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ABSTRACT

Agriculture can contribute to carbon mitigation by storing more carbon in the soil through greener cropping systems and by raising livestock differently. If farmers reduce their GHG emission and increase their carbon sequestration will it be a win-outcome where the new techniques will finally improve farmers' income? The study aims to assess whether mitigation strategies will imply a trade-off between environmental and economic objectives or a win-win situation. This study is applied to the case of small farmers in Burkina Faso using an analyse programming model, in which the farmers maximize their utility subject to constraints as emission limitation, land, labour, capital and food consumption.

The results show when the farmers produce only annual crops, integrating the emission reduction in their system impacts negatively their net cash income, compared to the baseline scenario, that could worsen their living conditions. By integrating perennial crops, farmers' utility increases and the net carbon balance becomes positive. Around 6.118tCO2eq is sequestrated individually. Policymakers should encourage farmers to adopt perennial crops in their annual cropping systems. Most small farmers are living below the poverty line. To reach the emission reduction objectives in the annual crops system, incentives are needed to compensate the lost income.

Key words: climate change and poverty, emission reduction, environmental regulations

1. INTRODUCTION

In Burkina Faso, the economic growth is strongly linked to their agricultural activities. The sector covers at least 80% of the labour force and constitutes the main source of income. Around 30% of the gross domestic product comes from agriculture (FAOSTAT, 2014)[1]. It accounts for 37% of export products and remains extensive, dominated (72%) by small-scale farms between 0.5 and 7 hectares (MEF, 2002).

Climate change talks regularly underline that developing countries' agriculture could play a stronger role in GHGs mitigation strategies. Agriculture act both as a sink and a source of carbon emission (Xiaomei and Yongsheng., 2002; Beach et al., 2006; McCarl and Schneider, 2000; Lal and Bruce, 1999). A growing number of research projects have investigated how agriculture in developing countries can reduce GHG emissions, capture GHGs while ensuring food security. The agricultural sector is responsible for 14% of the GHG emissions, through the cultivation of soils resulting in the loss of soil organic mainly methane (50%), nitrous oxide (70%) and CO_2 (20%) (Pretty et al., 2002; Schneider, 2000; IPCC, 2011). These emissions depend on the type of intensification and the type of soils. This relationship is not linear but follows the well-known diminishing return function (Groenigena et al., 2010; Linquist et al., 2012a). For similar soil types, nitrification is the dominant process that produces N_2O, and

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[1] http://faostat.fao.org/site/291/default.aspx

ammonium-based fertilisers contribute more to N_2O emission. A field that is more waterlogged might produce more N_2O from denitrification and NO_3 from fertilisers should be avoided (Hauser, 2003). The N_2O emission factors increased with increasing N application (McCarl and Muray, 2001). Each kilogramme of N-fertiliser used in the cropping system produces a global emission of 30 to 50 g of N_2O (Crutzen et al., 2008).

Globally, around a quarter of agricultural C sequestration can be achieved by adopting greener cropping practices (Paustian et al., 2004). Good agricultural practices can be a source of additional incomes to otherwise poor rural areas and act as a means of supporting better adaptation strategies to climate change. Agriculture could be a cheap alternative for overall emission reduction in the next decades (Schneider, 2000).
Other authors (West and Post, 2002; Post et al., 2001; Rochette and Janzen, 2005) proposed the use of rotations with legume crops which reduces reliance on external nitrogen inputs, including conversion of cropland to permanent grasses or trees, agroforestry, and better application of some inputs such as fertilisers and manure (Lal et and Bruce, 1999). The reduction of the herd size can be a mitigation option (McCarl and Murray, 2001) and proper design and management practices could make them effective carbon sinks. The conversion of conventional agriculture's use of fertiliser into organic farming can reduce the emissions. At the input level, the organic fertilisers gave the best SOC than using chemical fertilisers (Bostick et al., 2007). High crop yields could be maintained and input costs reduced (low input) by the appropriate management of soil, water, energy and biological resources (Pimental et al 1989; Chirinda et al., 2010b). An increase of the price of fertilisers by 10% decreases the use of those fertilisers leading to a reduction of GHG emission by 0.15% (Dumortier et al., 2011).

Potential agricultural strategies are manifold and have been subject to economic analysis (McCarl and Schneider, 2000 and 2003). The mitigation strategies can profitable or not for small farmers. Significant decreases in N2O emissions may be possible by decreasing N fertiliser inputs without affecting economic return from grain yield (Hoben et al., 2011). In degraded agricultural soils the sequestration practices are likely to be profitable for medium and high-resource endowment groups of farmers while those with low-resource endowment loose (Tschakert, 2004a and 2004b). The emission of GHGs per hectare is higher in fertiliser farming than organic farming and Chirinda et al (2010b) suggest that within organic cropping systems, both microbial activity and crop yields could be enhanced through inclusion of catch crops. The use of poultry litter urea nitrogen is more economical at high target yields than at low target yields (Delgado et Mosier, 1996). The conversion from conventional to organic farming led to reduced emissions per hectare, but yield-related emissions were not reduced. The strategies that promote the highest increase in soil carbon do not necessarily generate the highest net present values of the farm outputs Gonzalez-Estrada et al (2008). By linking grain yield with GHG emissions, it becomes possible to maximise economic viability with environmental conservation through appropriate levels of Fertiliser-N input (Mosier et al., 2008). Converting agriculture to agroforestry is a strategy that helps smallholder farmers adapt to climate change, protects environment and generates economic and social benefits (MECV, 2004: de Baets et al., 2007: Noordwijk et al., 2007) in Burkina Faso. Preliminary assessments suggest that some agroforestry systems can be CO_2 sinks and temporarily store carbon (Dixon, 1995). And influence microbial biomass, N mineralisation, soil C and N content, which can further alter the magnitude of crop growth, soil N_2O and CO_2 emissions in the present environmental conditions (Guo et al., 2009). This strategy also improves crops yields among other practices (Bostick et al., 2007).

The carbon sequestration in tree plantations involves a loss in consumer and private forest owners' welfare whereas agricultural producers and landowners gain from higher commodity prices (Adams, 1993). The imposition of various carbon permit entails a loss in the small agricultural sector (McCarl et al., 1999). By converting the crop area into forest, the total emission decreases by 14% (Dumortier et al., 2011). An analysis of the economic potential of soil carbon sequestration in agriculture and afforestation indicated that when there are low incentives for carbon emission savings, agricultural soil carbon sequestration is the most cost-effective strategy (Lal, 2011). The producers are assumed to convert land to trees if they are compensated for the agricultural rents of the land, where the rents reflect regional or country-level estimates of net returns to agricultural land (Antle et McCarl, 2002)

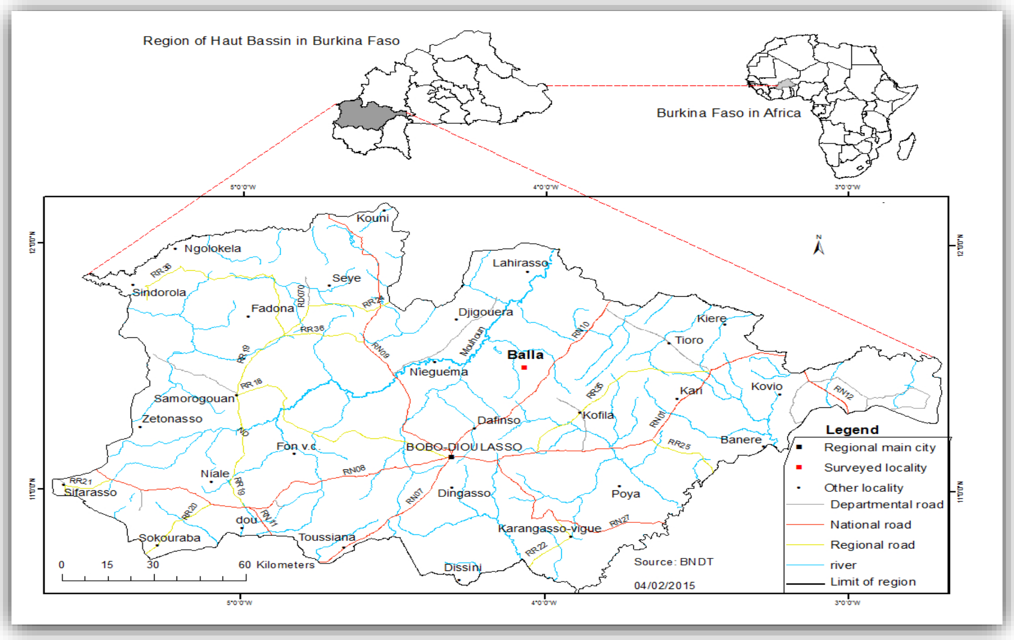
The impact of regulations on emission reduction and incomes is the subject of several controversial discussions. Regulations involve costs such as charges, taxes and the process of adoption and meeting regulative demands is time-consuming and creates "time costs" (Ashford et al, 1985). The producers that go through those regulations experience an additional strain on their financial resources. The usual hypothesis is that, by constraining the firms to reduce their pollution, the production costs increase and as a result, the profit of the firms reduces (Ambec & Barla, 2005). The traditional view highlights the negative relationship between profit and pollution reduction. Under a more recent revisionist view, environmental regulations are seen not only as benign in their impacts on incomes, but actually as a net positive force driving private firms and the economy as a whole to become more competitive in international markets (Jaffe et al, 1995; Simpson & Bradford, 1996). Porter (1991), Porter and Linde (1995) proved that there are opportunities to reduce pollution and firms have to utilise these opportunities because such regulations can induce innovative activities in firms leading to an increase in their competitiveness. For them an environmental regulation leads to win-win situations improving the social welfare (reduction of environmental damages) as well as private profit (offsets). Baumol & Wallace (1971) distinguished the taxes and charges based on price-standard approach, the standard/emissions limits and the certificates as environmental instruments.

Globally, for a policy of carbon sequestration to be adopted by farmers, the changes in the management must maintain or increase their productivity. Otherwise some compensation is needed to help farmers continue these management practices. Burkina Faso is involved in environmental issues at a regional and international scale. Statistics indicate that the carbon stock has decreased from 1990 to 2010 (MEDD, 2012; Samari, 2011). The Permanent Secretary of Environment and Sustainable Development (SP/CONEDD) implemented development plans to reduce carbon emissions and increase the gains of a greener economy. As these strategies lead to additional costs but also generate revenues, the main question is how these emission mitigation strategies will impact the welfare of farmers. The study focuses on the impact mitigation strategies on small farmer's welfare in Burkina. Three mitigation strategies are considered: the application of taxes, the emission limitation and the introduction of perennial crops in annual crops system. Specifically, the study analyses the welfare implication of imposing an emission tax on small households' annual crops productions. assesses the trade-off between incomes and carbon emission constraint at farm household level and analyses the win-win implication of introducing perennial crops in small-farms model.

2. METHODOLOGY

The village of *Bala* located in the Houet province, the *Haut-Bassins* region of Burkina Faso, is selected. This choice is motivated by the representativeness of the village in terms of socioeconomic and agricultural setting and biophysical characteristics and the availability of some secondary data. The local farming system is based on the homestead taking place around the family dwellings with acreage of between 0.25 and 4.5 ha and bush farming stretched on 1ha to 5ha and is practiced far from the compound. The application of fertilisers, manure, compost and crop residue is frequent to improve crop yields. These areas are exploited for several years, and once their fertility has decreased, they are left fallow over a number of years. The system is under rainfed conditions, extensively associated with a weak use of animal traction and mechanisation and large use of traditional tools, due to inadequate financial support and low level of farmers' incomes.

Figure 1: Study area



Source; Author

The village covers an area of about 10 000 ha. Rainfall varies between 800 and 1,500 mm per year, the rainy season starting in April. Rainfall is maximal in August and ends in November. The main crops are cotton, maize, sorghum, with small areas of groundnut, bean, voandzou, rice, sesame, "fonio" and perennials crops such as Shea trees, eucalyptus, cashew-tree and jatropha. Farmers apply inorganic fertilisers on cotton, rice and sometimes on maize. In the region, as cotton farmers have easy access to inputs, they use more chemicals than non-cotton farmers. The forest is dominated by wooded savannahs and shrub lands representing 43% of total area and woody savannah representing 22.68%. The annual average deforestation rate ranges from 0.2% to 1.5%. This is caused by agricultural activities (22.33% of the forest area).

Primary data have been collected from households and agricultural research stations. A comprehensive list of farmers was established in the village totaling 106 farmers, based on their crops activities. An interview has been done with each household to get information on his individual characteristics concerning annual crops activity, separate interviews were also held with agricultural research station officers and extension officers as a way of verifying the information obtained from the initial discussion with the farmers. The information about annual crops activity concerns only year 2014. The secondary data concerns the emission from agricultural activities. These emissions have been assessed by the IPCC (2007). A dynamic linear programming model associated to the utility farm household model. Due to the characteristics of the study area, the utility farm household model is modified to reflect the socio-economic setting of the study area. The characteristics included to the utility function are the types of soils, the types of intensification and the state of nature.

Four types of soil are identified: the uplands (thin and deep) and the lowland (low and high). The systems of production are the traditional crops system in which fertilisers are not applied to crops production; the average intensification where a small quantity of fertilisers are used, and the high intensification in which farmers apply an important quantity of fertilisers. The states of nature are the normal rainy season and the two extreme seasons when rainfall is low (dry season) and when rainfall is important (humid season). The planning horizon for simulation is 25 years in order to take into account the life cycle of perennial crops. Farmers' assets are composed by the credit (mainly for cotton and perennial crops production), their savings, the family labour, land and animals for traction.

The baseline scenario is to produce annual crops as usual and the main output is the net present value ($revt$) of annual net cash incomes ($revtot(a,t)$) generated. The model takes decisions about what commodities to produce. The major crops planted are maize, white sorghum, red sorghum, millet, groundnut, beans, cotton and rice. Farmers tend to produce all of them, while maximizing their utility. The use of constraining resources for one activity reduces its availability for other crops, then the household must find what combination of crops maximizes their utility. The net present value (NPV) is considered as a proxy for utility. Yields of each crop, $rendt(c,i,a,s)$, means that one hectare of crop c produced on soil s with a certain level of intensification i during a rainy season a produces $rendt(c,i,a,s)$ kilogramme of crops. Costs include the cost of inputs such as chemical fertilisers, manure, pesticides and seeds. Land and family labour are assumed to be free of cost. The family can buy food if necessary. The difference between the gross revenue and the total costs gives the annual net cash income $\mathrm{R}(a,t)$) (equation 1):

$$\mathrm{R}(a,t)=\sum_{c} VE(c,a,t) * pxv(c,a) - \sum_{cc} pxa(c,a) * AC(c,a,t) - \sum_{c,i,s} X(c,i,s,t) * (csem(c,i) + int(c,i,s)) - CRED(t) * Taux \qquad (1)$$

With:

$VE(c,a,t)$ the amount of crops sold in the market
$pxv(c,a)$ the seasonal selling price of corps
$X(c,i,s,t)$ the acreage allocated to each crop
$csem(c,i)$ the cost related to the seeds
$int(c,i,s)$ the cost involved by the use of inputs
$pxa(c,a)$ the consumer price of different crops
$AC(c,a,t)$ the quantity of grain bought by the farmer for the food needs
$\sum_{c} VE(c,a,t) * pxv(c,a)$ the total revenue
$\sum_{cc} pxa(c,a) * AC(c,a,t)$ the total expenditure for the purchase of grains
$CRED(t) * Taux$ the interest paid for credit
$\sum_{cc} pxa(c,a) * AC(c,a,t) + \sum_{c,i.s} X(c,i,s,t) * (csem(c,i) + int(c,i,s)) + CRED * taux$ represents the total costs

After, the NPV is computed for the simulation period (25 years) using a discount rate ($ydisc(t)$). The farmers do not know at the beginning, what will be the state of nature. If they can determine in advance the rainy season, they would choose the crops activities that provide the best incomes according to each state of nature. To take into account this ignorance in the computation of the net present value, the same probability is given to each state of nature noted prb(a).

$$Max\ revt = \sum_{a,t} prb(a) * ydisc(t) * (R(a,t)) \qquad (2)$$

The objective function is subjected to a set of constraints reflecting the non-negativity of output, input and the boundary of available resources. The constraints depend on some parameters in the production function:

The non-negativity constraint: $\mathrm{X, CRED, AC, VE} \geq 0$ (3)

It means that the level of different activities, the credit, the quantity of crops bought and sold must be greater or equal to zero.

The cash constraints indicate that the farmer can use his own cash (cap) and credit (CRED) he can get from the cotton company. The total farm expenses must not exceed the sum of the available cash and credit.

$$\sum_{c,i,s} (csem(c,i) + int(c,i,s)) * X(c,i,s,t) \leq cap + CRED \qquad (4)$$

There is also a limit to credit. The credit is only available to cotton producers. In the area the maximum amount (ccot) a farmer can get for one hectare of cotton is around 70,000 CFA.

$$\mathrm{CRED} \leq \mathrm{ccot} * \mathrm{X(cot)} \qquad (5)$$

with $\mathrm{X(cot)}$ the acreage of cotton

The total family labour is obtained by computing the individual labour time ($td(p)$ by the household's number of workers (pop). The total labour used for crop production cannot exceed the available family labour with the crop implementation period (p1) and the harvest period (p2)

$$\sum_{c.i.s} lab(c,i,s,p) * X(c,i,s.t) \leq td(p) * pop \text{ for all period} \qquad (6)$$

The total land allocated to the crop must be less than or equal than the available land owned by the farmers $\left(land(s)\right)$. Land is split into four types: The thin upland soil, deep upland, high lowland and low lowland.

$$\sum_{c,i} X(c,i,s,t) \leq land(s) \text{ for all type of soils} \qquad (7)$$

The household must satisfy the food need of the members by consuming a part of its production or by buying grains. There is an annual minimum quantity of grain necessary for each member. The individual amount of this quantity in terms of grains ($alim$) is 200 kg per year (FAO 2004) and the average household size (pop) is 8 persons. Due to individual food preferences, some may prefer eating millet, white sorghum, maize or rice. If the production is not enough, the household will buy extra grain. This means that the produced grains ($\mathrm{AU(C)}$) and the bought quantity ($\mathrm{AC(C)}$) must be greater than the minimum quantity ($\mathrm{alim} * \mathrm{pop}$).

$$\sum_{c} (AU(c,a,t) + AC(c,a,t)) \geq alim * pop \qquad (8)$$

In the scenario of emission limitation, the farmer is not allowed to exceed a fixed maximum quantity. The emissions from agricultural sector occur mainly from the use of inputs and the decomposition of the crops residues left at the field. Data from the study area revealed that the residues from crops after harvesting are used as source of energy and as feed for animals. Residues from groundnut and beans are used as animal feed while the residues from other crops are burnt as energy. The acreage allocated to produce bean and groundnut is less than 0.25 hectare. Then the quantity of residues from these crops activities is not important as only the residues from other crops activities are considered. It is assumed that those residues are removed from the field and used mainly as source of energy. Burning crops residues reduces the net CO2 emissions because the photosynthetic process of biomass growth removes about 95% of CO2 emitted when burning the biomass (Antle et McCarl, 2002). Only direct emissions (carbon dioxide (CO2), nitrous oxide (N2O), and methane (CH4)) involved by the use of inputs emissions are assessed.

The quantity of an input i used is proportional to the acreage. One hectare of the crop c needs $G(c,i)$ kilogramme of an input i. In addition, the emission is proportional to the kilogramme of input. One kilogramme of an input i implies δ_i kilogramme of emission, and then G_{ic} kilogramme implies $\delta_i G_{ic}$ amount of emission. Thus, when one hectare is produced, the total emissions for this crop are given by:

$$carb(c,i) = \sum_{i=1}^{I} \delta_i \, G(c,i) \qquad (11)$$

Finally, the total annual emission from all crops activities is:

$$\sum_{c,i,s} carb(c,i) * X(c,i,s,t) = Emis(t) \qquad (12)$$

In this scenario, the amount of emission allowed is limited. Limiting the emission does not mean reducing the inputs for intensive crops activities, rather it serves as a means to choose less pollutants among annual crops activities, with consideration of initial constraints. From the baseline scenario, some quantity of emission is reached. This amount is considered as the starting point of the limitation. By reducing a percentage of this amount, change occurs in the farming system. As the percentage of this limitation gets higher, so also the farmers are more bound by the emission constraint. Then, an additional constraint is added to initial constraints from the baseline scenario. The sum of the emission from the activities must not exceed the threshold (β) equal to a percentage of the reference amount from the baseline scenario.

$$\text{Emis(t)} \leq \beta \qquad (13)$$

The main idea is to assess the changes in crop activities and the effects those changes will induce on the incomes.

In the case of a scenario of taxation, farmers must pay a tax for each unit of emission, meaning that the emissions lead to additional costs in the utility function. In the model of Antle and Diagana (2003), the farmer receives or pays an amount per ton of C sequestered during each time period, and that amount are related to the quantity C its activities emit or store. This model is adapted to the study by integrating only the payment of taxes to the basic model. The objective function is given by:

$$Max\, revt = (R(a,t) - tax * Emis(t)) * pro(a) * ydisc(t) \qquad (14)$$

Where tax represents the taxes paid for each unit of emission and $Emis(t)$the total taxes amount paid for all crops activities. As the tax gets higher, the costlier it is to emit and it could be better for the farmer to replace the pollutant annual crops activities with those emitting less.

The third scenario analyses the effect of changing the cropping pattern on the farm by adopting the perennial crops cultivation. The same annual crops are considered while cashew trees and Jatropha are added as perennial crops. Both crops (Jatropha and cashew) are at the farm level. Jatropha grains are used to produce oils, fuel, soap and medicines; the cashew nuts are transformed to get final consumption production. This study assumes that the farmers just produce the grain and sell to other agents without any transformation. The production of perennial crops generates additional costs and revenues. Then the equation of total revenue earlier presented in equation (1) becomes:

$$\mathrm{R}(a,t)=\sum_{c} VE(c,a,t)*pxv(c,a)-\sum_{cc} pxa(c,a)*AC(c,a,t)-\sum_{c,i,s} X(c,i,s,t)*(csem(c,i)+int(c,i,s))+\sum_{cp,i.s.y} rendp(cp,i,s,y)*pxj(cp)*X(cp,i,s,y,t)-\sum_{cp,i,s,y}\big(Csep(cp,i)+intp(cp.i.s)\big)*X(cp,i,s,y,t-CRED(t)*Taux \qquad (15)$$

With:
cp the perennial crop activities
$rendp(cp,i,s,y)$ the yield of perennial crops
$pxj(cp)$ the selling price of perennial crops
$X(cp,i,s,y,t)$ the acreage of perennial crops
$Csep(cp,i)$ and $intp(cp.i.s)$ the seeds cost and inputs cost respectively, related to the perennial crop production.

If a farmer starts planting some perennial crops at year t, over the next number of years, it is possible to reduce or increase this acreage allocated to these crops. The reduction of acreage results in cutting trees while increasing it results to planting additional trees.

Cutting trees is denoted as $CXP(cp,i,s,y,t+1)$ and planting new trees as $NXP(cp,i,s,y,t+1)$. Cutting and planting involve labour and land use. Then the constraint related to these resources becomes:

$$\sum_{c.i.s} lab(c,i,s,p)*X(c,i,s.t)+\sum_{cp,i,s,y} labp(cp,p,y)*(XP(cp,i,s,y,t)+NXP(cp,i,s,t)+CXP(cp,i,s,t)\leq td(p)*pop \qquad (16)$$

$$\sum_{c,i} X(c,i,s,t)+\sum_{cp,i,y} XP(cp,i,s,y,t\leq land(s) \qquad (17)$$

In the case of the annual crops production associated to perennial crops, there are both carbon emissions and carbon sequestration. Each quantity of input involves a level of emission. Since perennial crops production also leads to emission, equation 12 is modified to take in consideration the emission due to perennial crops:

$$Emist=\sum_{c,i,s} carb(c,i)*X(c,i,s,t)+\sum_{cp,i,s} carp(cp,i)*XP(cp,i,s,y,t) \qquad (18)$$

Besides the emissions, the trees are able to sequestrate carbon. The IPCC report (2007) provides information on the GHG sequestration in ton carbon equivalent (CO2-eq). Knowing the acreage of trees, the annual sequestration can be assessed through equation 19 as follows:

$$Seq(t)=\sum_{cp.i.s.y} crbs(cp,i)*XP(cp,i,s,t) \qquad (19)$$

The total impact of producing annual and perennial crops on the global GHG balance noted $Cbal(t)$is:

$$Cbal(t) = Seq(t) - Emis(t) \quad (20)$$

$Cbal(t)$represents the CB. A positive difference means that the activities generate GHG sequestration while negative means that the activities generate GHG emission. The total impact of practicing agroforestry is gotten by adding the value of CB to the net present value. This computation can provide better satisfaction to farmer (if sequestration) or lesser in case of net emissions. It will be a win-win situation when the introduction of perennial crops improves farmers' utility, compared to the baseline scenario and a trade-off otherwise.

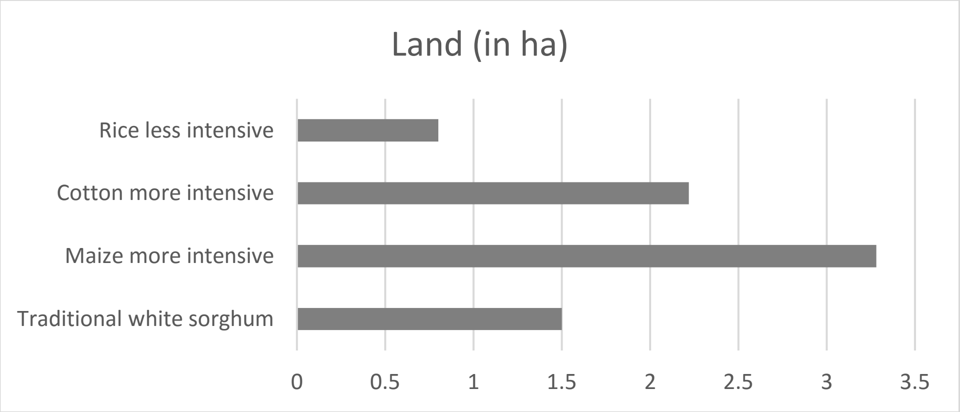
Simulation results should show a sufficient goodness of fit in the baseline scenario and resemble real-world development paths. The subjectivity of model validation involves the use of different ways and criteria. Modellers subjectively choose the tests they use to validate the model, the criteria to measure the validity tests, the criteria to measure the validity of their model. The model system can also be calibrated comparing the simulated values to empirical data. In the most ideal case, a valid model replicates each and every empirical observation. However, this is very difficult to achieve because of the information gap between the researcher and the decision maker. Thus, a more realisable approach will be to assess the extent to which certain model outputs, which are of policy and research interests, are depicted (Berger and Troost, 2012). In this study the baseline runs are compared with the respective observed values taken from our household survey data, using land allocation as an indicator variable. The model is validated iteratively, until the most important variables and constraints have been quantified.
Because of the lack of detailed field data in the study area, it is impossible to validate the emission mitigation scenario results (application of environmental regulations and the introduction of agroforestry) based on direct observation. Berger (2001) used an average observed value from the literature review. For this study, the validation is done for the baseline scenario only.

3. RESULTS AND DISCUSSION

3.1. The baseline scenario

By doing the crop production as usual, figure 1 presents all the crop activities that raise maximum satisfaction to small farmers.

Figure 1: Land allocation to different crops



Source: Author's estimations

The farmer produces 1.5 ha of traditional sorghum on thin upland soils, 3.28 ha of maize with high intensification on deep upland soils. Cotton is produced by 2.21 ha on deep and thin upland soils. Shallows are used to produce rice.

According to his preference, cereals such as millet, white sorghum, maize and rice compose the cereals food basket. The results suggest that the household's optimal consumption is white sorghum, maize and rice. The total annual and seasonal grain consumption is 1,600 kg that corresponds to the household's average amount of grain consumption. During the dry season, it is better to eat the production, while during normal or humid rainy seasons, the farmer purchases about 475 kg and 100 kg of rice respectively, in order to supplement the subsistence farming.

The NCI gotten by the household's crop activities is 528,500 CFA (dry season), 848,350 CFA (normal season) and 1,496,200 CFA (humid season). If the season is unknown, the annual NCI is 948,160 CFA. The planning horizon is 25 years. By computing the NPV for 25 years' simulation with a discount rate of 10%, an amount of 4,450,000 CFA is obtained during a dry season, 7,144,000 CFA in normal rainy season, 12,600,000 CFA in humid rainy season and 8,065,300 CFA if the season is unknown.

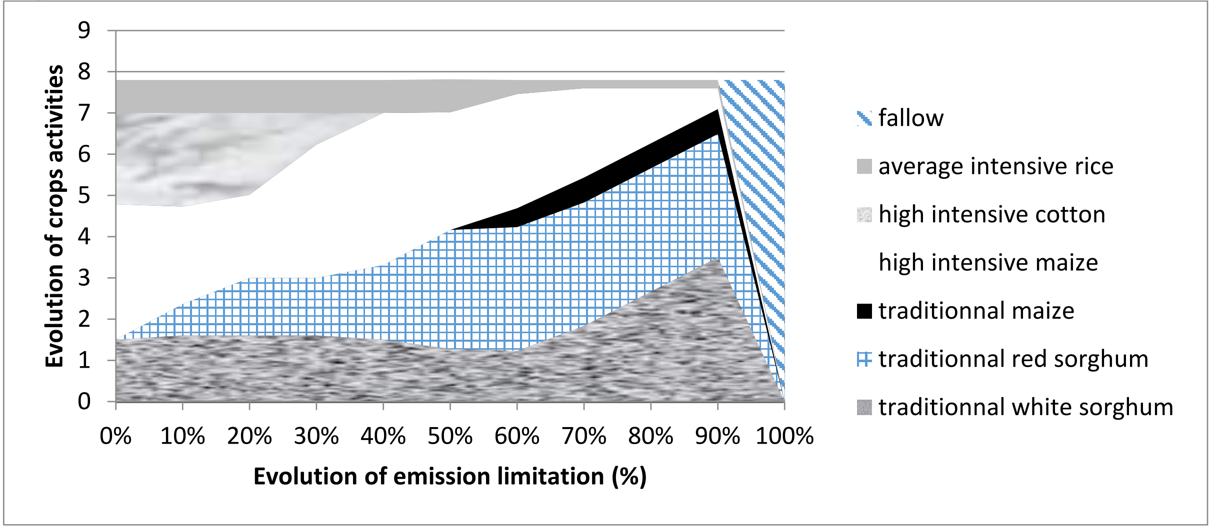
The NCI generated by the crop activities must allow the household to face some non-agricultural needs. In that case, one can compare the incomes from crop activities in order to highlight the poverty gap. The literature review shows that the daily minimal income per person in developing countries is $1.25 (USD), equivalent of 750 local currencies (FAO, 2007). The threshold considers the food needs and non-food needs. The comparison of the annual NCI generated by the activities and this threshold shows whether the household reaches the minimum level of income or not. It is found that the individual daily NCI is lower than the minimal amount whatever the rainy season. The daily and individual gap is 440 CFA during the dry season, 330 CFA during the normal season, 104 CFA in humid rainy season and 195 CFA when farmers are able to predict the rainy season.

3.2. Scenario of carbon emission limitation

This scenario consists in adding to the farming model, a constraint of GHGs emission. During his agricultural activities, a farmer is not allowed to exceed that fixed maximum quantity. Among their activities, some farmers produce more emissions than the others. For that, the best combination would be the ones who procure the highest income while respecting the emission constraint. In the baseline scenario, it is shown that the emission related to the activities is equal to 3.504 tons. By modifying this amount, change occurs in the farming system.

The following graph gives information on how land is allocated to different crops activities when changes are done on the GHG emissions.

Figure 2: Evolution of crop area with decreasing GHG emissions

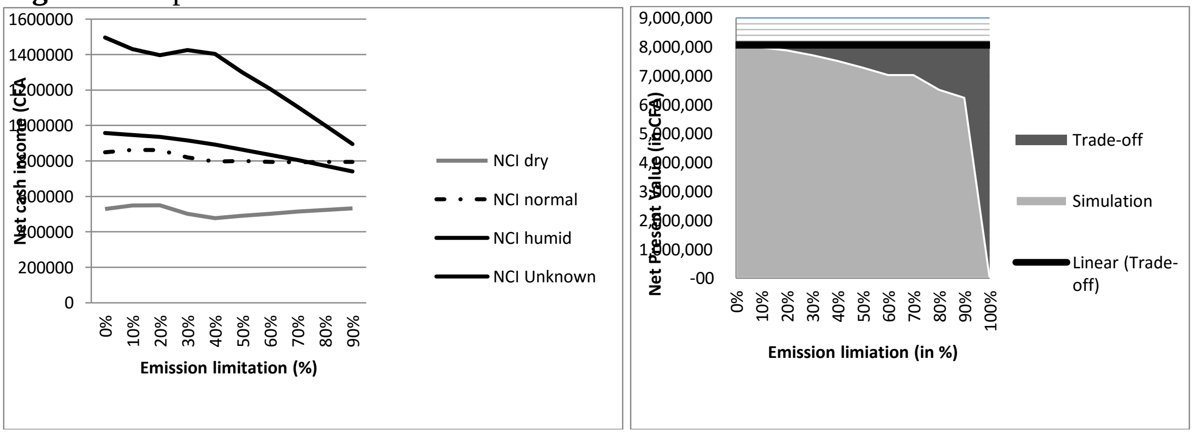


Source: Author's estimation

With no constraint on the emission limitation, the farmer produces 1.5 ha of white sorghum, cotton and maize with high intensification for 3.3 ha and 2.2 ha, while shallows are used to produce intensive rice for 0.8 ha. The farmer continues producing rice at this acreage until the point where he is obliged to reduce his emission to 50%. After 50% of the emission limitation, rice production decreases and reaches 00 ha when the farmer does not emit. The production of cotton starts decreasing and the farmer drops it when the limitation is fixed at 40%. The relinquishment of high intensive cotton favours the production of high intensive maize and traditional sorghum, which are less pollutant than cotton. But High intensive maize and rice are also relinquished progressively when the emission boundary reaches 50%. The farmer replaces these crops by low intensive rice, traditional maize and sorghum, whose share increases with an increase of the emission limitation.

Globally, if a farmer has not submitted to any emission constraint, he produces crops with high level of intensification, meaning crops with high levels of GHG emissions. When the GHG constraint is strengthened, he replaced the pollutant crops with the less pollutant. All crops activities emit at least a small quantity that is the reason why the farmer does not realise any crops activity when the constraint is fixed at 100%. In such cases, the cropland is laid to fallow. Changing land allocation leads to modification on the annual NCI from the crops activities, when the emission constraint becomes more and more strengthened.

Figure 3: Impact on NCI and NPV



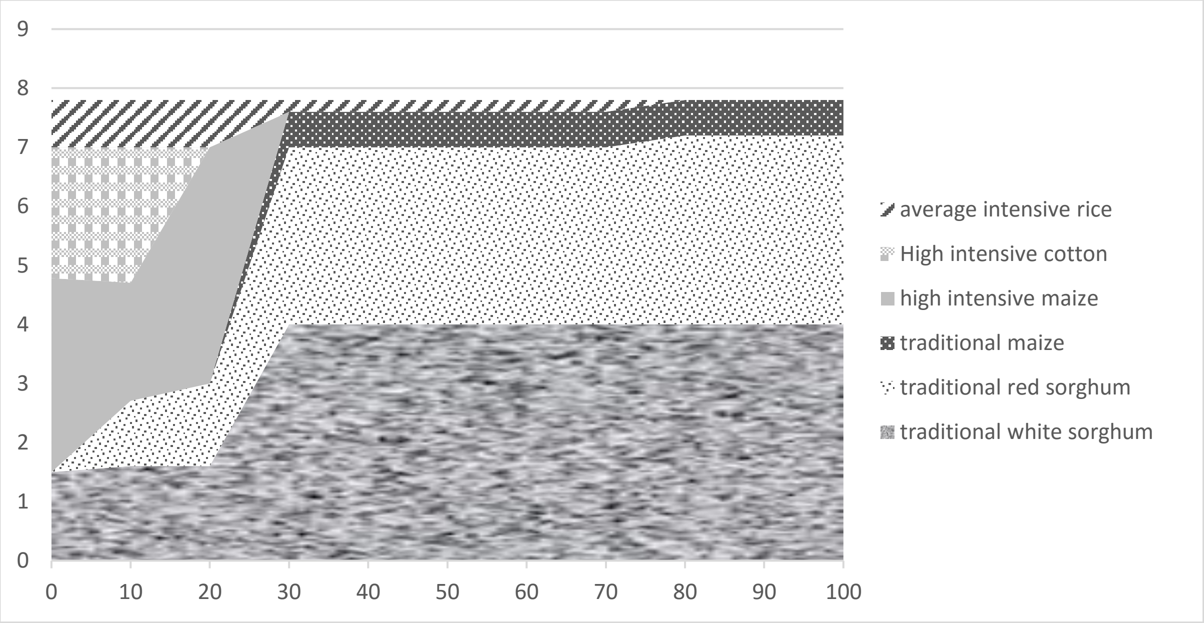
Source: Author's estimations

The evolution of the annual NCI varies according to the rainy season. In a dry rainy season, the amount is comprised between 400,000 CFA and 600,000 CFA. Until 20% of emission reduction, the NCI remains stable (530,000 CFA), starts decreasing at 25%, reaches the minimum amount (477,000 CFA) at 45% and restarts increasing. When the rainy season is normal, the reduction makes decreasing effects at 15% and remains stable after 25% of emission reduction. In humid seasons, the amount decreases until the emission reduction reaches 25%, makes a small increasing trend and falls back after 40%. The NCI generated introducing risk farmers' incomes vary between 947,000 CFA and 741,000 CFA. The variations on the amount of the seasonal NCI impact farmer's utility. The NPV generated in the baseline scenario is 8,065,300 CFA. In the simulated scenario, the NPV is decreasing when the limitation is strengthened, that involves a trade-off for small farmers.

3.3. Scenario of the strategy of taxation

As taxes increase, intensive crops are removed in favour of more traditional cropping systems, because these activities emit less. To reduce costs linked to taxes, farmers have to abandon intensive crops. The graph in figure 4 indicates the change in land allocation following the application of taxes.

Figure 4: Effects of taxes on land allocation



Source: Author's estimation

The traditional cropping system emits less carbon whereas the more input intensive system emits more. Without taxes, the farmers produce intensive crops such as cotton, maize, rice and a small quantity of traditional crops to satisfy food needs. With 10 CFA taxes per unit, the farmer reduces the production of cotton and increases the share of maize and sorghum. At 20 CFA of taxes, he stops producing cotton in favour of intensive maize, and traditional sorghum. When taxes reach 30 CFA, intensive maize is abandoned and intensive rice is reduced from 0.8 ha to 0.2 ha, in favour of traditional maize (0.6 ha). From 30 CFA to 70 CFA, the crop activities remain less intensive rice (0.2 ha), traditional maize (0.6 ha), white sorghum (4 ha) and red sorghum (3 ha). With more than 70 CFA, only traditional crops are planted. It concerns white sorghum (4 ha), red sorghum (3.2 ha) and traditional maize (0.6 ha).

The changing in crops activities impacts the income generation.

Figure 6: Impact on incomes

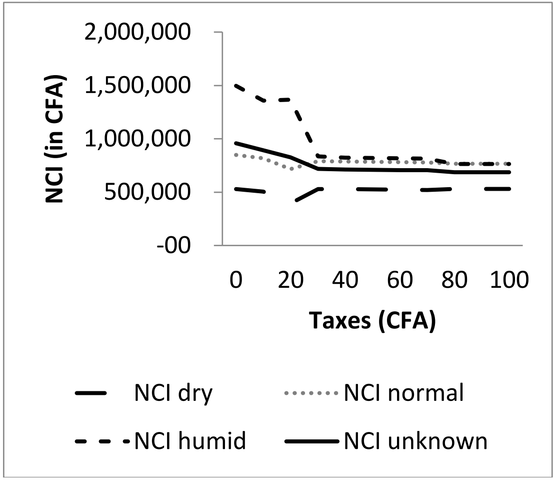
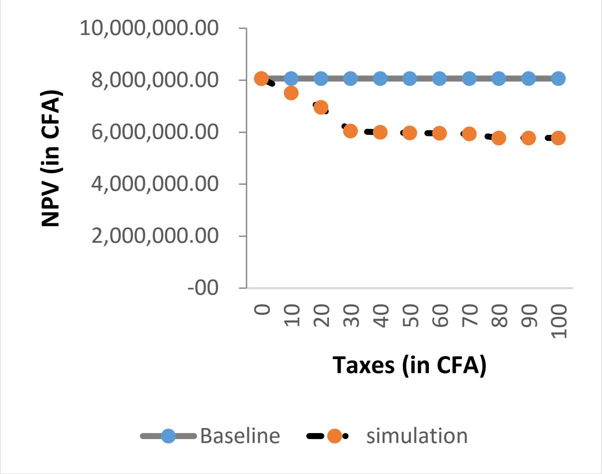


Figure 7: Trade-off curve



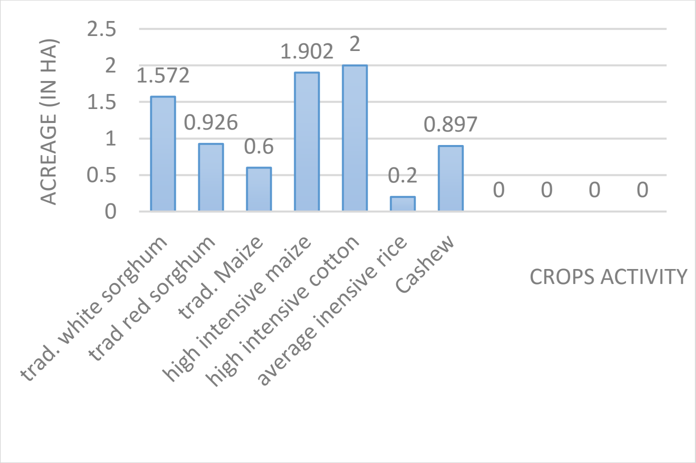
Source: Author's estimation

The seasonal NCI are decreasing. The decreasing amplitude is important for taxes between 0 CFA to 30 CFA. With more than 30 CFA of taxes, the amplitude is inconsiderable, making the NCI stable for all rainy seasons except during the dry rainy season. During a dry rainy season, the incomes decrease for an amount of tax between 0 CFA and 15 CFA, and restart increasing. This means that the application of taxes higher than 15 CFA is beneficial for farmers during a dry rainy season, but a trade-off in normal, humid or risky rainy seasons. The in the simulation decreases to 30 CFA of taxes, and remains relatively stable up to 70 CFA. Taxes higher than 30 CFA and less than 70 CFA do not effect incomes. At 70 CFA, farmers abandon intensive crop activities and adopt only traditional crop activities. The goal of applying taxes is to reduce emission as much as possible and maximise the NPV. An efficient amount of tax 70 CFA in which farmers adopt these traditional crops activities with a weak lowering of the NPV. The global impact of taxes is negative. The NPV of incomes is higher in the baseline scenario than the one from the taxes simulation scenario. The application of taxes to annual crop activities is not a win-win situation for small farmers.

3.4. Perennial crops as mitigation strategy

The plantation of perennial crops induces some larger modifications in the systems.

Figure 8: The land allocation among crop activities

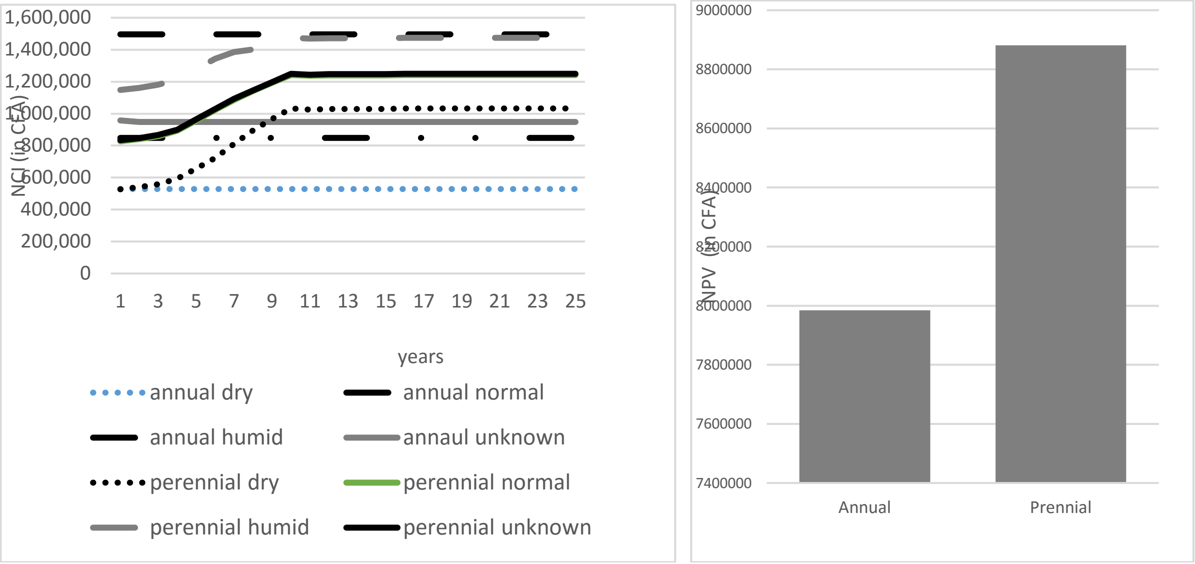


Source: Author's estimation

The farmer produces some traditional crops, sorghum and maize. The deep upland soils are used for intensive maize and intensive cotton production. Intensive rice is produced on the deep and thin upland soils while he produces sorghum on the thin upland soils. 0.89 hectares are allocated to plant cashew-trees.

A comparison allows assessing if the introduction of perennial crops in the farming system is a trade-off or a win-win situation for the small farmers

Figure: Impact on incomes



Source: Author's estimations

The first four years in dry and normal rainy seasons, the NCI from agroforestry and annual crop activities seems to be the same, but in risky seasons, the annual crops generate more NCI than the agroforestry. After four years, the NCI from agroforestry exceeds the annual crop production but the opposite occurs after a humid rainy season. During a humid rainy season, the annual crop activities provide more income to farmers than the agroforestry, while the other rainy seasons globally provide high incomes in agroforestry than annual crops.

The farmer's NCI is globally increasing and reaches a maximal level at the thirteenth. The NPV generate is 6,620,300 F, 8,921,000 F and 11,203,000 F in dry, humid and normal rainy season respectively and 8,792,700 F is season is unknown. The household's individual and daily NCI are not enough to cover the expenses especially during the dry season where the household is exposed to a higher risk. Crop yields are low and the incomes from the activities are reduced. The daily income is 360 CFA, 430 CFA, 512 CFA and 435 CFA during dry, normal, humid and unknown rainy seasons respectively. It means that people are poor when considering only their agricultural activities. The NPV obtained in agroforestry (8,881,500 CFA) is higher than the one with annual crops (7,984,700 CFA), then agroforestry becomes an opportunity for small farmers.

The perennial crops bring change on the carbon balance. The results show that the total annual emissions are decreasing while the sequestration and the carbon balance are increasing. From the first six years, the emissions exceed the sequestrations, which make the carbon balance negative. After six years, the carbon balance starts being positive and stay at a yearly amount of 7.618 tCO2e. The importance of agroforestry is the role it plays in carbon sequestration. Analysing only the financial income of this activity without taking into account the environmental aspect distorts the assessment of the agroforestry impact. Giving the volatility of the carbon price, a sensitivity analysis of the price indicates the marginal effect of such price variation.

Table 1: Sensitivity of carbon price

Carbon Price					
Variation	In %	Env. NPV a1	Env. NPV a2	Env. NPV a3	Env. NPV un.

3,755	0	6,678,089	8,878,872	11,260,927	8,939,296
3,380	10%	6,672,311	8,873,094	11,255,149	8,933,518
3,004	20%	6,666,533	8,867,316	11,249,371	8,927,740
2,629	30%	6,660,755	8,861,538	11,243,593	8,921,962
2,253	40%	6,654,977	8,855,760	11,237,815	8,916,184
1,878	50%	6,649,199	8,849,982	11,232,037	8,910,406
1,502	60%	6,643,421	8,844,204	11,226,259	8,904,628
1,127	70%	6,637,643	8,838,426	11,220,481	8,898,850
751	80%	6,631,865	8,832,648	11,214,703	8,893,072
376	90%	6,626,087	8,826,870	11,208,925	8,887,294

Source: Author’s computation

Considering the value of the CB, the NCI is higher than those from annual crops system for all type of rainy season. Without the CB, the humid rainy season was not better when perennial crops are added to the cropping system. To sum up, when perennial crops are introduced within the annual crop system, the generated incomes are higher except after a humid rainy season. By computing the value of the CB, all rainy seasons become more attractive in terms of net cash income rather than the annual. The conclusion is that there is win-win situation between annual crops production and agroforestry, because farmers obtain high level of income by protecting the environment through the reduction of the GHG emissions. The overall trend of the NPV is decreasing subjected to price variability. Besides this decreasing, it still remains higher than the NPV from the baseline scenario, meaning that this activity improves the small farmers’ income.

3.5. Model validation

The model is validated through the crop allocation, by comparing the simulated value to the observed value in the study area, as well as to the general average value observed at the country level.

Table 6 : The validation of the model

	Average observed value (ha)	Fieldwork value (ha)	Simulated value (ha)
Traditional millet	0.5	0.25	0
Traditional sorghum	1.5	2	1.5
Maize less intensive	0.5	0	0
Maize more intensive	2	3	3.281
Cotton more intensive	1.5	2.5	2.219
Rice less intensive	0.25	0.5	0.8
Traditional groundnut	0.75	0.25	0
Traditional bean	0.25	0.25	0

Source: Estimation using field data

Primary data collected are averaged in order to compare it to the baseline results and other secondary data. The comparison of simulated results to data, both national and regional level, in terms of land size allocated to crops shows that the difference is not important. Simulated values are close to information collected and also the secondary data at the national scale. The model is also tested for sensitivity by changing some parameters mainly on the binding variables such as labour force, including other parameters like prices and credit. The variation of these parameters does not affect the crops activities.

The conclusion is that the simulated results reflect the reality as the model is validated by modelling farmers' decisions to generate results.

4. CONCLUSION

As mitigation strategies lead to additional costs but can also generates revenues, the main question is how these emission mitigation strategies from the agricultural sector could impact small households' welfare.

Three simulated scenarios are compared to the baseline scenario. In the baseline scenario the farmer produces traditional sorghum and intensified crops such as maize, cotton rice, generating a NPV of 8,065,300 CFA, with an annual emission of 3.504 tCO2eq. When the emission constraint is strengthened, pollutant crops are replaced by the less pollutant ones. Both scenarios, emission limitation and taxation involve a trade-off situation for small farmers. The farmer combines traditional and intensive crops when introducing perennial crops to the farming system. In that situation, annual incomes and the NVP are improved.

Both emission limitation scenario and taxation are not suitable for small households, but favour less pollutant crops. These instruments can be an additional policy instruments to achieve the emission reduction promoted by the government, but the goal of poverty reduction and gain from green economy are not achieved. Additional incentives might be required. Current traditional land tenure prevents farmers from investing in this agroforestry. Policymakers must enhance forest governance and land tenure by seeking ways to enforce the country's legal framework. Small households do not have financial resources to buy tree seeds and often use the channel of natural tree regeneration (Kalame et al, 2009). Support is needed at this level to help these actors participate in climate mitigation. The success of such programmes is hinged on creating awareness in rural communities through the appropriate information channels.

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