7]Chambers, R., 1994, The origins and practice of participatory rural appraisal. World Development, 22(7): 953–969.

[8]Cochet, H., Devienne, S., 2006, Fonctionnement et performances économiques des systèmes de production agricole : une démarche à l'échelle régionale. Cahiers Agricultures 15(6): 578–583 (1). DOI: 10.1684/AGR.2006.0028, Accessed on 21.03.2017.

[9]Cornet, D., Vernier, P., Amadji, F., et al., 2006, Integration of yam in cover crop based cropping system: constraints and potential. In: Proceedings of the 14th triennial symposium of the international society for tropical root crops (ISTRC), Thiruvananthapuram, India, 2006.
[10]Coursey, D.G., 1981, The interactions of yam and man. J. Agric. Tradit. Bot. Appl. 1: 5–21. DOI: 10.3406/jatba.1981.3829, Accessed on 11.07.2018.
[11]Darnhofer, I., Schneeberger, W., Freyer, B., 2005, Converting or not converting to organic farming in Austria:Farmer types and their rationale. Agriculture and Human Values, 22(1), 39–52. https://doi.org/10.1007/s10460-004-7229-9, Accessed on 13.05.2018.
[12]De Sardan, O.J-P., Bierschenk, T., 1993, Les courtiers locaux du développement. Bull. l'APAD, 12, 2–6.
[13]Diby, L.N., Hgaza, V.K., Tié, T.B., Assa, A., Carsky, R., Girardin, O., et al., 2011, How does soil fertility affect yam growth? Acta Agr. Scand. 61 : 448–457. DOI: 10.1080/09064710.2010.505578, Accessed on 13.05.2018.
[14]Doré, T., Le Bail, M., Martin, P., Ney, B., Roger-Estrade, J., 2006, L'agronomie aujourd'hui. Versailles. ed Quae, 313 p.
[15]Dumont, R., Vernier, P., 1997, L'igname en Afrique de solutions transférables vers le développement. Cahier de la recherche développement, 44: 115-120.
[16]Ekins, P., Simon, S., Deutsch, L., Folke, C., De Groot, R., 2003, A framework for the practical application of the concepts of critical natural capital and strong sustainability. Ecol Econ 44: 165-185.
[17] FAO, 2001, Soil Fertility Management in Support of Food Security in sub-Saharan Africa. Rome: Organisation des Nations Unies pour l'alimentation et l'agriculture.
[18]FAO, WOCAT, TerrAfrica, 2011, La pratique de la gestion durable des terres Directives et bonnes pratiques pour l'Afrique subsaharienne. 243p.
[19]FAOSTAT, http://www.fao.org/faostat/en/#home, Accessed on 03.12.2020.
[20] Floquet, A.B., Maliki, R., Tossou, R.C., Tokpa, C., 2012, Évolution des systèmes de production de l'igname dans la zone soudano-guinéenne du Bénin. Cah Agric 21: 427-37. doi: 10.1684/agr.2012.0597, Accessed on 03.05.2019
[21]Freeman, R.E., 1984, Strategic Management: a Stakeholder Approach. Basic Books, New York, pp.52-80
[22]Frossard, E., Aighewi, B.A., Aké, S., Barjolle, D., Baumann, P., Bernet, T., Dao, D., Diby, L.N., Floquet, A., Hgaza, V.K., Ilboudo, L.J., Kiba, D.I., Mongbo, R.L., Nacro, H.B., Nicolay, G.L., Oka, E., Ouattara, Y.F., Pouya, N., Senanayake, R.L., Six, J., Traoré, O.I, 2017, The Challenge of Improving Soil Fertility in Yam Cropping Systems of West Africa. Frontiers in Plant Science 8:1953. doi: 10.3389/fpls.2017.01953, Accessed on 11.07.2018.
[23]Frossard, E., Aighewi, B., Aké, S., Barjolle, D., Bernet, T., Dao, D., Diby, L.N., Floquet, A., Hgaza, V.K., Ilboudo, L.J., Kiba, D.I., Mongbo, R.L., Nacro, H.B., Nicolay, G., Oka, E., Ouattara, Y.F., Pouya, N., Six, J., Traoré, O.I., 2019, Biophysical, Institutional and Economic Drivers of Sustainable Soil Use in Yam Systems for Improved Food Security in West Africa, Tropical Agriculture and Development (published by the Japanese Society for Tropical Agriculture) 12（2): 114 − 121.
[24]Giezendanner, F.D., 2012, Genève Instruction publique, culture et sport Service Ecoles-Médias. Retrieved from http://icp.ge.ch/sem/cms-spip/IMG/pdf/taille-d_un-echantillon-aleatoire-et-marge-d_erreur-cms-spip.pdf, Accessed on 04.06.2018.
[25]Hinvi, J.C., Nonfon, R., 2000, La production et la commercialisation des semenceaux d'igname à Bouaké : une nécessité de plus en plus incontournable. In Ebert A.W., Djinadou K. (ed), L'igname et la pomme de terre en Afrique de l'Ouest. Actes de l'atelier sous régional sur l'igname et la pomme de terre, INA, Bénin, 7-8 juin 2000. Cotonou, WADSU/INRAB, pp. 81- 89.
[26]Hounkonnou, D., Brouwers, J., Van Huis, A., et al., 2018, Triggering regime change: a comparative analysis of the performance of innovation platforms that attempted to change the institutional context for nine agricultural domains in West Africa. Agricultural Systems 165. Elsevier: 296–309.
[27]Husson, F., Lê, S., Pagès, J., 2016, Analyse de données avec R, 2ème édition revue et augmentée - Presses Universitaires de Rennes, Rennes, pp.169-202.
[28]Kassi, S.,, Koné, A.W., Tondoh, J.E., et al., 2017, Chromoleana odorata fallow-cropping cycles maintain soil carbon stocks and yam yields 40 years after conversion of native- to farmland, implications for forest conservation. Agriculture, Ecosystems & Environment 247: 298–307. DOI: 10.1016/j.agee.2017.06.044, Accessed on 15.08.2020.
[29]Kiba, D.I., Hgaza, V.K., Aighewi, B., Aké, S., Barjolle, D., Bernet, T., Diby, L.N., Ilboudo, L.J., Nicolay, G., Oka, E., Ouattara, F.Y., Pouya, N., Six, J., Frossard, E., 2020, A Transdisciplinary Approach for the Development of Sustainable Yam (Dioscorea sp.) Production in West Africa, Sustainability, 12, 4016; doi:10.3390/su12104016, Accessed on 25.06.2020.
[30]Kuivanen, K.S., Michalscheck, M., Descheemaeker, K., et al., 2016, A comparison of statistical and participatory clustering of smallholder farming systems - A case study in Northern Ghana. Journal of Rural Studies 45: 184–198. DOI: 10.1016/j.jrurstud.2016.03.015, Accessed on 12.06.2017.
[31]Lebot, J., 2009, Tropical root and tuber crops cassava, sweet potato, yams and tarot. Crop production science in horticulture 17,CABI, Wallingford UK, 413p.
[32]Maliki, R., Toukourou, M., Sinsin, B., Vernier, P., 2012, Productivity of yam-based systems with herbaceous legumes and short fallows in the Guinea-Sudan transition zone of Benin. Nutr. Cycl.

Agroecosyst. 92: 9–19. DOI: 10.1007/s10705-011-9468-7, Accessed on 03.05.2019.

[33]Mango, N., Hebinck, P., 2016, Agroforestry: A second soil fertility paradigm? A case of soil fertility management in Western Kenya. Cogent Social Sciences, 2(1), 1–17. https://doi.org/10.1080/23311886.2016.1215779, Accessed on 15.08.2020.

[34]Mbetid-Bessane, E., Havard, M., Djamen, N.P., Djonnewa, A., Djondang, K., et al., 2003, Typologies des exploitations agricoles dans les savanes d'Afrique centrale: un regard sur les méthodes utilisées et leur utilité pour la recherche et le développement, Cirad-Prasac, 10 p.

[35]Nahapiet, J., Ghoshal, S., 1998, Social Capital, Intellectual Capital, and the Organizational Advantage. Acad Manage Rev; 23: 242-66.

[36]Norman, D., Atta-Krah, K., 2017, Systems research for agricultural development. In: Sustainable Intensification in Smallholder Agriculture. Dited by: Öborn, Ingrid, et Al. Routledge. London, UK, pp.19–42.

[37]Olutumise, A.I., 2020, Transportation system and output market participation nexus among yam producers in southwest region of Nigeria. Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, 20(4), 365–380.

[38]Pretty, J., 2003, Social capital and the collective management of resources. Science; 302: 1912-4.

[39]Pretty, J., Hine, R., 2002, What is Sustainable Agriculture? In: Pretty J, Hine R, eds. Reducing Food Poverty with Sustainable Agriculture: A Summary of New Evidence. Essex: CES Report. UK: University of Essex.

[40]Putnam, R., 2000, Bowling Alone. The Collapse and Revival of American Community. New York: Simon and Schuster, pp.93-115.

[41]Reed, M.S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C.H., Stringer, L.C., 2009, Who's in and why? A typology of stakeholder analysis methods for natural resource management. Journal of Environmental Management, 90(5), 1933–1949. https://doi.org/10.1016/j.jenvman.2009.01.001, Accessed on 25.02.2019.

[42]Sangakkara, U.R., Frossard, E., 2014, Home gardens and Dioscorea species – a case study from the climatic zones of Sri Lanka. J. Agric. Rural Dev. Trop. 115: 55–65.

[43]Soro, D., Dao, D., Girardin, O., Tié, B.T., Tschannen, A.B., 2010, Adoption d'innovations en agriculture en Côte d'Ivoire: cas de nouvelles variétés d'igname. Cahiers Agricultures 19: 403–410.

[44]Soro, D., Dao, D., Carsky, R., Asiedu, R., Assa, A., et al., 2007, Amélioration de la production de l'igname à travers la fertilisation minérale en zone de savane de Cote d'Ivoire. Savanes africaines: des espaces en mutation, des acteurs face à de nouveaux défis, Actes du colloque, 27-31 mai 2002, Garoua, Cameroun, 8p.

[45]Triomphe, B., Floquet, A., Letty, B., et al., 2017, How can external interventions build on local innovations? In: Sustainable Intensification in Smallholder Agriculture. Edited by: Öborn I, Vanlauwe B, Phillips M, Thomas R, Brooijmans W, Atta-Krah K. London, UK: Routledge, pp. 334–349.

[46]Triomphe, B., Floquet, A., Letty, B., Kamau, G., Almekinders, C., Waters-Bayer, A., 2016, Mieux évaluer et accompagner l'innovation agricole en Afrique. Leçons d'une analyse transversale de 13 cas d'études. Cahiers Agricultures, 25(6), 64003. https://doi.org/10.1051/cagri/2016050, Accessed on 08.05.2017.

[47]Vernier, P., Dossou, R., 2003, Un exemple de la sédentarisation de la culture des ignames: les cas des Kokoro (D. rotundata) au Bénin. Agronomie Africaine 15(4): 187–193.