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Sustainable Agroforestry Adoption in a Small-Scale Food Production System: the Case of Yam in Rotation with the Intercropping Gliricidia Sepium and Herbaceous in the Guinea-Sudan Zone of Benin

Raphiou Maliki[1*], Brice Sinsin[2], Laurent Parrot[3], Jacques Lancon[3], Anne Floquet[4] and NeBambi Lutaladio[5]
[1]Institut National des Recherches Agricoles du Bénin (INRAB), P. O. Box.2128, Calavi, Benin.
[2]Faculté des Sciences Agronomiques de l'Université d'Abomey-Calavi (FSA/UAC), P.O. Box 01-526, Cotonou, Benin.
[3]Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), P. O. Box 34398, Montpellier Cedex 5, France.
[4]Centre Béninois pour l'Environnement, le Développement Economique et Social (CEBEDES), P. O. Box 02-331, Cotonou, Benin.
[5] Food and Agriculture Organisation of the United Nations (FAO), P. O. Box 00100, Roma, Italy.
*Corresponding author email id: malikird@yahoo.fr

Abstract **– West Africa is now confronted with a land scarcity and slash-and-burn shifting cultivation systems come to their limits. With the aim of designing more sustainable yam cropping systems, the agronomic research is promoting alternative agroforestry yam-based systems. Alley cropping was implemented in several research structures and was transferred in rural areas. The most important constraints of alley cropping adoption are its pruning workload as well as competition between shrubs and crops for nutrients and light. It is well-known today that smallholders deeply readjust technologies developed in close relationship with researchers when confronted with various constraints. Farmers have been adjusting the alternative systems with alley cropping to their own constraints. This paper investigates adoption, constraints, and adaptations of mixed inter-cropping an agroforestry tree species, *Gliricidia sepium*-herbaceous in the Guinea-Sudan zone of Benin. The differences between adopters and non-adopters of yam-based agroforestry systems with *Gliricidia* in terms of their age, education, gender, Households' size, active members of the family, farm income, land tenure, extension contact, training, credit, belong to organisation and other socioeconomic and agro-ecological variables are examined. Results from logistic regression analysis suggest that extension contact, credit and population density in zone are important variables in determining the adoption of new yam-based agroforestry systems. It was observed that farmers adapted technologies to suit their situation.**

Keywords **– Adaptation, Adoption, Diffusion, Gliricidia sepium, Benin, Logit, Yam, Sustainable agriculture.**

I. Introduction

West Africa currently produces more than 40 million t year-1 yam, that is 90% of worldwide production [1]. The production increase was obtained on larger yam-cultivated areas in slash-and-burn and shifting cultivation systems, indicating that only a limited degree of intensification was under way.

Benin is the world's fourth ranking producer, after Nigeria, Cote d'Ivoire, and Ghana. Nowadays, farmers hardly have the possibility to rely on long duration fallow and yam is being cultivated in 1 or 2-year herbaceous fallow–yam or maize/sorghum-yam rotation systems with manual incorporation of residue into the soil [2].

Current yam-based cropping systems, which involve shifting cultivation, slash-and-burn or short fallow, often result in deforestation and soil nutrient depletion [3]. 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 ten years or more of fallow, for example allows the accumulation of easily degradable organic matter to regenerate soil fertility [4]-[5]. Where population increases, available land per inhabitant is reduced and fallow periods shorten. Traditional long-fallow shifting cultivation can no longer continue in most of humid sub-Saharan Africa. Increasing population densities are posing a serious threat to natural resources and agricultural production. Farmers' response to higher food demand has been either an increase in cultivated area or/and a reduction of fallow period. The minimum fallow duration to maintain crop production was estimated at 12 years [6]. Fallow periods in most of the humid zone of West and Central Africa are actually between 5 and 2 years [7], reinforcing the need to seek alternative food production systems [6].

Yam is a demanding crop in terms of organic matter and soil fertility, especially the most appreciated and market-valued cultivars (early maturing *Dioscorea rotundata*) used for the popular dish called "fu-fu" (pounded yam) [8].

Agroforestry is thought to have the potential to improve soil fertility through the maintenance or increase of soil organic matter and biological nitrogen (N2) fixation from nitrogen fixing tree species [9]. Biologically, agroforestry species that replenish soil fertility have the potential to reverse soil fertility decline, thereby increasing crop yields. Various studies have shown the potential of agroforestry as an approach to sustainable agriculture production and soil management, especially in the tropics [10]-[9]. However, adoption of agroforestry technologies has generally been low [11]. Furthermore, research on agroforestry to date has predominantly focused on the biophysical aspects of agroforestry technologies with little attention given to socioeconomic studies relating to agroforestry adoption [12]-[13]-[14].

Studies from Malawi have shown that gliricidia, [*Gliricidia sepium* (Jacq) Walp, Ruta], a fast growing tree species and a nitrogen fixer, can yield over 5.4 t ha-1 year-1 of coppiced biomass [10]. When prunings of *Gliricidia* were added to maize, [15] observed a significant increase in topsoil preseason inorganic nitrogen (N). Because of its high N contribution from its foliage, *Gliricidia* is considered as one of the promising soil fertility replenishment agroforestry species in the Guinea-Sudan zone of Benin.

Research was undertaken to solve the main problems of arable lands degradation in West Africa and in Benin in particular and especially to increase the adoption of powerful innovations in farming systems. Previously, crop in alley cropping was perceived as the most advantageous agroforestry systems in West Africa. The alley cropping was implemented in several research structures and was transferred in rural areas [16]-[17]-[18]. Nevertheless, the rate of adoption was low and discouraging. The most important constraints for agroforestry systems adoption, notably alley cropping [16], are its pruning workload as well as competition between shrubs and crops for nutrients and light [19]-[20].

It is well-known today that smallholders deeply readjust technologies developed in close relationship with researchers when confronted with various constraints (land, soil quality, labor, cash, etc). A first range of adaptations was implemented by smallholders in the Guinea-Sudan zone of Benin. This is focused on alley cropping system but included farmers criticisms and adaptations in order to develop a new range of technologies. The density of shrubs was reduced in order to reduce the labour required for repeated coppicing and herbaceous (legumes, graminaceous or crops) were included in the rotation cropping systems with yam in order to maintain soil fertility. In the agroforestry-yam based system at the end of the rotation, the plot remains under fallow during a few years before being cleared for yam and *Gliricidia sepium* usually grows to medium-sized shrubs.

However, the factors influencing adoption of this technology in a Small-Scale Food Production System have not been systematically investigated in the region. Investigation of why some technologies are more readily adopted than others requires key information about the socioeconomic and biophysical interactions that affect farmers ‘decision making. Technologies that are proven successful through research trials may have low adoption rates because of many reasons including wrong targeting resulting from lack of farmer participation [21]-[22]-[14].

It is generally agreed that farmers adopt an innovation if they expect it to contribute to better achieving their goals with, which may include economic, social and environmental aspects, while considering risk-related issues at the same time. In this paper, we intend to identify factors that may explain the adoption of yam-based system in rotation with the mixed intercropping *Gliricidia sepium*-herbaceous for soil conservation and sustainable yam production. We explore several demographic or institutional factors in view of providing relevant pointers for more effective and efficient public policies as regards the dissemination of the improved yam-based cropping systems. In section 1, we present the study area in the Guinea-Sudan zone of Benin, the yam-based systems recommended to farmers and the process of diffusion and adoption implemented. In section 2 we describe the survey methodology and adoption model used for assessment. In sections 3 and 4, results are exposed and discussed.

II. Methodology

A. Study Area

The study was carried out in the Guinea-Sudan zone of Benin in a low (Savalou, Bante, Savè and Ouesse) and in a relatively high population density zone (Dassa-Zoume, Glazoue).

This area lies between the latitudes 7°45 ' and 8°40' North and longitudes 2°20 ' and 2°35 ' East. The climate is the transitional climatic Guinea-Sudan type with a gradient from bimodal to monomodal rainfall distribution from the south and the north of Benin respectively. Annual rainfall in the study area varies from 1,100 mm to 1,200 mm with unequal distribution [23].

The soils are plinthosols and luvisols. The soil physical properties vary according to their clay content [24]. Vegetation is a degraded woody savannah type. Maize, yam, cassava and groundnut are annual cropping systems and the cash crops are cotton and soybean.

B. Process of Evaluation Agroforestry Technology and Diffusion of Innovation

Yam-based alley cropping with *Gliricidia sepium* was introduced in 1990 in the Guinea-Sudan zone of Benin to improve farming systems. In the yam-based alley cropping with *Gliricidia sepium*, yam is cultivated in an intercalated arrangement of crop, in alley of *Glricidia sepium*. The lines of shrubs are separated between them of 3 meters. On the line, the seedlings of *Gliricida* are distant 1 m from/to each other (space: 3m × 1m). Two lines of ridges of yam are installed inside the alley. The cut of the shrubs of *Gliricidia* is carried out to 1.5 m of the ground. Two to three prunings of the shrubs are carried out during the yam production cycle. The tree is used as well tutor as for the prunings production. The stems of *Gliricidia* are used as alive tutors for the yam lianas.

The process of participatory research is iterative and knows the following stages (Figure 1): diagnosis, selection of the priorities of research, experimentation, participative follow-up-evaluation, adaptation of technologies, and generation of diffusion approach. In 2000, assessment of alley cropping with *Gliricidia sepium* was conducted in the Guinea-Sudan zone of Benin in low and relatively high population density zone with different socio-professional groups such as group of adult men (GAM) ; group of old men (GOM) ; group of women (GW) ; group of young people (GYP) ; group of immigrant adult men (GIAM). The prioritization matrix and the contingent ranking matrix (synthesis matrix at regional level) were used for constraint degree of severity [25]. Following parameters were considered in the data analysis:

Relative importance of a constraint (IR): is the score that the end-users group gave to a constraint. The participants freely established the score notation. The maximum score corresponded to the constraint that the socioprofessional group considered most important or the sum of maximum when the synthesis matrix was concerned. The minimum score was selected equal to zero for the group.

Constraint degree of severity (DS): is the percentage of the note given to a constraint compared to the maximum score.

Constraints of which in particular the difficulty of pruning in yam-based alley cropping system was expressed by different socio-professional groups in both zones with high degree of severity (DS) of 80%.

In addition, smallholders expressed the problem of competition between shrubs and crop, surplus of the labour, bush fires, difficulty of collecting and spreading of the prunings, mobilization of cropping plots due to the presence of shrubs: trees, difficulty of ploughing enters the hedges, difficulty of transport of the prunings, low availability of the agroforestry seed, repeated pruning in alley cropping, difficulty of weeding (because of the spreading or hidden prunings), financial problem/crédit with DS ranged in this order from 68% to 11%.

On the basis of diagnosis, agroforestry systems integrated new range focused on the reduction density of shrubs with the mixed intercropping *Gliricidia sepium* and herbaceous (legumes, graminaceous or crops) for subsequent yam production were generated and diffused. This is focused on alley cropping system but included farmers criticisms and adaptations in order to develop a new range of technologies. The density of shrubs was reduced (4m × 4m) in order to reduce the labour required for repeated coppicing and herbaceous (legumes, graminaceous or crops) were included in the cropping systems in order to maintain soil fertility [20].

Since 2000 the technology was transferred to smallholder farmers and diffused in the Guinea-Sudan zone of Benin by way of participatory training, farmer field schools (FFS) and visits in close partnership with extension workers.

The results of research are presented in the framework of village restitution. Successful outcomes observed by each farmer in a particular field help to increase participation by the remaining farmers. Field training and visits are organized to document different points of view by farmers, extension workers and researchers. A scientific workshop is organized for researchers from the National Agricultural Research System (SNRA), who present and discuss the results of their research [26] (Figure 1). Major research findings are communicated to the Regional Research and Development Committee (CRRD), the main link in the agricultural research management cycle in Benin. Some 50% of farmers and end users of the technologies are members of the CRRD, the remaining 50% being researchers, intermediate users such as the Regional Centre for Agricultural Development (CeRPA), NGOs, development partners and political decision makers. The research results are presented in simple and accessible form during the forum and are discussed with the participation of farmers. The CRRD forum can transfer the best and most affordable results in terms of technical and economic performance to extension services for widespread promotion of the adopted technologies. After fine-tuning of the technologies, a manual is drafted in a multi-field and multi-institutional approach in collaboration with farmers, researchers and the extension structures. The document proposes a technical road map with illustrations, comments and discussion of the economic issues. This technical and economic reference (RTE) was produced for farmers, agricultural professionals, extension workers and researchers for the dissemination and promotion of the technology.

C. Theoretical Model of Adoption

The dependent variable, adoption of soil conservation innovation with the mixed intercropping *Gliricidia sepium* and herbaceous for subsequent yam, is dichotomized by assigning a value of one if a farmer is an adopter and zero otherwise. Because the dependent variable is dichotomous, the regression is non-linear in form and ordinary least squares will not provide useful estimators [27]. Instead a dichotomous logistic model technique is used to regress adoption on a set of explanatory variables. Many studies have used the logistic analysis approach to examine similar issues in various geographical regions and for different technologies [28]-[12]-[29].

$$y_i^* = \beta' x_i + u_i \tag{1}$$

Where y_i^* unobservable variable, but determined by the dummy variable y defined by

$$y = 1 \ if \ y_i^* > 0 \tag{2}$$

y = 0 otherwise

From equations (1) and (2), the probability that y = 1 a particular farmer will adopt soil conservation innovations with the mixed intercropping *Gliricidia sepium* and herbaceous for increasing yam productivity is:

$$\text{Prob}\,(y=1) = \text{Prob}\,(u_i > -\beta' x_i) = -F(-\beta' x_i) \tag{3}$$

and the probability that y = 0 that the farmers will not adopt, is:

$$\text{Prob}\,(y=0) = \text{Prob}\,(u_i < \beta' x_i) = F(-\beta' x_i) \tag{4}$$

where in equation (3) and (4), F is the cumulative distribution function. We assume that u is independent of X, the vector of characteristics associated with smallholder farmers, and has a standard logistic distribution [30] and β is the vector of estimated coefficients. A combination of equations (1) and (2), yields the probability that a smallholder farmer will adopt the technology as:

$$1 - F(-\beta' x_i) = \frac{\exp(\beta' x_i)}{1 + \exp(\beta' x_i)} = A(\beta' x') \tag{5}$$

and the likelihood [27] is:

$$L = \prod_{y_i \to 0} F(-\beta' x_i) \prod_{y_i \to 1} \left[1 - F(-\beta' x_i)\right] \tag{6}$$

The confidence interval is another goodness-of-fit measure. After estimating the βs, confidence intervals (CI), a statistical inference for the model parameters can be performed to help judge the magnitude of the significance [31]. A confidence interval only has the specified probability of containing the parameter if the

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sample data on which it is based is the only information available about the value of the parameter by using the formula in equation (7).

$$\beta \pm z_{\alpha/2}(ASE) \qquad (7)$$

where ASE is the asymptotic standard error and z is the α/2 critical value from a t- distribution with (n/k) degrees of freedom.

The magnitude of changes in the probability of adoption as the regressor changes is best captured by the marginal effect, usually evaluated at its mean of the explanatory variable. Following [32], we denote the logistic cumulative function by A(-) which is between zero and one. Substituting A(-) as the standard logit in equation (3), we find the marginal effects of the regressors on the probability as:

$$A(1-A)\beta \qquad (8)$$

The derivatives of the likelihood estimates of the coefficients yield the probability of being in one of the dichotomous groups, an adopter or non-adopter. This will give the measure of strength of response for the independent variables. However, the change in the probability can be expressed in percentage change by multiplying with 100.

The equation used to estimate the parameters is:

$$E(y_i) = \alpha + \beta_1 ZONE + \beta_2 SUDISP + \beta_3 GENDER + \beta_4 NBOUCH + \beta_5 FTRAV + \beta_6 ORIGIN + \beta_7 CONTACT + \beta_8 CREDIT + \beta_9 NIVELEV$$

D. Empirical Model of Adoption

The choice concerned the Research and Development (R&D) sites where the systems were generated and off R&D sites implying certain heterogeneity in the agro-ecological, socioeconomic and cultural level [33]. Selected Villages were located in the relatively high and low population density zones.

To establish the base of the survey, the results from the "third population census" [34] and other relevant documents were analyzed [33]. Statistical data concerning the yam smallholder farmers from several villages in the "Collines Department" were also used. Total sample of 306 farm households in six districts of the "Collines Department" in the study area were surveyed including 25% and 75% of the sample for the R&D and off R&D sites respectively.

This sampling distribution took into account the size of the population in order to better assess the scale of the adoption in the "Collines Department". In each village, sampling was conducted along a transect that accounted for agro-ecological diversity with the aim of including maximum possible of variability. This made it possible to calculate the total number of yam smallholders in the study area and the number of yam smallholder farmers in each site or village for the survey.

Twenty-seven villages in the "Collines Department" with low and relatively high population densities were surveyed including adopters and non-adopters of yam-based cropping system in rotation with the mixed intercropping *Gliricidia sepium* and herbaceous. A checklist was used for the socio-economic investigations and data collection at the level of the farm household. Fifty explanatory variables were considered for the study. Out of fifty explanatory variables, nine independent variables more meaningful were selected with the correlation analysis and included in the model. ZONE (population density in zone), SUPDISP (land availability), GENDER (sex), NBOUCH (Farm household size), FTRAV (labour availability), ORIGIN (owner status: indigenous or immigrant), CONTACT (contacts with external services for advice), CREDIT (formal financial credit), NIVELEV (livestock size).

Justifications, methods, and predicted signs for each independent variable in the models are discussed (Table 1).

The variable ZONE expresses the geographical diversity of social, cultural and ecological constraints linked with demography, land pressure and, as a consequence, soil degradation [35]-[36]. In zones where soils are degraded, smallholders could be more inclined to adopt new systems. This variable takes value 1 in a relatively high population density zone and 0 otherwise. SUPDISP is the land availability for yam cropping systems. Land security is useful for the soil fertility investment. Land availability could lead farmers to clear new woody fallow for yam production (traditional shifting cultivation system) versus improved yam-based system with *Gliricidia* and herbaceous. A negative sign is expected for this variable. GENDER is the variable sex. Many studies were carried out on gender analysis about new technologies [37]- [38]-[39]-[40]. Generally, unfavourable land status attributed for women could be prejudicial for adoption of innovative technologies. GENDER is a dummy variable which takes value 1 for men and 0 otherwise. NBOUCH is the farm household size supposed positively correlated to the adoption of new technologies. FTRAV is the variable relative to household labour availability. Importance of labour for adoption of new technologies is reported [41]-[42]. This variable is expected to influence positively adoption of improved yam-based systems. ORIGIN is the farm owner social status. We supposed that indigenous farmers will be more prone to adopt improved yam-based system than immigrant. In fact, the loan is particularly practiced by immigrants in the study area which is unfavourable for long term soil fertility investment [43]. This variable takes value 1 if the owner is indigenous and 0 otherwise. CONTACT identifies farmers who have connections and dealings with the external agents (researcher, extension agent). It is an important variable for diffusion and adoption of innovations [44]-[45]. This variable could influence positively the adoption of improved yam-based system with *Gliricidia* and herbaceous. The variable takes value 1 if the smallholder farmer ties contacts with the external structures (at least one contact per month), and 0 otherwise. CREDIT expresses the access to the formal credit. The use of innovative yam-based system requires inputs purchase (seeds or seedlings and mineral fertilizers for maize). Difficulties of cash limit farmers' investments [38]-[44]. Access to credit can raise this constraint and support adoption. This variable takes value 1 if the farmer obtains formal credit and 0 otherwise. NIVELEV is the livestock size (sheep, goat and cow).

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Table 1. Statistical description of adoption factors in the study zone in the Guinea-Sudan zone of Benin (n = 306 farm household surveyed)

Acronym of variable	Description of variable and value	Mean	Standard deviation
ZONE	Demographic zone/population density (1=yes ; 0=no)	0.39	0.49
SUPDISP	Household land surface available per ha	8.25	7.61
SEXE/GENDER	Male or female (1=yes; 0=no)	0.82	0.38
NBOUCH	Household' size	7.63	4.88
FTRAV	Household' labor size	2.66	2.39
ORIGIN	Owner status: indigenous or immigrant (1=yes ; 0=no)	0.83	0.38
CONTACT	Contact with the change agents (1=yes; 0=no)	0.59	0.49
CREDIT	Access to credit (1=yes ; 0=no)	0.06	0.24
NIVELEV	Livestock size (sheep, goat and cow)	4.53	12.05

Legend: ZONE: population density in zone; SUPDISP: land surface available in farm household, GENDER: sex (male or female) of the smallholder farmer; NBOUCH: Farm household size; FTRAV labour force within the households; ORIGIN: owner status (indigenous or immigrant); CONTACT: smallholder farmers' contacts with the research or extension workers; CREDIT: formal financial credit for inputs; NIVELEV: livestock size.

The natural pasture is the endogenous practice for providing forage to ruminants. In crop/livestock integration system, herbaceous legumes established in dynamic of rotation can provide forage for animal feeding, and the field is useful for subsequent crops as yam. This variable is supposed to influence positively the adoption of improved yam-based system.

SPSS was used for the descriptive analysis and correlation of the independent variables. LIMDEP version 7.0 was used for the empirical model [32].

III. Results

A. Multivariate Analysis of Adoption of Yam-Based System in Rotation with the Mixed Intercropping Gliricidia Sepium and Herbaceous

Adoption of yam in rotation with the intercropping Gliricidia and herbaceous (TMA) was 11% (Table 2).

The percentage of adopter's women was 0% whereas 11% were recorded for men. The models had rather good predictive and estimated properties.. The percentage of correct prediction was high (89%). Results of Student's test revealed that seven variables determined the adoption of TMA: "CONTACT" with external agents, "CREDIT" and population density in "ZONE".

Further, the rate of adoption of TMA was higher in the relatively high population density zone (7%) than in the low-density zone (4%) (Table 3).

The rate of adoption was also higher in the Research and Development (R&D) sites (8%), where farmers had much more in contact with research and extension than in the other sites (3%).

IV. Discussion

A. Adoption of Yam-Based System in Rotation with the Mixed Intercropping Gliricidia Sepium and Herbaceous in Low and Relatively High Population Density Zone

Adoption of yam-based system in rotation with the mixed intercropping *Gliricidia sepium* and herbaceous (TMA) is highly expressed in the zone with the relatively high population density compared to the low population density zone. In the denser zone, land pressure is relatively high with an increasingly scarcity of fertile soils for yam production, and farmers look relatively inclined to develop more sustainable and more productive systems.

Studies conducted by [35] in the Bamileke area, Cameroun, or [46] in the vicinity of Kano, Nigeria, corroborates the feeling that land scarcity is a major incentive to switch to intensive agriculture. In northern Benin, where the population density is lower than 100 inhabitants per km², intensive agriculture is much less frequent than it is in the south where the population density frequently exceeds 200 inhabitants per km².

B. Adoption of Yam-Based System in Rotation with the Mixed Intercropping Gliricidia Sepium and Herbaceous in the Research and Development and off Research and Development Sites

The highest adoption in the Research and Development (R&D) sites than Off Research and Development sites (off R&D) was probably due to more frequent interactions between smallholder farmers and the R&D research team through demonstration plots, training and field visits, village meetings at which results of research were presented showing the advantages of innovations based on a specific farmer's field, information exchange between farmers and knowledge production [20]. Contacts are especially helpful in the early stages of technology experimentation, where technology abandonment rates are usually higher [47]-[48].

Table 2. Econometric model of the discriminating factors affecting adoption of yam in rotation with the mixed intercropping Gliricidia sepium, herbaceous cover and crop in the Guinea-Sudan zone of Benin

Acronym of variable	Estimated β	T test
ZONE	0.064	1.660*
SUPDISP	3.53E-04	-0.137
SEX	0.022	0.541
NBOUCH	0.005	1.393
FTRAV	0.008	1.068
ORIGIN	-0.063	-1.415
CONTACT	0.089	2.428**
CREDIT	0.191	2.540**
NIVELEV	-0.001	-1.067
Number of adopters	33	
Sample size	306	
Log-probabilities	-109.72	
χ2	-	
% of prediction	89	

Legend: **p<0.05 represents significant level at 5%; β = estimated coefficient for each independent variable.

"Reference [49] argued that a landholder's probability of making a good decision increases over time with increasing knowledge of, and perhaps experience with, the practice or technology". They report that land managers go through a typical sequence of acquiring and applying new knowledge, beginning with becoming aware of the technology or innovation. The land managers progress through a (non-trial) evaluation stage, where they collect information and begin to assess its usefulness in their own context, followed by a stage of small-scale trials. And then, if this is successful, adoption, review and modification and finally either fully adopting or abandoning the innovation. It has also been shown that land managers who participate in property management planning activities have a greater capacity to adopt more sustainable land management practices, indicating a link between knowledge and skills, and the capacity to change [49].

The formal credit supports inputs and could be an additional benefit for adoption of innovative yam-based systems as well as on R&D and off R&D sites. Smallholder farmers in majority were often in prone to financial difficulties because of their low incomes and purchasing power. This situation limited inputs acquisition (equipments, mineral fertilizers, seeds...). Past research indicated that financial constraints were self-reported by land managers as an important barrier to the adoption of changed management practices [50]-[51]-[52]-[53]-[54]. For example, a study of land manager attitudes in the Burdekin Dry Tropics region in northern Queensland found that operational and financial constraints were perceived as the most important impediments to the adoption of natural resource management activities or changed practices. Similar surveys in the Burnett Mary and Queensland Murray Darling regions found that 76% and 81% of respondents respectively identified cash flow as the highest rated constraint. But nevertheless, studies showed that financial resources may not be the main limiting factor when land managers consider adopting new technologies or changed practices. For example, [55] suggested that where it can be shown that farm family income exceeds $50,000 per year then the constraints for undertaking changed practices were not necessarily financial. One suggestion is that land managers may be constrained by the perception that improved practices provide greater benefit to society at large than to the individual.

C. Adoption of Yam-Based System in Rotation with the Mixed Intercropping Gliriridia Sepium and Herbaceous According to the Gender

Women who have more insecure land rights are more prone to adopt yam-based rotation with herbaceous legumes versus agroforestry yam-based system in rotation with the mixed intercropping *Gliriridia sepium* and herbaceous. This fits with former studies. For instance, [29] former work showed that male farmers are more likely to adopt than women agroforestry in Cameroon. The authors argue that sustainable agricultural systems targeted to women farmers must be compatible with their land and tree tenure. Where women do not have secure rights to land, technologies which require that land be put under trees for a long period of time are unlikely to be adopted by women farmers. In such areas, short season improved fallow systems may be more appropriate for women farmers.

D. Constraints, Adaptation, Opportunities and Implications for the International Applications

Adaptations of the yam-based cropping with the new agroforestry system were developed by smallholder farmers in the Guinea-Sudan zone of Benin: practice of only one pruning of *Gliricidia* at 0.5 m of ground, the mixed intercropping *Gliricidia*-maize-herbaceous (*Aeschynomene histrix*) or grain legumes (groundnut), the mixed fallow of *Gliricidia*-graminaceous (*Andropogon gayanus*)... Instead of pruning these shrubs at land clearing time, most of the smallholders use early fire of *Gliricidia* fallow in order to reduce the labor demand and improve light and nutrients access to subsequent yam crops. This practice that fits with traditional slash-and-burn wooded fallow and yam systems, allows the prunings removal, contributes to the accumulation of the dry sheets of *Gliricidia* on the soil and the regeneration of the shrubs. This adapted practice also allows the renewal of the old plantations showing of large barrels of the shrubs of *Gliricidia* and mobilizing more crops space. The adapted agroforesttry system is car-reproducible.

Table 3. Adoption and non-adoption of yam-based agroforestry system with Gliricidia sepium in intercropping with herbaceous as part of site and population density in the Guinea-Sudan zone of Benin

Site type	Population density	Adoption type	Categories	Size of smallholder farmers survived	Rate of adopters (%)	Rate of non adopters (%)	Rate of adoption on R-D sites (%)	Rate of adoption on off R-D sites (%)	Rate of adoption in relatively high population density (%)	Rate of adoption in low population density (%)
R-D sites	Relatively high population density	Adopter	Adopter women	1	0		0		0	
			Adopter men	14	5		5		5	
		Non-adopter	Never adopted	14		5				
			disadopter	8		3				
	Low population density	Adopter	Adopter women	0	0		0			0
			Adopter men	8	3		3			3
		Non-adopter	Never adopted	25		8				
			disadopter	0		0				
Off R-D sites	Relatively high population density	Adopter	Adopter women	0	0			0	0	
			Adopter men	6	2			2	2	
		Non-adopter	Never adopted	65		21				
			Disadopter	11		4				
	Low population density	Adopter	Adopter women	0	0			0		0
			Adopter men	4	1			1		1
		Non-adopter	Never adopted	150		49				
			Disadopter	0		0				
	Total			306	11	89	8	3	7	4

This shows a rate of resumption of the plantation of more than 80% after early fire use at the shrubs foot with an exponential new seedlings growth emerging from the *Gliricidia* shrubs root. This is in opposition to traditional cleared wooded forest systems resulting in the systematic death of the trees. The dry and alive stems of the shrubs going up to 7 m in height or more ensure the staking of the yam lianas the following campaigns. The practice implemented in a dynamics of rotation makes it possible to ensure the production of fertilizing biomass in In comparison with the traditional forest fallow system by which the incineration decimating the shrubs with a gramineous fallow of *Andropogon gayanus* colonization.

In the case of the mixed intercropping Gliricidia -maize-herbaceous (*Aeschynomene histrix*) for example, the system was appreciated for its capacity to increase crop yield (yam) and supplemented the animal feeding (*Aeschynomene histrix*) according to farmers' opinions. However, smallholder farmers in the study area expressed constraints for *Aeschynomene* used as more particularly the small size of seeds and the problem of the management of seeds during planting, lignified stems of *Aeschynomene* after two years of plant growth and the problem of the *Aeschynomene* biomass incorporation, crop competition, animal divagation, absence of markets for seed.

Constraint related to the lignified stems of *Aeschynomene* after two years and the biomass incorporation was expressed. Smallholder farmers adapted the technology with the practice of early incorporation after one year of biomass production or conducting both mulching and biomass incorporation into the soil.

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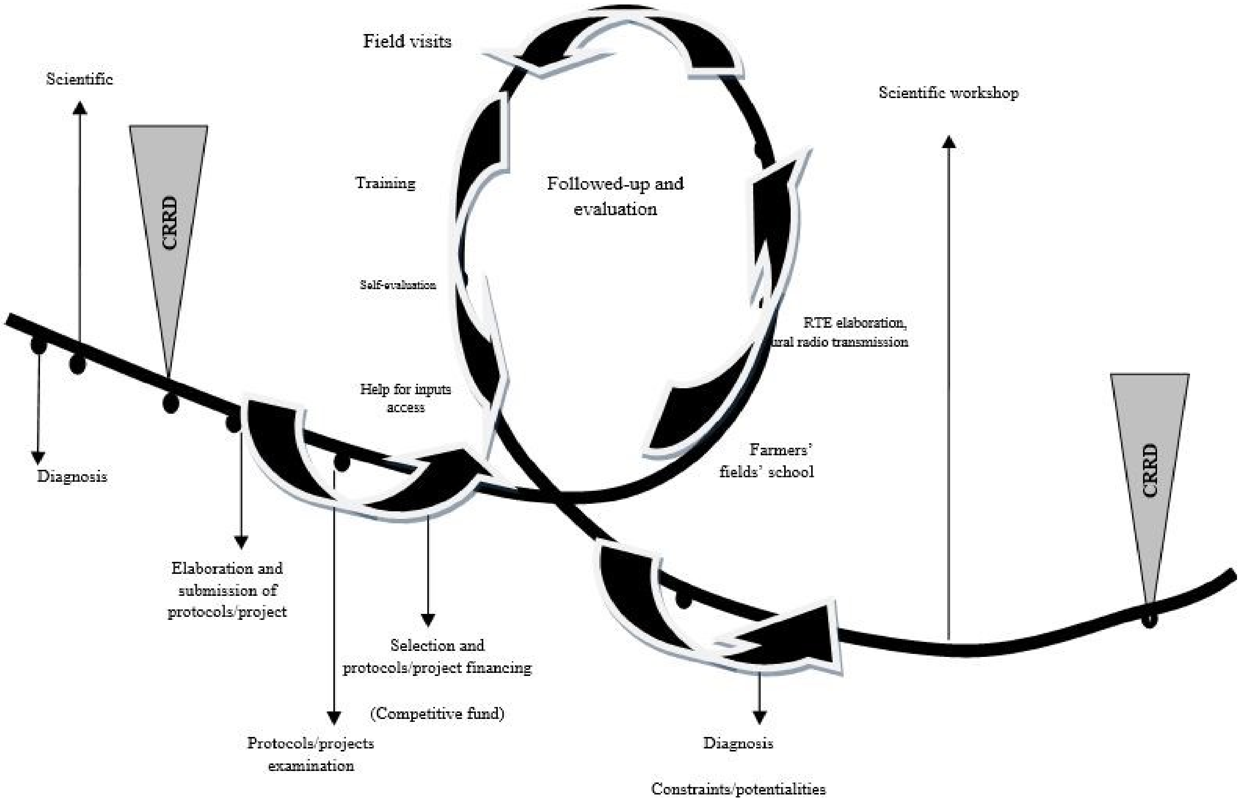

Fig. 1. Annual cycle of Research and Development (R&D) for yam-based agroforestry system with Gliricidia sepium in intercropping with herbaceous in the Guinea-Sudan zone of Benin

Three-quarters of biomass could be manually incorporated into the soil in October-November during ridging, and the remaining biomass could be left on the surface as mulch in order to reduce workloads related to the incorporation. The practice of fire wall and fire of reference around the plot is necessary to avoid the burning of the mulch in dry periods. The mulch will contribute to protect seed yam from solar radiations, to improve soil humidity and earthworms' activity.

The crop-livestock integration with the agroforestry system should be an opportunity for yam production in dynamic of rotations, because of agropastoral potential in the Guinea-Sudan zone of Benin. Integration of forage legumes into the traditional fallow management can help improving both forage supply at a time of feed scarcity and soil fertility. Corralling contracts in the fence-based cropping systems with forage legumes are important form of crop-livestock interaction during the dry season and could contribute to manures supply and nutrient cycling for the benefit of crops and soil. This practice returns both manure and urine to soil and can conserve nutrients.

A detailed attention deserves to be given to the technical, institutional and political problems facing end-users and more information, as well as advices are required in order to improve the level of adoption of yam-based technologies with herbaceous legumes.

V. Conclusion

With the aim of designing more sustainable yam cropping systems, the agronomic research is promoting alternative agroforestry yam-based systems. Alley cropping was implemented in several research structures and was transferred in rural areas. The most important constraints of alley cropping adoption are its pruning workload as well as competition between shrubs and crops for nutrients and light. It is well-known today that smallholders deeply readjust technologies developed in close relationship with researchers when confronted with various constraints. Farmers have been adjusting the alternative systems with alley cropping to their own constraints. This paper investigates adoption, constraints, and adaptations of mixed inter-cropping an agroforestry tree species, *Gliricidia sepium*-herbaceous in the Guinea-Sudan zone of Benin. The differences between adopters and non-adopters of yam-based agroforestry systems with *Gliricidia* in terms of their age, education, gender, Households' size, active members of the family, farm income, land tenure, extension contact, training, credit, belong to organisation and other socioeconomic and agro-ecological variables are examined. Results from logistic regression analysis suggest that extension contact, credit and population density in zone are important variables in determining the adoption of new yam-based agroforestry systems. It was observed that farmers adapted technologies to suit their situation. Although these systems are currently not yet widely used by smallholders, we predict that they will be adopted as soon as land pressure increases. We then propose to promote durable and replicable agroforestry-yam based systems with the mixed intercropping *Gliricidia sepium* and herbaceous in the Guinea-Sudan zone of Benin, through a favourable legislative, economic and political environment to support local initiatives. Collaborations between research, development and extension structures should also be favoured to support the development and dissemination of innovations.

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