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Effects of local institutions on the adoption of agroforestry innovations: evidence of farmer managed natural regeneration and its implications for rural livelihoods in the Sahel

Joachim N. Binam[1*], Frank Place[2], Arinloye A. Djalal[1] and Antoine Kalinganire[1]

* Correspondence:
J.binam@cgiar.org
[1]World Agroforestry Centre (ICRAF)-West and Central Africa Regional Office-Sahel node, P.O. Box E5118, Bamako, Mali
Full list of author information is available at the end of the article

Abstract

The present study aims at (1) assessing how the existing local formal and informal institutions affect farmer managed natural regeneration (FMNR) practices and, (2) evaluating the benefits of such practices on livelihoods. The propensity score with continuous treatments was used to assess the effects of a set of covariates on FMNR as well as the impacts of that practice on income, cereal production and caloric intake using data collected from 1,080 rural households in Burkina Faso, Mali, Niger, and Senegal. This study demonstrated that regeneration of trees on farms, whereby farmers play an active role in the types of trees and their densities, is important as a practice and safety-net by providing cash income, caloric intake and diet, and crops supplements throughout dryland areas of West Africa. Overall, FMNR cannot be excluded as a recommendation in any geographical region. In addition, the study concludes that the effects of institutions in fostering FMNR practices in the Sahel are mixed. In areas with well-structured formal and informal institutions, populations seem to have adopted a better collaboration attitude with the local government by developing plans for a good management and protection of natural resource including FMNR practices. However, in areas where these commissions are being assimilated to governmental institutions, the willingness to raise incentives towards a better management of natural resources is less perceived. While recognizing the benefits of trees and tree products on caloric intake and diet, there is a need to explore in much more details, the FMNR-food nexus in future researches by going beyond what was covered from this study.

Keywords: Agroforestry, Livelihoods, Local conventions, Natural regeneration, Sahel

JEL: D04, Q12, Q15, Q23, Q57

Background

The dry areas of the developing world occupy about 3 billion hectares and are home to 2.5 billion people: 41% of the Earth's land area and more than one-third of its population. About 16% of this population lives in chronic poverty (Solh and Saxena 2011). Drylands have limited natural resources. They already face serious environmental constraints, which are likely to worsen as a result of climate change. The West African Sahel and dry savannas is one of the five developing-country regions where dryland agriculture faces serious challenges.

Dryland agro-ecosystems include a diverse mix of food, fodder and fiber crops; vegetables, rangeland, and pasture species; fruit and fuel-wood trees; medicinal plants; livestock, and fish. Dryland systems are characterized by persistent frequent droughts, water scarcity, rapid population growth, high climatic variability, land degradation and desertification, and widespread poverty.

Two of the biggest challenges facing Sahelian countries today are reducing poverty, especially among rural households, and preventing climate shocks by protecting the ecosystems, which provide essential services for a growing population whose survival is dependent to a large extent on a combination of subsistence rain-fed crop farming, and extensive livestock rearing, supplemented with the gathering of agroforestry tree products (AFTPs) including wood, grasses, fruits, leafy vegetables, nuts, and condiments.

Connecting the valuation of ecosystem services with the rural poor in the identified countries could make a significant contribution to both these challenges. Most of the population in Sahel consists of smallholder subsistence farmers who produce their own food in less than one hectare (Place et al. 2013). Indeed, as indicated by Sanogo et al. (2016), those farmers critically depend upon local ecosystems for survival and are directly affected by changes in availability of ecosystem goods and services. Thus, the loss of ecosystem services, important for livelihoods and many other ecological and environmental functions, can be devastating for the rural poor in Sahel. A more productive use of natural resources contributes to increasing food security and raising incomes among the rural poor in the Sahel. For example, deforestation has contributed to soil erosion, loss of agricultural productivity, and the scarcity of fuelwood. The loss of wetlands has threatened the availability of water leading to a need to invest in ecosystem services in order to improve people's resilience (Polak, 2008).

By using their land properly, collectively and individually, smallholder farmers can provide valuable services, such as carbon sequestration, water flow, or biodiversity protection. For example, it has been shown according to Weston et al. (2015) that Sahelian parklands resulting from the conversion of forest to agricultural landscapes are important sources of benefits both for rural populations and the landscapes. Indeed, trees from agroforestry parklands can reduce wind speed while increasing soil fertility and air humidity and reduce diseases like fungal attacks (Bayala et al. 2014). Regarding soil properties, recent studies of Sahelian agroforestry parklands have revealed a decrease in soil bulk density and as a consequence, soil under trees displayed higher porosity compared to adjacent open areas (Sanou et al., 2010; quoted by Bayala et al. 2014). Beyond the above mentioned supportive services, trees in the parklands also contribute to the reduction of carbon in the atmosphere by accumulating biomass via photosynthesis. As asserted by Bayala et al. (2014), this process is important for improving soil properties when accumulated biomass is stored in the below-ground compartment as soil carbon. Nevertheless, the improvement in soil fertility parameters by trees has been a controversial issue because trees may have simply grown in spots of higher fertility. Ajayi et al. (2007) and Place (2009) claim that, incentive policies such as subsidies and institutional support for certain soil fertility management options may have a considerable indirect influence in shaping farmers' decisions on soil fertility replenishment and other sustainable management of common resource strategies.

In addition, two decades of research into the management of what economists call common-pool resources suggests that, under the right conditions, local communities can manage shared resources sustainably and successfully. These findings challenge the long-held belief in the "tragedy of commons." In a recent study, Allen et al. (2012) found that, tragedy is not inevitable when a shared resource is at stake, provided that people communicate. In many places, communities have come together for the sake of the environment and their own long-term well-being.

As such, institutions that support ecosystem services can be used as tools to help protect ecosystems and improve rural livelihoods by allowing smallholder farmers to generate income through providing valuable public goods. The systems that support the provision of ecosystem services range from a neighborhood, to a watershed, to a country, to a continent. Managing them effectively requires a set of nested institutions that can encompass some of these multiple scales and interact with each other to create a proper management. To enhance the capacity of farmers in sustaining tree-based production systems, an enabling institutional, technical, and policy environment needs to be promoted.

In a recent paper on land tenure and agricultural productivity in Africa, Place (2009) indicates that the adoption of agroforestry is influenced by various factors. Some of them (including climate conditions, household and farm characteristics, and attributes of the particular agroforestry technology) have relatively little to do with policy, while others are directly linked to the existing policy (local formal and informal institutions). Forest policies can inhibit tree growing on farms by regulating harvesting, cutting or sale of tree products and certain tree species. Such protective policies discourage farmers from planting and protecting new trees that emerge.

A number of studies provided a description of the functions of some of the major species found in Sahelian parklands indicating that agroforestry tree products (AFTPs) can play three main functions in the household economy of rural communities living in or adjacent to the parkland (Kouyaté 2005; Kalinganire et al. 2007). Firstly, they help to fulfill households' subsistence and consumption needs in terms of energy and nutrition as well as medical and construction purposes. Secondly, they serve as a safety-net in times of crises (e.g., income shortages due to crop failure) and thirdly, some AFTPs provide regular cash income (Kouyaté 2005; Kalinganire et al. 2007).

However, despite the importance of famer managed natural regeneration (FMNR) practices for farmers' livelihoods the benefits from FMNR have not been studied extensively in the Sahel region. What is mainly missing is an economic quantification and livelihood effects (Haglund et al. 2011; Nyemeck et al. 2015). Furthermore, there has been no systematic study of how such benefits vary across the landscape according to the parklands, or countries. Our paper aims to fill this gap by (1) assessing how the existing local formal and informal institutions affect farmer FMNR practices and, (2) evaluating the benefits of such practices on food production, rural income and caloric intakes and diet.

Overview of research on farmer managed natural regeneration

Farmer managed natural regeneration involves regeneration of trees on farms, where farmers are actively involved in manipulating the natural biological regeneration into one that suits them. The types of activities that farmers carry out under FMNR include: thinning of unwanted emergent trees, protection of desired emergent trees from grazing through micro structures or fencing, managing water for young trees, taking action against insects and disease, retention of mature trees so that the rootstock may regenerate more young trees, ploughing practices that preserve emergent trees, and annual care of the regenerated trees. In the drylands, it can be argued that virtually all farmers practice FMNR to some degree (e.g., all farmers will actively thin trees from their fields). It is rather the degree to which it is done which differs considerably. The technical potential for FMNR in the drylands is high throughout almost all dryland areas because no input system is required—just the in situ germplasm (seed and roots) in the soil.

Evidence of the active practice of FMNR is most available for the Sahel in Niger, Mali and Burkina Faso (Reij et al 2009). But there is also evidence from Ethiopia, Kenya, Uganda, Malawi, Zambia, and Zimbabwe. In two lakes bordering districts in Malawi, it was recently found that although faidherbia seeds are readily available, 70% of all plants established between 2008 and 2010 was through regeneration (some being mediated through livestock) (Glenn 2012).

The technical potential for FMNR is related to environmental conditions: in the drier environments, rainfall limitations make it more difficult to regenerate trees in the absence of supplemental watering. The other major limiting factor is the presence of germplasm in the soil. It is well known that the diversity of soil borne tree germplasm varies across sites, although there is no mapping of its variation. Indicators of poor soil borne tree germplasm would be the lack of trees in the landscape and heavily eroded soils.

Besides environmental conditions, other factors may limit the technical potential of FMNR. At the household level, adoption analysis was done on the Sahel with a sample of 1000 households involved in the study (Place et al. 2013). Very few factors were found to be significant in explaining the number of new trees regenerating on the farm. The most consistent finding was that FMNR was positively related to the number of mature trees on the plot, which supports the biological explanation of the dependence on existing soil-borne germplasm. It also suggests that farmers with a higher number of mature trees may see the benefits of trees more clearly and thus be keen to establish more.

Overview of institutions governing natural resource management in the Sahel

Institutions can broadly be defined as structures and practices of formal and informal rules that regulate social behaviors (Jessop and Nelson 2003, Geraldi 2007). Analyses of socio-ecological factors, such as tree tenure, land and tree property and access rights, as well as benefits sharing from tree resources, provide insight into what Howard and Nabanoga (2007) qualified as the decision-making and power loci of a community. Indeed, as reported by Toulmin et al. (2002), if the institution that creates and enforces tenure regulations is weak, then the regulations no matter how well formulated, may not be enforced or abided by. Hilhorst (2008) argued that these institutions work best when they are adaptive, when rules are clear, enforced and nuanced, when they are legitimized by external organizations, and are faced with slow exogenous change. Yatich et al. (2014) argued further that collaboration between informal and formal institutions is essential for effective resource management. Therefore, an understanding of governance institutions in relation to natural resources is important to better formulate effective pro-ecosystem service policies.

Institutions governing farmland in the Sahel

Generally, control over access to farmland is in the hands of the lineage that started farming first in the village, personified in the male-head or lineage. The head of the family can grant strangers temporary access to land (secondary right). Pastoralists tend to have a host in the community who will help them to secure their secondary rights to pasture and crop residues as well as rights of passage (Mikulcak, 2011; Leach et al. 2011) (Table 1).

Private rights apply on intensively managed lands, but farmers may allow communal access to some tree products. Permanent landholders usually reserve for themselves exclusive tree planting and felling rights, but may encourage tree pruning and gathering of tree products by other community members. Restrictions occur depending on the value of tree species and quantity harvested. Because planting in some extent confers ownership, permanent landholders generally do not authorize tree planting to those with secondary rights.

Institutions governing common lands in the Sahel

In the semi-arid zone of West Africa, forests, pastures, and fallows are resources that are used by multiple groups (herding cattle, cutting wood, gathering, hunting, and bee keeping) with competing interests. Since colonial times, central government has sought to control access and use of forest lands declared as public lands (Yatich et al. 2014). Some forests were even classified and thus protected. Herd mobility and secured access to strategic resources, such as water and dry season grazing, are critical for pastoralist production systems. Recently, most Sahelian countries have revised their forestry legislation but many basic provisions remain (see Table 2).

In principle, the new forest codes go some way towards recognizing customary rights and, in some cases, devolving management of certain forest resources to local populations. In practice, even if farmland technically falls outside forest domain, because rural landholdings are often non-registered, they continue to fall under the state control. Consequently, many restrictions which were originally intended to protect trees are also applied to trees on farms and in fallows, with the result that farmers are prevented

Table 1 Land tenure arrangements in the Sahel

Tenure arrangement	Rights
Inheritance	Full rights (access, withdrawal, management, exclusion, alienation). After the death of the family founder), the field commonly used by the family is passed to the children. The land is divided on the basis of the existing law. Each married male heir becomes a head of his household and of the share of land he inherited.
Purchase	Full rights (access, withdrawal, management, exclusion, alienation). All 'bundles of rights' to the land, including exclusion and alienation, are sold from the land owner to the buyer. The buyer becomes owner of the land.
Lease	Access, limited withdrawal and management rights (in accordance with Owner). The land is transferred in exchange for either money or any other 'security deposit'. It remains at any time the property of the initial owner who holds exclusive alienation rights. The person leasing has certain management and usage rights. This tenure arrangement is valid as long as the deposit is not repaid
Loan (temporary borrowing)	The land is loaned for a temporary or undefined period, without any security deposit or monetary transaction. Borrowed land stays at any time the property of the initial owner who holds exclusive alienation rights. The land may at any time be resumed by the owner.

Source: Adapted from Mikulcak, 2011

Table 2 Forestry policies in selected countries

Country	General principles	Standard of Management	Measures of conservation/ protection	Institutions of management
Mali	• Land and ownership is vested on the state or local council notably under the decentralization process • Access, use and management of indigenous trees is controlled	• Bushfires regulated but not completely disallowed • Disconnections between provision of law and practices • Bylaws and local conventions not formally recognized and an mainly oral	• Special protection of 11 indigenous tree species • Existence of classified forest and parklands recognized • Necessity for implementation of texts and better communication • Some legalized bylaws are being considered as effective instrument in the governance of natural resources	• Forest service manages classified forests as well as on-farm protected tree species • Forest services are devolved at the regional level and manage forest jointly with local government/territories and communities
Niger	• Forest and natural resources are considered as national patrimonies • Promotion of a secured and fair access of all to the natural resources • Forest considered as a safe investment	• Agroforestry is being considered as type of land use • The practice of bushfire is regulated • Integrated vision regarding natural resources management and multifunctional use of the space	• Special protection of 15 indigenous tree species • The existence of private and public forest is recognized and legalized bylaws are being considered as effective instrument in the governance of natural resources • Necessity of the implementation of texts and better communication among actors • The law is however not well known and not fully implemented	• Use of forest service and local communities also involved to manage forest resources • Presence of land administration services nationwide

Source: Compiled from Yatich et al. (2014)

from carrying out basic management activities which are crucial in optimizing their land use systems.

Local governance institutions managing access and use of natural resources in Sahel

Many Sahelian countries have undergone an institutional shift within the last decades. Communities in rural areas display a wide diversity of cultures and type of livelihoods pursued. As noted by Hilhorst (2008) there is a juxtaposition of various formal and informal authority structures and laws. The most significant institutions that prevail in the selected countries pertain to customary authorities, village land management commissions, and local conventions (Ouedraogo 2007; Djire and Dicko 2007). Table 3 provides an overview of these institutions and the roles they can play in promoting, managing, and regulating access and use of natural resources.

Data and methodological framework

Site selection and data collection

Data used in this study were collected in 2012 from a survey of 1080 households and focus group discussions in four Sahelian countries, namely Burkina Faso, Mali, Niger, and Senegal.

Two research questions guided this study: (1) how do the existing local institutions (formal and informal) affect the practice of farmer managed natural regeneration? (2) How does that practice impact on rural livelihoods?

Villages were randomly selected in the countries, and within each village, a two-step procedure was used to sample households. Through key informants, all households in a

Table 3 Local governance institutions managing access and use of natural resources in selected Sahelian countries of West Africa drylands

Type of institution	Description and role	Country			
		Burkina F.	Mali	Niger	Senegal
Customary authorities	Organization structure that reflects socio-cultural and economic diversity headed by authorities chosen through customary decision-making process and expected to act as custodians. They also intervene to prevent, mediate or manage conflicts including those related to natural resources use	Yes	Yes	Yes	Yes
Village land management commissions	More formal governance institutions expected to contribute to reconcile the various, and sometimes contradictory land tenure regimes and eliminate tenure-related obstacles to socio-economic development. They play a significant role in natural resource management and even land administration.	Yes	Yes	Yes	Yes
Local conventions	More or less formalized negotiated agreement designed and formulated to regulate access and use of common natural resources. The defined rules and regulations are formulated through a process of stakeholder consultation and dialogue to address issues related to bushfire surveillance brigades, marking out livestock tracts, fixing periods for harvesting wild fruits or entering grazing lands, quotas for resource use, and protection of regenerating forest among others.	Yes	Yes	Yes	Yes

Source: Adapted from Leach et al. (2011)

village were listed and identified as having a high or low density of trees on their farms (which proxies for adoption of FMNR). Then a random sample of 10 households in each strata was selected giving sample sizes of 240 for Burkina Faso and Mali; 480 and 120 for the Republic of Niger and Senegal, respectively. Convenience sampling was used to invite respondents into the focus group discussions, basing the selection on the respondents' knowledge and practice of agroforestry. Local extension agents and enumerators helped to identify appropriate individuals with sufficient knowledge of agroforestry.

The household survey collected quantitative data about FMNR practices, including: tree species, number and age; sourcing of tree products (e.g., fruits and fuelwood) from farm and non-farm landscapes; all sales of tree products for the 2011–12 agricultural year; crop and livestock production and sales; income from other activities; and characteristics of households and their land. Household members were also asked qualitative questions to understand their perception of a broad set of benefits, costs, and risks associated with FMNR. One major interest was whether households perceive FMNR to have any additional environmental services, such as improved soil fertility, improved water management; if the regenerated vegetation is perceived as a buffer against shocks; and whether the integration of FMNR helps to reduce overall risks (e.g., variation of production and income).

The focus group discussions questionnaire aimed to identify the major benefits from FMNR and how they are distributed across individuals, households, and locations as well as to understand the main constraints in adopting FMNR. In addition, focus group discussions and exchanges with key respondents and experts' opinion captured the existing institutions governing natural resources in the different villages. These were used to ascertain how they affect the practice of farmer managed natural regeneration.

Methodological framework

Much of the work of propensity score analysis has focused on cases where the treatment variable is binary. In practice, more than two conditions may be compared. This often happens when we want to estimate the impact of dosage analysis with treatment dosage (Bia and Mattei 2008). Hirano and Imbens (2004) developed an extension to the propensity score method in a setting with a continuous treatment as in the case of this study where the treatment variable (FMNR practice) is a continuous treatment. The analysis of treatment dosage with propensity scores may be generalized in two directions. In the first, one estimates a single scalar propensity score using ordered logistic regression, matches on the scalar propensity score and, proceed in a two-treatment group situation (Joffe and Rosenbaum 1999). In the second direction, one estimates propensity score for each level of treatment dosage (i.e., if there are five treatment conditions defined by differential doses, one estimate five propensity scores for each participant). Propensity scores derived in this fashion are called *generalized propensity scores* (GPS). This method, originally developed by Imbens (2000), uses the inverse of a particular estimated propensity score as a sampling weight to conduct a multivariate analysis of outcomes.

The generalized propensity score estimator

Building on Imbens (2000), Hirano and Imbens (2004) developed a generalization of the binary treatment propensity score and labeled the method a GPS estimator or propensity score with continuous treatments. Thereafter, Bia and Mattei (2008) developed a software program in *Stata* called *gpscore* to implement the GPS estimator. The basic idea of the GPS according to Bia and Mattei (2008) is to assume a random sample of size N, indexed by $i = 1, 2, \dots N$. For each unit of i in the sample, we observe a $p \times 1$ vector of pretreatment covariates, X_i; the treatment received, T_i; and the value of the outcome variable associated with treatment, Y_i. Using the counterfactual framework (Rubin 1997; Holland 1986), unit i has a set of potential outcomes, defined as, $\{Y_i(t)\}_{t \in \Gamma}$, i = 1,….., N, where τ is a continuous set of potential treatment values. Under this definition, Hirano and Imbens (2004) refer to $\{Y_i(t)\}_{t \in \Gamma}$ as the unit-level dose-response function, and a dosage analysis is interested in the average dose-response function, $\mu(t) = E\{Y_i(t)\}$. According to Hirano and Imbens (2004), $\{Y_i(t)\}_{t \in \Gamma}$, T_i, and X_i, $i = 1, \dots, N$, are defined on the common probability space; T_i is continuously distributed with respect to the Lebesgue measure on Γ; and $Y_i = Y_i(T_i)$ is a well-defined random variable. With the preceding, the GPS is defined as the conditional density of the treatment T given the covariates, or the GPS is $R = r(T, X)$, where $r(t, x) = f_{T|X}(t|x)$. The GPS has a balancing property similar to the propensity score under the setting of binary treatment. Hirano and Imbens (2004) proved two theorems with respect to the balancing property of GPS: (1) weak un-confoundedness given the GPS and (2) bias removal with GPS.

The implementation of the GPS method consists of three steps.

Step 1: modeling the conditional distribution of the treatment given covariates: r(t, x)

Practically, this is the step in which researchers estimate the GPS at a given level of treatment and observed covariates X and then perform the balancing check. Hirano and Imbens (2004) used a flexible parametric approach to estimate the

GPS. That is, they assume a normal distribution for the treatment given the covariates:

$$g(T_i)|X_i \sim N\left(\beta_0 + \beta' X_i, \sigma^2\right)$$

where $g(T_i)$ is a suitable transformation of the treatment variable. While the parametric model assumes the normal distribution, the actual distribution of treatment dosage T_i in the sample may not be normally distributed. To correct for normality, one can do a transformation of T_i by taking the logarithm of T_i or by applying other transformations. The formula for estimating GPS for each observation based on the estimated regression model is:

$$\hat{R}_i = \frac{1}{\sqrt{2\pi\hat{\sigma}^2}} exp\left[-\frac{1}{\sqrt{2\hat{\sigma}^2}}\left\{g(T)_i - \hat{B}_0 - \hat{B}' X_i\right\}^2\right]$$

Next, users need to test the balancing property and whether the GPS balances observed covariates. The balance check observes six steps (Bia and Mattei 2008).

Step 2: estimating the conditional expectation of the outcome given the treatment and GPS

In this step, the conditional expectation of the outcome, Y_i, given T_i and R_i, is modeled as a flexible function of its two arguments. In practice, one can use a quadratic approximation or polynomial approximations of order not higher than three. The quadratic approximation is

$$E[Y_i|T_i, R_i] = \delta_0 + \delta_1 T_i + \delta_2 T_i^2 + \delta_3 R_i + \delta_4 R_i^2 + \delta_5 T_i R_i.$$

According to Hirano and Imbens (2004), there is no direct meaning to the estimated coefficients in the selected model, except that testing whether all coefficients involving the GPS are equal to zero can be interpreted as a test of whether the covariates introduce any bias.

Step 3: estimating the dose response function to discern treatment effects as well as their 95% confidence bands

This last step consists of averaging the estimated regression function over the score function evaluated at the desired level of the treatment. Given the estimated parameters in step 2, researchers can estimate the average potential outcome at treatment level t, which is also known as the dose-response function. This is the final statistic that shows the outcome differences associated with the treatment dosage. The dose-response function is given by:

$$\hat{E}[Y_t] = \frac{1}{N}\left(\hat{\delta}_0 + \hat{\delta}_1 t + \hat{\delta}_2 t^2 + \hat{\delta}_3 \hat{r}(t, X_i) + \hat{\delta}_4 \hat{r}(t, X_i)^2 + \hat{\delta}_5 t \hat{r}(t, X_i).\right.$$

At this stage, one can estimate the dose response functions for user treatment values and use bootstrapping to form standard errors and confidence intervals. The *Stata dose response* programme (Bia and Mattei 2008) can draw two types of plots to show the final results: one plot shows the dose response function, and the other plot shows the estimated treatment effect function (also known as estimated derivatives).

Empirical model

To ascertain the effects of formal and informal institutions on investment in agroforestry through FMNR, the data collected in 2012 from 1080 households in Burkina Faso, Mali, Niger, and Senegal, are used. The dependent variable, practice of FMNR, is measured by the density of trees kept and managed by the household on its farmlands. In many observational impact studies involving technology adoption, there is generally a cohort using the technology compared against a control group that did not use the technology. However, FMNR is a complicated technology that does not necessarily fit into two categories. First, virtually all trees in the Sahel are regenerated naturally and it is not always easy to identify the degree to which the regeneration was facilitated by farmers' practices. Thus, adoption is defined more as the degree of natural regeneration with or without farmer management/assistance.

Based on field experience and observations, the household questionnaire was designed to capture four aspects related to two dimensions: (1) knowledge continuum including farmers' knowledge of FMNR practice and the diversity of the species managed on the farmland as compared to the main species found in the area; and (2) compliance continuum including ownership of at least one farm plot and the number and size of trees kept and managed in the farm. The "degree" of the practice can then be reflected in the tree density (i.e., number per hectare) and age distribution of the trees. Thus, farmers with a high tree density of young trees reflect active FMNR practitioners.

Older trees can often be more than 100 years old. Therefore, a good number of the mature trees may have been inherited by the current farmer and do not result from previous FMNR practiced by him or her. Trees may be kept on farm because of an appreciation for the benefits or an inherited way of farming from parents. There may also be unobserved variables at household or plot level that make certain sites more amenable to tree growth. Moreover, divergence between households in inherited and regenerated trees can also result from factors at the community or landscape level.

There are several institutional factors that have been identified as limiting the potential for FMNR, such as fire setting, free grazing, and rights and regulations over trees. The use of fire and free grazing systems generate benefits in terms of grass regeneration, clearing of debris, catching wild rodents for food and in the case of free grazing, offering a cheap mechanism for feeding livestock. Thus, it is not easy to find institutional reforms that can accommodate the interests of FMNR with others. However, practices such as controlled fires, rotational grazing (the flip side being rotational exclosure areas), and the promotion of livestock corridors are all options that have been successfully implemented in the drylands. These factors are generally regulated through governing formal and informal structures defined by codes of conduct, norms of behavior and conventions. In this study, we are interested in local conventions (LOCONV) and formal village land management commissions (COFO/CVGT).

In addition, a number of covariates are specified to reflect the potential effects of other variables on FMNR. These additional factors that may influence a household's decision about agroforestry practices are classified into two constructs: household structure and household endowment (access to assets and information). *Household structure variables* include household size and the number of active members in the household.

Access to assets provides households with leverage to invest in productive activities and generate more output, which increases their probability of participating in market transactions. Access to assets is an indication of endowment and wealth. In general, well-endowed households tend to experience lower transaction costs and have more flexibility in allocation of resources to market activities (Siziba et al., 2013). Included in this category are *production assets* including size of arable land, number of livestock owned; *transportation assets,* captured by ownership of transport equipment such as cart. The total land area may have indirect positive impacts on investment in trees by enabling farmers to generate production surpluses, to overcome credit constraints, where land can be used as collateral for credit (Kabore et al. 1997), and allow them to adopt improved agroforestry technologies that increase productivity of tree products. In other words, the more arable land a household has, the higher the level of output and thus the higher the propensity to practice FMNR.

Access to information tends to improve decision-making skills and affects the know-how of farmers. The construct proxy representing access to information consists of level of education of the household head, ownership of a cell phone, distance to the main market, and membership of farmer groups. The variable measuring proximity to the main market reflects how far farmers have to travel to reach important sources of information that are located in the nearest town where there are government offices and markets. It is expected that longer distances increase travel time and travel costs, which impact negatively on adoption of agroforestry innovation. Participation in farmer groups increases a household's awareness of the type of information needed for production and marketing decisions. Many farmer groups also engage in group marketing as well as credit provision to their members. Table 4 gives definitions and summary statistics of the variables used in the analysis.

Results and discussion

Table 4 presents summary statistics for the sampled households. The average number of trees kept and managed on the farmland is reported in the top of the table. As is clear, there is significant variation among the countries. Niger is clearly an exception: the average number of trees recorded is more than double of that reported in Burkina Faso and Senegal.

A significant proportion of villages in Mali and Burkina Faso have formal and/or informal natural resource institutions that govern access and the use of natural resources. These can be identified as local conventions or a village land management commission. Of the sampled villages in Mali, 71% have a local convention. In Burkina Faso, 98% of the sampled villages have a local land management commission. Surprisingly, Mali is the only country where no land management commission was found in the sampled villages.

Factors influencing FMNR on the farmland

In general, the uptake of agroforestry technologies is more complicated than that of annual crops (Mercer, 2004) because of the multi-components and multi-years through which awareness, acceptability and evaluation take place (Ajayi et al. 2006). Several studies have been carried out to gain insights into the adoption of agroforestry and the factors that drive the adoption of agroforestry (Phiri et al., 2004; Place et al., 2002; Ajayi et al. 2006). In the process of estimating the conditional expectation of the selected outcomes, the study ran a maximum likelihood regression to ascertain the effects of certain of the covariates on the treatment and to create the GPS. The results of the maximum likelihood estimations are reported in Table 5. The covariates are ordered in blocks corresponding to the categories: household structure, household endowment (physical and information assets), and institutional covariates. As indicated by the chi-

Table 4 Summary of variables used in the analysis

Variable description	Countries			
	Burkina Faso (*N* = 240)	Mali (*N* = 240)	Rep. of Niger (*N* = 480)	Senegal (*N* = 120)
Continuous treatment variable: Number of young trees kept and managed in the farmlands	40 (50.9)	56 (54)	110 (135)	48 (59)
Outcome variables				
Income per capita (ln $)	4.09 (4.9)	7.58 (4.03)	7.04 (3.79)	5.98 (5.14)
Value of tree products (FCFA)	30,000 (38,480)	34,400 (68,030)	5525 (5500)	17,670 (19,765)
Crop production (ln kg)	7.2 (2.33)	7.31 (2.4)	5.5 (2.28)	6.87 (1.53)
Food consumption score (FCS)	22.52 (15.6)	23.87 (8.01)	29.3 (19.4)	31.7 (11.9)
Covariates				
Household structure				
Number of active members in the household	3 (1.72)	9 (4.8)	4 (1.5)	6 (2.0)
Household size	8 (4.0)	16 (10.0)	12(6.0)	12 (6.0)
Household endowment				
Production assets				
Size of arable land (ha)	5.96 (5.53)	9.09 (9.05)	2.17 (1.9)	8.3 (5.8)
Number of livestock units owned	10.48 (12.10)	17.2 (22.6)	9.9 (5.01)	5.34 (5.05)
Transportation assets				
If the household owns a cart (1 = yes)	29.2%	92.1%	43.5%	64.2%
Information assets				
If the household owns a TV (1 = yes)	56.7%	18.3%	1.5%	27.5%
If the household owns a cell phone (1 = yes)	61.3%	71.7%	25.2%	54.2%
If the highest level of education of the household head is primary (1 = yes)	84.5%	74.5%	10.04%	79.2%
If the highest level of education of the household head is secondary (1 = yes)	50%	38.3%	66.7%	61.7%
Average distance from the main markets (km)	20.07 (20.03)	5.3 (3.7)	7.4 (5.6)	7.1 (5.3)
If the household is a member of at least one CBO (1 = yes)	57%	28%	18%	15%
Institutional factors				
Proportion of villages with local conventions (%)	33	71	19	17
Proportion of villages with village land management commission (%)	98	0	29	17
If the household has access to credit (1 = yes)	70%	24%	19%	35%

Source: data compiled from the household surveys (values in parenthesis are standard deviations)

squared statistic, overall the model is valid in explaining factors that influence the investment in trees through FMNR in the selected Sahelian countries.

Consistent with our expectations, access to information, size of available land, access to markets and formal norms and rules are important factors influencing the FMNR

Table 5 Factors influencing investment on trees in the farmland among farmers in West Africa Sahel

Variable description	Countries				
	Burkina Faso (*N* = 240)	Mali (*N* = 240)	Rep. of Niger (*N* = 480)	Senegal (*N* = 120)	Sahel (*N* = 1,080)
	Coefficient (S.E)	Coefficient (S.E)	Coefficient (S.E)	Coefficient (S.E)	Coefficient (S.E)
Constant	0.677 (0.03)***	4.118 (0.227)***	1.206 (0.038)***	1.073 (0.069)***	2.351 (0.505)***
Covariates					
Household structure					
Number of active members in the household	−0.045 (0.037)	−0.004 (0.009)	−0.023 (0.038)	0.012 (0.054)	−0.29 (0.025)
Household size	−0.004(0.016)	0.005 (0.004)	0.026 (0.017)	0.032 (0.033)	0.023 (0.015)
Household endowment					
Production assets					
Size of arable land (ha)	0.042 (0.012)***	0.176 (0.003)***	0.199 (0.030)***	−0.017 (0.022)	0.064 (0.009)***
Number of livestock units owned	−0.009 (0.004)**	−0.001 (0.002)	−0.006 (0.006)	−0.002 (0.020)	0.004 (0.006)
Transportation assets					
If the household owns a cart (1 = yes)	−0.136 (0.146)	0.113 (0.183)	0.320 (0.126)**	−0.200 (0.225)	0.279 (0.168)*
Information assets					
If the household owns a cell phone (1 = yes)	0.211 (0.092)**	0.194 (0.111)*	0.317 (0.138)**	0.501 (0.241)**	0.464 (0.157)***
If the highest level of education of the household head is primary/ functional (1 = yes)	−0.047 (0.130)	0.027 (0.124)	0.550 (0.560)	0.285 (0.274)	0.143 (0.038)***
Average distance from the main markets	0.000 (0.001)	−0.017 (0.011)	0.045 (0.011)***	0.069 (0.018)***	0.003 (0.001)**
If the household is a member of at least one CBO (1 = yes)	0.174 (0.092)**	0.169 (0.097)*	0.063 (0.154)	−0.340 (0.287)	0.444 (0.172)**
Institutional factors					
If there is an operational local convention within the community (1 = yes)	0.156 (0.140)	0.167 (0.067)**	0.833 (0.254)***	0.060 (0.073)	0.678 (0.220)***
If there is existing land management commission within the village (1 = yes)	0.025 (0.012)**	–	−0.230(0.156)	−0.559 (0.276)**	−0.787 (0.215)***
If there is both local convention and land management commission within the village (1 = yes)	0.085 (0.072)	–	−0.908 (0.320)**	−0.116 (0.075)	−0.155 (0.374)

Table 5 Factors influencing investment on trees in the farmland among farmers in West Africa Sahel *(Continued)*

If the household has access to credit (1 = yes)	−0.351 (0.167)**	0.162 (0.120)	0.212 (0.149)	0.069 (0.017)***	0.353 (0.184)*
CHI- SQ	109.96	51.92	85.30	52.65	145.61
$P(\chi^2)$	0.000	0.000	0.000	0.000	0.000

Source: authors' estimations from household surveys data; ***$P < 1\%$; **$P < 5\%$, and *$P < 10\%$

practice. The important role of information in influencing FMNR is highlighted by the positive and significant sign of two variables: the ownership of a cell phone and membership of at least one community-based organization (CBO). In fact, agroforestry technologies as compared with conventional agricultural practices are new phenomenon (Ajayi et al. 2006). The promotion of tree-based systems requires skills in terms of management of trees. Capacity of doing this needs to be built and requires a multidimensional approach including field demonstrations as well as a proper dissemination of information using different information and communication technology tools. There is a growing agreement in developing countries that the use of cell phones is an effective and efficient way to communicate timely information on agroforestry innovations to farmers.

In addition, farmers can be ingenious in problem solving and if they pick-up information about FMNR from friends or other acquaintances they may well innovate and adapt the method to their own conditions. Because of its flexibility and multiple options, FMNR is a practice that can trigger the innovative creativity of farmers. The positive and significant sign of the variable CBO confirms the assertion that farmers tend to believe their trusted peers more than formal advisers when discussing the advantages and disadvantages of a new technique, approach or tool. It is therefore easier and helpful for them to interchange ideas and experiences on the technique through formal or informal CBOs.

Another important factor in explaining the practice of FMNR is the size of arable land. This variable has a positive and significant effect meaning that ownership of more arable land increase the practice of FMNR in the Sahel. In some countries including Niger for example, the habit of leaving and managing trees in crop fields is a standard farming practice. Typically, access to more arable land will encourage farmers to maintain and manage more valued trees on their farms (Pye-Smith 2013).

Effective demand in the market and the supply chain beyond production is also important in ensuring that farmers will receive attractive returns for their efforts in using sustainable agricultural practices such as FMNR. As such, policies and institutions that encourage and enable the marketing of indigenous tree products, permit FMNR practitioners to be aware of the existing opportunities of FMNR technology to provide immediate, medium and long term individual and public benefits simultaneously.

The institutional factors portrayed in this study are the formal and informal governance institutions established to play a role in natural resource management and land administration. These are captured by two dummy variables representing the village land management commissions and the local convention. According to the results reported in Table 5, those variables can exert (1) a positive influence on the FMNR practices, (2) negative impacts, (3) ambiguous or no direct effects.

Local conventions seem to have a positive and significant effect on FMNR practice and this result is particularly strong in Mali, Niger, and Sahel as the whole. Indeed, there is a growing interest in strengthening community-based natural resource management and participation in those countries (Yatich et al. 2014). Traditional West African tree tenure systems are extremely complex and further complicated by the current movements towards decentralization in many of West African Sahelian countries (Alinon and Kalinganire 2008). In fact, as noted by Howard and Nabanoga (2007), tenure is more than just legal ownership, it creates beneficiaries and victims based on how ownership is divided and how power relations accompany that ownership. Von Benda-Beckmann quoted by Leach et al. (2011) suggests that this includes not only the many rights that one owner may have in tree and other resources but also the ways in which these rights are expressed through ideology, legal institutions and power dynamics. Because the local conventions are more inclusive and their territorial coverage in many cases more important (in some cases, the facilitation of those conventions is increasingly focused on the more complex situations involving several local government territories or the district level, such as livestock corridors), they appear to be considered as a pro-agroforestry institution. In addition, they provide a more secured frame within which farmers in different communities are sensitized to invest in trees. Due to the community consensus plan materialized within the local conventions, farmers perceive the population of valued local species to be increasing, and they are eager to continue that trend by planting or protecting more trees each year.

The effect of the variable "village land management commission" is mixed, i.e., positive and significant in Burkina Faso and negative in Senegal. In areas where the village land management commissions work well because of their flexibility such as in Burkina Faso, there is a lot of buy-in and populations collaborate better with the local government in developing sustainable natural resource management plans and practices such like FMNR. However, in some countries like Senegal where these commissions are being assimilated to governmental institutions, local communities are less compliant to the established rules, norms and recommendations related to sustainable management of natural resource. In addition, forest codes are often poorly understood by rural people. Faced with lack of resources, most forest services are unable to enforce regulations properly. Moreover, because of some misbehavior from individual forest agents, these institutions are sometimes seen as disincentives towards FMNR practice. Therefore, the local management of resources will need to be accompanied by institutional change within forest services with a greater emphasis given to capacity building in participatory approaches and a formal acknowledgement of the sustainable nature of traditional management practices.

The results also indicate that there is a need to develop a more integrated institutional framework and find ways to enhance effective participation across institutions. Indeed, the results indicate that in villages where populations are regulated by both local conventions and a village land management commission, farmers seem to be discouraged to invest in trees on their farmlands.

Assessing the effects of FMNR practice on livelihoods and caloric intakes

Effects on income

With the *gpscore programme*, the study first took a logarithmic transformation of the treatment variable. Results of this transformation are not desirable: the Kolmogorov-

Smirnov test of the normality assumption shows that the log-transformed treatment variable is not normally distributed. The analysis then chose the zero-skewness log transformation of the treatment variable; the Kolmogorov-Smirnov test shows that the assumption regarding normality under this transformation is statistically satisfied at the 0.01 level. Using this transformation, the study ran the maximum likelihood regression to create the GPS model for each country. Using the medians of the transformed treatment variable for the different sub-groups, the study estimated five sets of GPSs for all units. Results show that the GPSs improve covariate balances.

The study then moved to estimate the conditional expectation of the outcomes, given the treatment and GPS, and employed the conditional expectation to estimate the dose-response functions or treatment effects at the different selected treatment levels (i.e., percentile density of trees kept and managed on the farmland at the following levels: 25, 50, 75, 100%) and their 95% confidence bands. Results are presented in two types of plots: one plot shows the dose-response function and the other plot shows the estimated treatment effect function also known as estimated derivatives (Fig. 1).

Taking the dose-response function results, generally speaking in the Sahel, it appears that there is a sharp increase of income received from marketing of tree products when the number of trees kept and managed on the farmland ranges from 10 to 40/ha. After the threshold of 22000 CFA benefit, the total amount earned from selling tree products harvested on farm decreases to 20000 CFA when the number of trees ranges from 45 to 100/ha. The treatment effect functions show the marginal effect of maintaining and managing trees on income. Globally the plot suggests that in the Sahel, for those who have less than 45 trees/ha on their farmland, every one percentage-point increase in the number of trees kept and managed on the farm decreases the amount of income received from tree products. The marginal effects again show that farmers who are less involved in the practice of FMNR (i.e., farm with less than 40 trees/ha) are more sensitive to income change than those with more trees (i.e., higher than 40/ha). The findings may suggest that in order to earn more income from the FMNR practices, there is an optimal number of trees needed to be kept and managed on the farm.

Figure 2 shows the disaggregated results per countries. The results from the dose-response functions show that there is a sharp decline of income received from tree products in Burkina Faso when the density of trees on the farmland is less than 20/ha. The revenue received from tree products tends to be stable at 30,000 CFA/ha when the density of trees is higher than 20/ha. The maximum amount expected to be received by selling tree products is 40,000 CFA/ha with a farm of 15/ha density in Burkina Faso. In Mali, FMNR practitioners with 20 trees/ha are better off in terms of revenues received from tree products (42000 CFA). This amount sharply declines when the density ranges from 21 to 40 trees/ha. After the 40 trees/ha threshold, the revenue received from tree products gradually increases with every unit of tree increase during the practice of FMNR to be stabilized around 40,000 CFA. By contrast, even if the figures in terms of trend and density look alike in many cases across countries, Niger and Senegal exhibit the lowest amount of incomes that can be expected from tree products (15,000 to 17,000 CFA in Niger) and (15,000 to 20,000 CFA) in Senegal. These findings also suggest that the species favoured by farmers vary from place to place; so does the density of the tree. Some projects have advised farmers to keep 20–40 trees/ha, but densities of over 150 are not unusual. In addition, while there are common parkland species

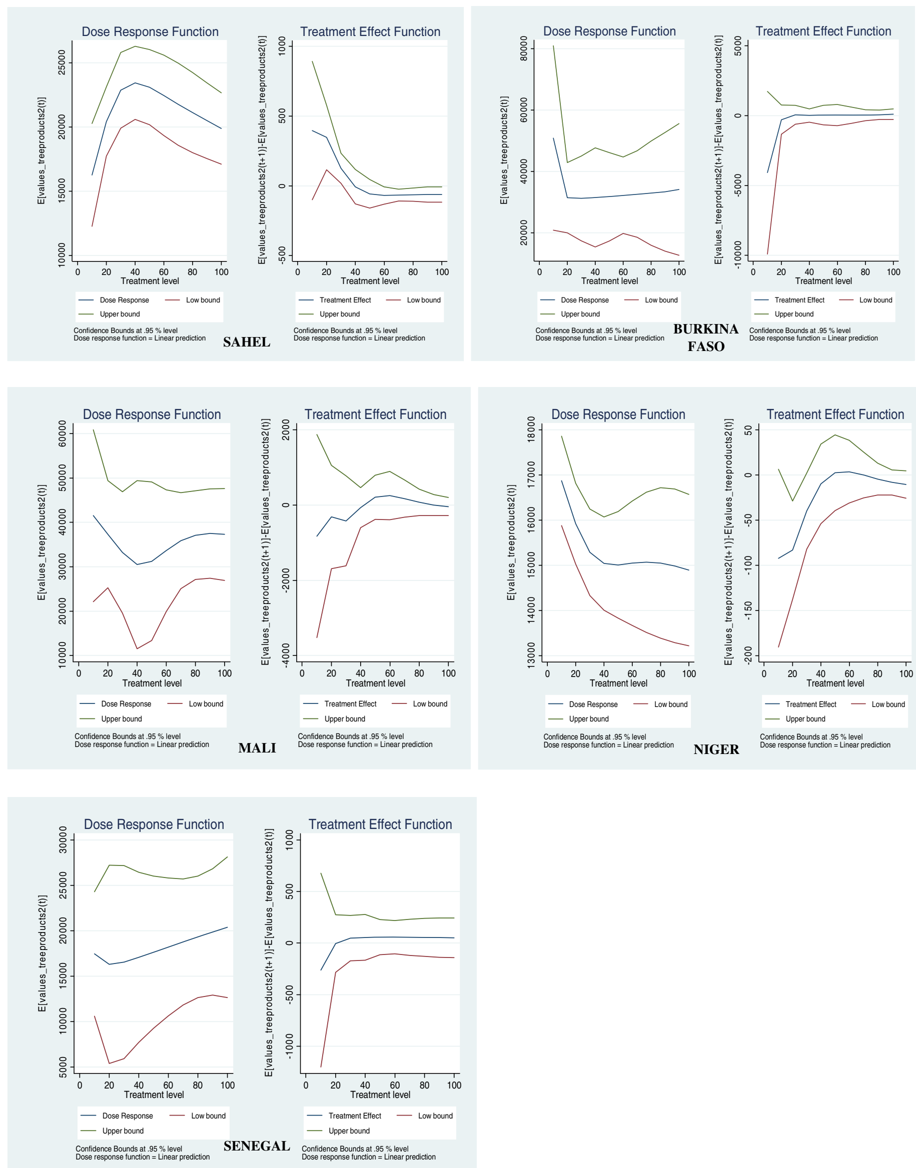

Fig. 1 Estimated effects of investment on trees on the household income-dose-response function results, derivative, and 95% confidence bands

throughout the Sahelian/Sudanian ecozones, the composition of species differs across space due to rainfall conditions, topographical location, soils and farmers' preferences for tree species and functions (Faye et al. 2011).

Effects on crop production

Cereals and vegetables are the most common staple crops associated with trees in the Sahel. Crop yield improvement is another major benefit pathway of trees. The pathway to increase yields is due to micro climate regulation (from all trees), improved soil fertility in its broadest sense of physical, chemical and biological aspects (more so from certain species than others), and potential impacts on water availability for crops-under certain contexts only Bayala et al. (2014).

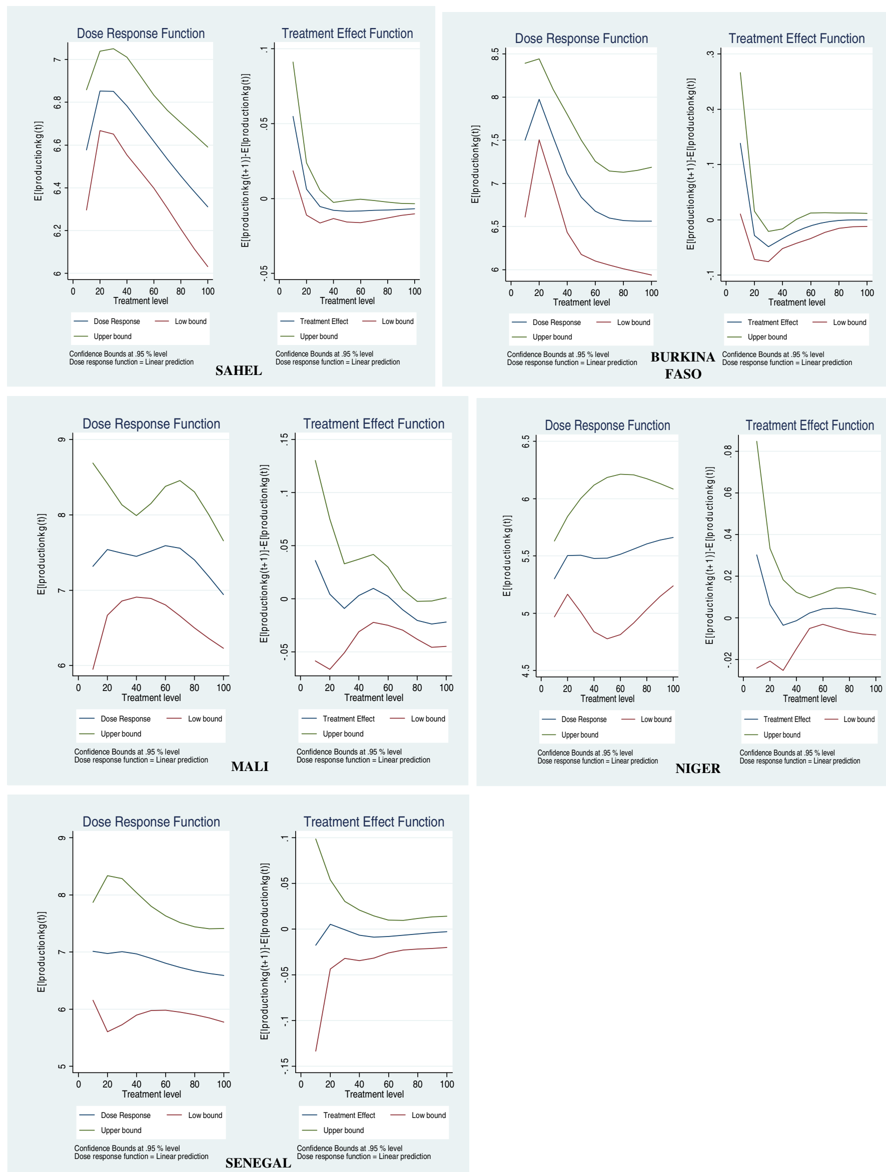

Fig. 2 Estimated effects of investment on trees on crop production-dose-response function results, derivative, and 95% confidence bands

This study also tried to assess the impact of FMNR on crop production. Considering the dose-response results in Fig. 2, there is a sharp increase in crop production when the density of trees ranges between 15 to 20 trees/ha. When the density ranges from 20–40/ha there is an increase with a constant slope (in other words, the effects on crop production tend to be constant); above the density level of 40 trees/ha, the crop production decreases with increasing density levels. The dose-response plots show that, the maximum effect is reached when the density of trees ranges from 20 to 40/ha, indicating an increase of crop production by 915.985 kg (=$e^{6.82}$) or 274.25 kg/ha (=915.985/3.34) in the Sahel. The same calculations can be done for each of the countries indicating an increase of the expected quantity of cereals produced by 401.38 kg/ha in Burkina Faso; 198.9 kg/ha in Mali; 112.76 kg/ha in Niger and; 132.12 in Senegal.

The marginal propensity to benefit from increased crop production as indicated by the treatment effect functions shows that FMNR practitioners with less than 40 trees/ha are more sensitive to the changes in crop production than those with a higher number of trees/ha. Indeed, the plot suggests that for FMNR practitioners who have less than 40 trees/ha, every one percentage-point increase in keeping and managing trees on their farmland decreases the effects on crop production, and the stronger effect was associated with the management of about 20 trees/ha (+5% in the Sahel; +14% in Burkina Faso; +4% in Mali; +3% in Niger and about +1% in Senegal).

These findings again suggest that the effects of trees on crop production might be affected by both the density and quality of tree species. Indeed, many tree species also assist staple crops through soil-fertility improvement. This was demonstrated in an analysis of more than 90 peer-reviewed studies on the planting of nitrogen-fixing green fertilizers, including trees and shrubs, which found consistent evidence of benefits to cereals in semi-arid countries, although the level of response varied by soil type and by the technology used (Sileshi et al. 2008; Bayala et al. 2012). In fact, past studies on tree–crop interactions have clearly shown that trees have highly varying effects on the associated crops when comparing the yields of associated crops in the influence zone of trees with that of a treeless monoculture control plot (Oginosako et al (2006); Baggnian et al. (2013); Bayala et al. 2012, 2014).

Effects on caloric intake and diet

Most definitions of food security vary around that proposed by the World Bank (1986); major components of the most common definitions are summed up by Maxwell and Frankenberger as "secure access at all times to sufficient food for a healthy life" (Maxwell 1996). In an emergency food security assessment (EFSA), three key sets of indicators are used to estimate the dimensions of the food security problem (World Food Programme WFP 2009):

- "Mortality rates give an indication of risks at the population level".
- "Nutrition indicators are used to estimate nutrition status at the individual level".
- "Food security indicators focus on assessing access to food and food consumption at the household level".

In our analysis, we employ the most commonly used food consumption indicator, i.e., the "food consumption score (FCS)". This is a proxy indicator that represents the dietary diversity, energy and macro and micro (content) value of the food that people eat. It is based on dietary diversity—the number of food groups a household consumes over a reference period; food frequency—the number of days on which a particular food group is consumed over a reference period, usually measured in days; and the relative nutritional importance of different food groups (World Food Programme WFP 2009). Households are asked to recall the foods that they consumed in the previous 7 days. Each item is given a score of 0 to 7, depending on the number of days on which it was consumed during a week. For example:

- If potatoes were eaten on three of the last seven days, they are given a frequency score of 3;

- If potatoes were eaten on three of the last seven days, even if they were eaten twice on each of those days, at two meals, they are still given a frequency score of 3.

In the analysis, food items were listed according to food groups and the frequencies of all the food items surveyed in each food group were summed. Any summed food group frequency value over 7 was recorded as 7. Each food group is assigned a weight reflecting its nutrient density. For example:

• Beans, peas, groundnuts and cashew nuts are given a weight of 3, reflecting the high protein content of beans and peas and the high fat content of nuts;

• Sugar is given a weight of 0.5, reflecting its absence of micronutrients and the fact that it is usually eaten in relatively small quantities.

The household FCS was calculated for each household by multiplying each food group frequency by each food group weight, and then summing these scores into one composite score.

Solving the problem of food and nutritional security requires a range of interconnected agricultural approaches, including improvements in the productivity of staple crops, the bio-fortification of staple foods, and the cultivation and/or management of a wider variety of edible trees that provide fruits, nuts and vegetables for more diverse diets (Frison et al. 2011). Exotic and indigenous fruits cultivated and managed in agroforestry systems are important in Sahelian countries. As well as directly providing edible products, trees in agroforestry systems support food production by giving shade and support to nutritious vegetable crops (Yamba and Sambo 2012; Maliki et al. 2012; Garrity et al. 2010; Susila et al. 2003). The results from the sampled households showed that overall, 39.78, 36.97, and 23.25% FMNR households respectively fall under poor, borderline and acceptable quality diet. In addition, those under borderline and acceptable quality diet are those managing on average a high and diversified number of trees in their farmlands.

Figure 3 exhibits the two-type plots reporting the effects of FMNR practice on caloric intake and diet.

According to the treatment effects plots, the contribution of trees on caloric intake and diet tends to decrease when the density ranges from 15-20 trees/ha, after the 20 trees/ha threshold, an increase in the number of trees kept and managed on the farmland increases the food consumption score gradually with every unit increase in the number of trees managed by the farmers to a maximum score of 30 points increase in Niger and Sahel. The score tends to stabilize at 22 points increase in Burkina Faso and Mali, and 30 points increase in Senegal, when the minimum density is 20 trees/ha. Summarized results of the regressions analysis are reported in Table 6.

Conclusions

This study demonstrated that regeneration of trees on farms, whereby farmers play an active role is important as a practice and tree products can serve as a safety-net in times of crises (e.g., income shortages from other income sources, e.g., crop failure) as they may be ready for harvest to serve as emergency food or to be processed and sold. Often, some of these species provide opportunities to marginalized members of the communities such as women and the poor, since they are a valuable source of income and help to mitigate risks during crisis by providing alternative food and economic

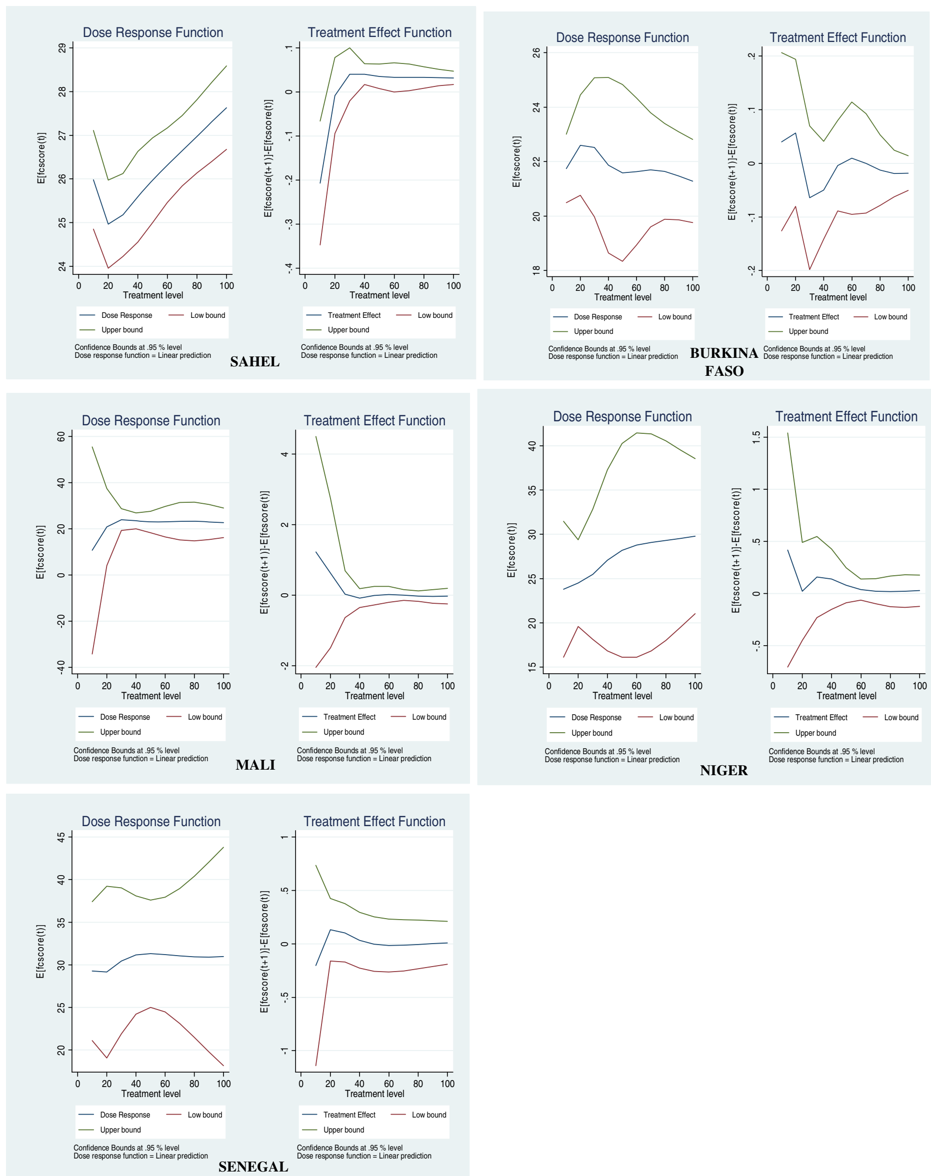

Fig. 3 Estimated effects of investment on trees on caloric intakes and diet-dose-response function results, derivative, and 95% confidence bands

resources. In addition, deficiency of iron and vitamin A is prevalent in most parts of dryland countries including Mali. However, fruit trees which are popularly used by the local communities contain appreciable amounts of nutrients and energy and thus useful food supplements. Pulp from the baobab fruit has been reported to contain an average of 283 mg/100 g of Vitamin C. The vitamin is important as an antioxidant, hence the prevention of certain types of diseases, ranging from pulmonary, to cancer prevention (Chadare, et al., 2008). For instance, a child could cover 100 percent of its vitamin C requirement by eating only about 10 g of baobab pulp a day. Moreover, the fruit and the kernel of karite have high nutritional value. From the results reported for Burkina Faso (Lamien et al. 1996), the pulp provides protein amounting to 1.9 g per 100 g of matter and about 4.8 Kcal per 100 g, while the kernel provides protein of 6.8 g per 100 g of

Table 6 Summary of key findings (regression analysis)

		Country				
		Burkina Faso	Mali	Niger	Senegal	Sahel
Factors affecting FMNR	Three categories of factors observed here					
	Pre-disposing factors featured by: • Landholding size	Positive influence	Positive influence	Positive influence	No significant influence	Positive influence
	Facilitating factors featured by access and use of information through: • Ownership of cell phone • Being member of community-based organization (CBO) Access to credit	Positive influence Positive influence Negative influence	Positive influence Positive influence No significant influence	Positive influence Positive influence No significant influence	Positive influence Positive influence Positive influence	Positive influence Positive influence Positive influence
	Re-enforcing factors featured by: • Average distance to the main market as a proxy of the market attractiveness of AFTPs • Existence of an operational local convention • Existence of an operational land management commission	No significant influence No significant influence Positive influence	No significant influence Positive influence	Positive influence Positive influence No significant influence	Positive influence No significant influence Negative influence	Positive influence Positive influence Negative influence
Effects on livelihoods	*Effects on income* *Dose response function* indicating an increase of income given a range level of trees being kept in the farmland as a result of FMNR practice *Treatment effects function* that shows the marginal effect of FMNR on income	The revenue received from tree products tend to be stable at 30,000 CFA/ha (US$60) when the density of tree is higher than 20/ha. The maximum amount expected to be received by selling tree products is 40,000 CFA/ha (US$80) with a farm of 15/ha	FMNR practitioners with 20 trees/ha are better off in terms of revenues received from tree products (42,000 CFA or US$84). This amount sharply decline when the density ranges from 21 to 40 trees/ha. After the 40 trees/ha threshold, the revenue perceived from tree products gradually increase with every unit of tree increase during the practice of FMNR to be stabilized around 40000 CFA (US$80).	Exhibit with Senegal the lowest amount of incomes that can be expected from tree products (15,000 to 17,000 CFA i.e., $30 to $34)	Exhibit with Niger the lowest amount of incomes that can be expected from tree products (15,000 to 20,000 CFA i.e., $30 to $40)	Indicates a sharp increase of income (up to a 22,000 CFA or US$44 threshold) from trees products when the number of trees being managed in the farmland ranges from 10 to 40/ha Farmers who are less involved in the practice of FMNR (i.e., farm with less than 40 trees/ha) are more sensitive to income change than those with

Table 6 Summary of key findings (regression analysis) *(Continued)*

						more trees (i.e., higher than 40/ha) as the effects of changes in income tend to be stable as it appeared in the plot.
	Effects on crop production *Dose response function* indicating an increase of income given a range level of trees being kept in the farmland as a result of FMNR practice	The maximum effect is noted when the density of trees ranges from 20 to 40/ha, indicating:				
		An increase of the expected quantity of cereals produced by 401.38 kg/ha	198.9 kg/ha increase observed among the FMNR practitioners	112.76 kg/ha maximum observed in Niger	132.12 kg/ha increase observed in Senegal	General increase of crop production by 274.25 kg/ha in the Sahel as the whole
	Treatment effects function that shows the marginal effect of FMNR on income	The plot suggests that for FMNR practitioners who have less than 40 trees/ha, every one percentage-point increase in keeping and managing trees in their farmland decreased the effects on crop production, and the stronger effect was associated with the management of about 20 trees/ha with a:				
		+14% increase in Burkina Faso	+4% increase in Mali	+3% increase in Niger	Only +1% increase in Senegal	+5% general increase in the Sahel as the whole
	Effects on calorie intakes *Dose response function* indicating an increase of income given a range level of trees being kept in the farmland as a result of FMNR practice *Treatment effects function* that shows the marginal effect of FMNR on income	According to the treatment effects plots, the contribution of trees on food security tends to decrease when the density ranges from 15-20 trees/ha, after the 20 trees/ha threshold, and increase in the number of trees kept and managed in the farmland increase the food consumption score gradually with every unit increase in the number of trees managed by the farmers to a maximum threshold level of FCS:				
		The score tends to be constant at 22 points increased when the minimum density is 20 trees/ha	Same as Burkina Faso	30 points increased in observed in Niger	The effects tend also to be constant at 30 points increased of the food consumption score in Senegal	30 points increased is also observed in the Sahel as the whole

Source: authors' summary

matter and 579 Kcal per 100 g. The fruit is a source of vitamins and energy. The kernels undergo an elaborate preparation process to produce oil and butter for home consumption, and increasingly for selling. The kernels are dried, cracked, pounded to form a paste, boiled and the butter is then skimmed off. Every woman makes sure that she has enough shea butter in the home for cooking to last at least until the following harvest. In addition, in some places where the markets of fruit tree products are functioning well, fruit trees cultivation offers great potential for income generation.

The analysis of factors affecting FMNR in the Sahel did not find many household's characteristics constraining significantly the FMNR practice in more than one country. However, several institutional factors have been identified as promoting or limiting the potential for FMNR, such as rights and regulation rules over trees and natural resources in general. For example in the Sahel, the use of fire and free grazing systems generates benefits in terms of grass regeneration, clearing of debris, catching wild rodents for food and in the case of free grazing, offering a cheap mechanism for feeding livestock. Thus, it is not easy to find institutional reforms that can accommodate the interests of FMNR with others. However, practices such as controlled fires, rotational grazing and the promotion of livestock corridors through local conventions are all options that have been successfully implemented in the drylands.

Markets for tree products are other factors that impacts on incentives to manage trees. For FMNR in particular, market development may have different effects. On the one hand, markets surely do influence collection and marketing behavior of farmers as the case of shea in Burkina and Mali has demonstrated. In general, as tree product markets develop, there is more incentive to maintain trees on farms. There may be further incentives concerning the selection of species to retain based on market signals, but only if market signals persist for a long period of time since changes in tree species composition is a long term operation in the drylands.

Recommendation domains

1. Overall, FMNR cannot be excluded as a recommendation in any of the dryland zones. FMNR will continue to support the largest number of established trees on farms in the drylands. Its importance at a landscape level is likely to increase as well, the more that agricultural expands into woodland and bush lands. The other tree related alternatives to FMNR require the planting of trees. Opportunities for planting will remain very limited in arid drylands and limited in semi-arid drylands. A major exception will be low-lying areas of the landscape, but even there, other enterprises may be preferred over tree planting, thus reaffirming the importance of FMNR for trees. Within a particular dryland zone, there may be further nuances on recommendations for how to practice FMNR. For example, certain institutional arrangements such as improved grazing management may be an important complementary action in some places while not in others.

2. The issue of forest regulations which create disincentives for farmers is one that is widespread in the developing world. These include the banning of felling or cutting of a number of species without obtaining a prior permit, at a fee. Violation of such regulations entails a hefty fine, and so farmers will often remove young trees from their land to avoid having to deal with such regulations in the future. Among such regulations, the adverse effects of the Sahelian forest codes have long been recognized (e.g., McLain

(1992)) and there have been many dialogues in the region to try and move forward. Although not backed by formal policy change, the recent regreening in Niger has been attributed to a significant extent by the relaxation of enforcement of such policies (Reij et al 2009). A recent analysis of the forest codes and recommendations for action are in Yatich et al (2014). *National policies need to be complemented by institutional support at the local level to reduce current constraints of property rights and other institutional constraints affecting the promotion of FMNR*. In addition, *there is a need to develop a more integrated institutional framework and find ways to enhance effective participation across institutions*.

3. Access to information tends to improve decision-making skills, which in turn affects the know-how of farmers. Indeed, agroforestry technologies as compared with the conventional agricultural practices that farmers have known, have been used to and have received training for a much longer period, are generally incipient and relatively new phenomenon (Ajayi et al. 2006). *The promotion of tree-based systems requires skills in terms of management of trees. Capacity of doing this needs to be built at all level and requires a multidimensional approach including field demonstrations as well as a proper dissemination of information using different information and communication technology tools. In addition, be aware of the existing opportunities of FMNR technology to provide immediate, medium and long term individual and public benefits simultaneously need to be well-communicated to many stakeholders*.

Limitations of the study

1. While recognizing the benefits of trees and tree products on caloric intake and diet, the results from this study establishing a correlation between FMNR and caloric intakes should be taken with cautious given that, "a snapshot of one week consumption cannot provide enough information to claim that FMNR household are food secured or not. In fact, the FCS does not capture seasonal changes, quantify the food gap, capture intra-household food consumption etc…" In addition, while the evidence base for the role of forests and tree-based systems for food security and nutrition is growing (Sunderland et al. 2013; Bhaskar et al. 2015), there remain many gaps in our understanding of this relationship and its potential contribution to reducing global hunger. There is a need to explore much more details the FMNR-food nexus in future researches by going beyond what was covered from this study, particularly in "relation to the integrated management of multi-functional landscapes, and the multi-scalar and *cross-sectoral governance* approaches that are required for the equitable delivery of these benefits".

2. The types of trees that will be desirable for farmers to retain, as well as the densities of trees, may also differ across locations. For example, where fertilizer use is extremely low, promoting regeneration of trees which have known positive soil fertility properties will be more important. Similarly, the promotion of higher tree canopies in locations with high current or expected temperatures would be recommended if current crop choices are to be maintained. Unfortunately, these types of nuances cannot be neatly mapped out as they require information that was not readily available. However, such information can be collected quickly and cheaply by programmes promoting FMNR.

3. Land tenure would has been a constraining factor, but in the study area, over 85% of all land plots were inherited in each of the countries. This still may be an issue for women and the plots that they manage, but this could not be assessed with data at hand.

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Authors' contributions
JNB carried out the review and development of key concepts and produce a draft manuscript. FP analyzed the data and also contributed towards improving sections and subsections of this manuscript. ADA contributed by providing further insights and improvements to many of the sections and subsections of the manuscript. AK structured the draft manuscript and contributed to improving many of the sections and subsections. All the authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]World Agroforestry Centre (ICRAF)-West and Central Africa Regional Office-Sahel node, P.O. Box E5118, Bamako, Mali.
[2]International Food Policy Research Institute (IFPRI), Institution and Market, Washington 20006, USA.

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