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Greenhouse Gas Emission Reduction in Agriculture: Trade-off or Win–Win Situation for Small Farmers in the Sudanian Area of Burkina Faso?

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***Abstract*:** Agriculture can contribute to carbon emission mitigation by storing more carbon in the soil through greener cropping systems. This study aims to assess the impact of mitigation strategies on small farmers' welfare. It uses a case study of small farmers in Burkina Faso, relying on an analyse programming model, in which farmers maximize their utility subject to a set of such constraints. The results show that integrating an emission reduction will negatively impact farmers' utility, while integrating perennial crops increases their utility and the net carbon balance. Policymakers should therefore encourage farmers to adopt perennial crops in their cropping systems. To reach the emission reduction targets in the annual cropping system, incentives are needed to compensate for their foregone income.

1. Introduction

Agriculture supports the livelihoods of 90 per cent of Africa's population and provides employment for about 60 per cent of the active population (Kanu *et al.*, 2014). Climate change constitutes a serious global environmental issue and Africa is especially vulnerable (Vincent and Cull, 2014). Agriculture and food security are affected. Farmers' production, consumption and resource allocation decisions are influenced. About 57.43 per cent of the farm households are vulnerable to climate shocks, the major ones being strong winds, rainfall, heat waves, floods and droughts (Lokonon, 2017).

Many factors such as demographic pressure, economic growth and the technology for food production and consumption, affect climate change. Rural poverty, population growth and the technology for food production and consumption influence land degradation and forest coverage, which in turn increases the emission of greenhouse gas (Lufumpa, 2005; Stein, 1992). Economic growth has a positive effect on CO_2 emissions (Ben *et al.*, 2015). Debates over climate mitigation strategies point to developing countries' agriculture as an important source to reduce levels of GHGs emissions. Agriculture plays the role of both a sink and a source of carbon emission (Li and Feng, 2002; McCarl and Schneider, 2000). The sector is responsible for 14 per cent of overall GHG emissions, through loss of soil organic methane (50 per cent), nitrous oxide (70 per cent) and CO_2 (20 per cent) (Pretty *et al.*, 2002). These emissions depend on the type of intensification and the type of soils. This relationship displays a more decreasing than a linear pattern (Van Groenigena *et al.*, 2010). For similar soil types, nitrification is the dominant process that produces N_2O, and ammonium-based fertilizers contribute more to N_2O emission. A field that is more waterlogged might produce more N_2O from denitrification and NO_3 from fertilizers should be avoided (Hauser, 2003). The N_2O emission factors increased with increasing N application. Each kilogramme of N-fertilizer used in the cropping system produces a global emission of 30 to 50 g of N_2O (Crutzen *et al.*, 2008).

Around a quarter of agricultural carbon sequestration can be achieved by adopting greener cropping practices (Paustian *et al.*, 2016). 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.

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Other authors (West and Post, 2002; Rochette and Janzen, 2005; Beach *et al.*, 2008) proposed the use of rotations with vegetable 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 fertilizers and manure. The conversion of conventional agriculture's use of fertilizer into organic farming can reduce the emissions. The organic fertilizers gave the best soil organic carbon (SOC) content than using chemical fertilizers (Bostick *et al.*, 2007).

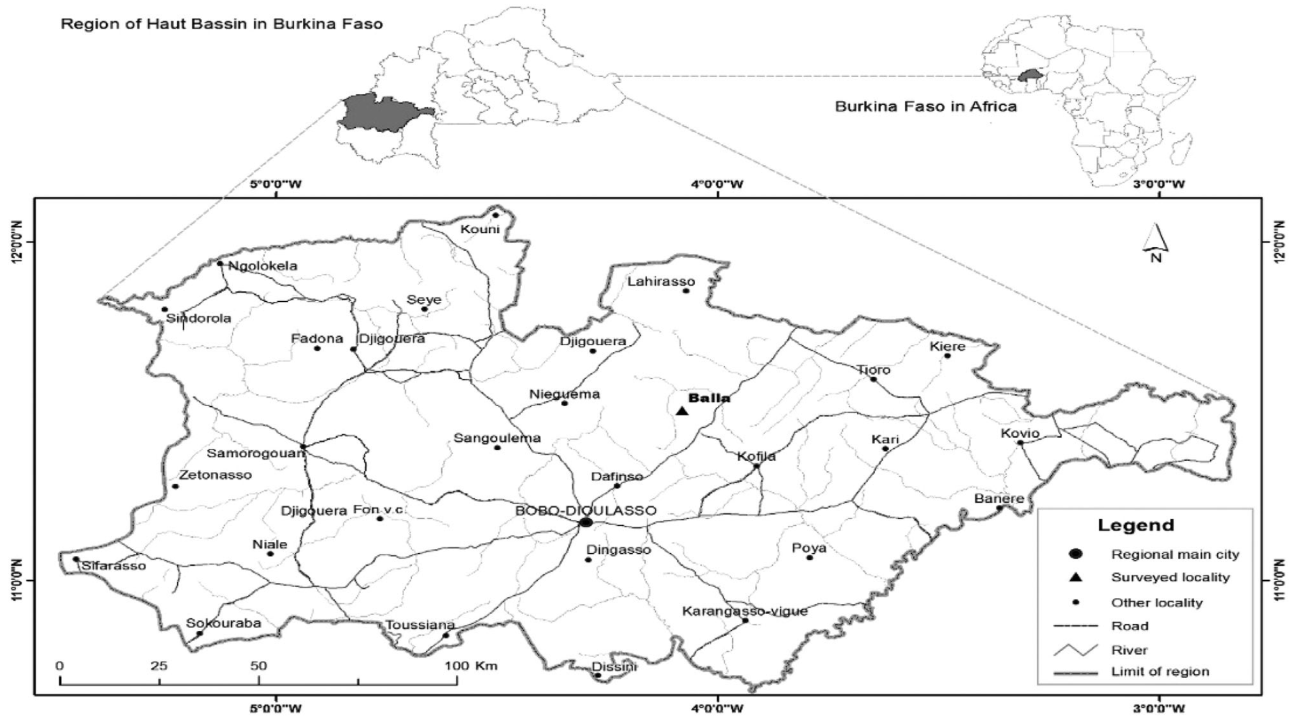
Through the adoption of sustainable land management practices, high crop yields could be maintained and input costs reduced (Diao and Sarpong, 2011; Chirinda *et al.*, 2010). An increase of the price of fertilizers by 10 per cent decreases the use of those fertilizers leading to a reduction of GHG emission by 0.15 per cent (Dumortier *et al.*, 2011). Potential agricultural strategies are manifold and have been subject to economic analysis. Significant decreases in N_2O emissions may be achieved through a decrease in use of N-fertilizer 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 might lose (Tschakert, 2004a,b). The emission of GHGs per hectare is higher in fertilizer intensive-farming than in organic farming. Chirinda *et al.* (2010) suggest that within organic cropping systems, both microbial activity and crop yields could be enhanced through inclusion of catch crops. 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 maximize economic viability with environmental conservation through appropriate levels of Fertilizer-N input (Crutzen *et al.*, 2008). Converting agriculture to agroforestry is a strategy that helps smallholder farmers adapt to climate change, protects the environment and generates economic and social benefits (MECV, 2003; De Baets *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 mineralization, 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).

Trees store carbon and their destruction releases carbon into the atmosphere contributing to GHGs. 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 *et al.*, 1993). By converting the crop area into forest, the total emission decreases (Dumortier *et al.*, 2011). When there are low incentives for carbon emission savings, agricultural soil carbon sequestration is the most cost-effective strategy (Lal, 2011). The producers convert land to trees if they are compensated for the agricultural rents of the land.

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 and Heaton, 1983). 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 and 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 (Simpson and Bradford, 1996). Porter and van der Linde (1995) proved that there are opportunities to reduce pollution and firms have to utilize 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 as well as private profit. Baumol and Oates (1971) distinguished the taxes and charges based on a price-standard approach, the standard/emissions limits and the certificates as environmental instruments.

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. Countries have presented their approaches to reduce the vulnerability and the GHGs emission through their intended nationally determined contributions achieving a net balance between sources and sinks of GHGs (AfDB and CIF, 2015). In Burkina Faso, statistics indicate that the carbon stock has decreased from 1990 to 2010 (Samari, 2011). Development plans have been implemented 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

Figure 1: Study area



Source: Authors.

application of taxes, the emission limitation and the introduction of perennial crops in an 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 a small-farms model.

2. Method

The village of *Bala* located in the Houet province, the *Haut-Bassins* region of Burkina Faso, is selected (Figure 1). This choice is motivated by the representativeness of the village in terms of socioeconomic and agricultural setting and biophysical characteristics. The local farming system is based on the homestead with acreage of between 0.25 and 4.5 ha and bush farming stretched on 1 ha to 5 ha. The application of fertilizers, manure, compost and crop residue is frequent to improve crop yields. The system is under rainfed conditions, extensively associated with a weak use of animal traction and mechanization and large use of traditional tools, due to inadequate financial support and low level of farmers' incomes.

The village covers an area of about 10,000 ha. 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 fertilizers on cotton, rice and sometimes on maize. 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 per cent of total area and woody savannah representing 22.68 per cent. The annual average deforestation rate ranges from 0.2 per cent to 1.5 per cent. This is caused by agricultural activities (22.33 per cent of the forest area).

Primary data have been collected from households to get information on their individual characteristics concerning annual and perennial crops activity. A comprehensive list of farmers was established in the village totalling 106 farmers, based on their crops activities. 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 are only for year 2014. The secondary data are about 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 has been used. 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 in 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 fertilizers are not applied to crops production; the average intensification where a small quantity of fertilizers is used, and the high intensification in which farmers apply an important quantity of fertilizers. 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 outcome 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 $rendt(c,i,a,s)$ kilogrammes of crops. Costs include the cost of inputs such as chemical fertilizers, 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):

$$\begin{aligned}\mathrm{R}(a,t) = {} & \textstyle\sum_c VE(c,a,t) * pxv(c,a) - \sum_{cc} pxa(c,a) * AC(c,a,t) - \sum_{c,i,s} X(c,i,s,t) * \\ & (csem(c,i) + int(c,i,s)) - CRED(t) * Taux \end{aligned} \tag{1}$$

with: $VE(c,a,t)$ the amount of crops sold in the market; $pxv(c,a)$ the seasonal selling price of crops; $X(c,i,s,t)$ 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; $CRED(t)$ the interest rate applicable to loan on this activity $\sum_{cc} pxa(c,a) * AC(c,a,t) + \sum_{c,i,s} X(c,i,s,t) * (csem(c,i) + int(c,i,s)) + CRED * taux$ 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 $prb(a)$.

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

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:

$$\text{The non-negativity constraints}: \; X, CRED, AC, VE \geq 0 \tag{3}$$

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.

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

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.

$$CRED(t)\ \leq ccot\ *X(cot,i,s,t) \tag{5}$$

with $X(cot)$ the acreage of cotton.

The total family labour is obtained by multiplying 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 ($p2$):

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

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

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

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, 2008) and the average household size (pop) from the primary data 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 $(AC(C))$and the bought quantity $(AC(C))$ must be greater than the minimum quantity $(a\ lim*pop)$.

$$\sum\nolimits_{c}(AU(c,a,t)+AC(c,a,t))\geq alim*pop \tag{8}$$

In the scenario of an emission limitation adoption, the farmer is not allowed to exceed a fixed maximum quantity. The emissions from the 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 a source of energy and as feed for animals. Residues from groundnut and beans are used for animal food while the residues from other crops are used as an energy source by burning them. The acreage allocated to produce bean and groundnut is less than 0.25 hectare. Therefore, the quantity of residues from these crops is not important and only the residues from other crops are considered. It is assumed that those residues are removed from the field and used mainly as a source of energy. Burning crops residues reduces the net CO_2 emissions because the photosynthetic process of biomass growth removes about 95 per cent of CO_2 emitted when burning the biomass (Antle and McCarl, 2002). Only direct emissions (carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4)) involved by the use of inputs emissions are assessed.

The quantity of an input i used is proportional to the acreage. One hectare of 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:

$$carb(c,i)=\sum\nolimits_{i=1}^{I}\delta_i G(c,i) \tag{9}$$

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

$$\sum\nolimits_{c,i,s}carb(c,i)*X(c,i,s,t)=Emis(t) \tag{10}$$

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. The higher the percentage of this limitation, the tighter the emission constraints to farmers. Then, an additional constraint is added to initial constraints from the baseline scenario. That is, the sum of the emission from the activities must not exceed the threshold (β) which is equal to a percentage of the reference amount from the baseline scenario.

$$Emis(t) \leq \beta \tag{11}$$

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

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 is related to the quantity C that 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:

$$Max\ revt = (\mathrm{R}(a,t) - tax * Emis(t)) * pro(a) * ydisc(t) \tag{12}$$

where *tax* represents the taxes paid for each unit of emission and $Emis(t)$ the total taxes amount paid for all crops activities. The higher the tax level, the costlier is emission and it could be better for the farmer to replace the polluting crops activities with those with less emission.

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 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:

$$\begin{aligned}\mathrm{R}(a,t) = {} & \textstyle\sum_c VE(c,a,t) * pxv(c,a) - \sum_{cc} pxa(c,a) * AC(c,a,t) - \sum_{c,i,s} X(c,i,s,t) * (csem(c,i) + int(c,i,s)) \\ & + \sum_{cp,i.s.y} rendp(cp,i,s,y) * pxj(cp) * X(cp,i,s,y,t) - \sum_{cp,i,s,y} (Csep(cp,i) \\ & + intp(cp,i,s)) * X(cp,i,s,y,t - CRED(t) * Taux\end{aligned} \tag{13}$$

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 the acreage allocated to these crops. The reduction in acreage results in cutting trees while increasing it results in 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:

$$\begin{aligned}& \textstyle\sum_{c.i.s} lab(c,i,s,p) * X(c,i,s.t) + \sum_{cp,i,s,y} labp(cp,p,y) * (XP(cp,i,s,y,t) + NXP(cp,i,s,t) + \\ & CXP(cp,i,s,t) \leq td(p) * pop\end{aligned} \tag{14}$$

$$\sum_{c,i} X(c,i,s,t) + \sum_{cp,i,y} XP(cp,i,s,y,t \leq land(s) \tag{15}$$

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 10 is modified to take into consideration the emission due to perennial crops:

$$Emis(t) = \sum\nolimits_{c,i,s} carb(c,i)*X(c,i,s,t) + \sum\nolimits_{cp,i,s} carp(cp,i)*XP(cp,i,s,y,t) \tag{16}$$

The IPCC report (2007) provides information on the GHG sequestration in ton carbon equivalent (tCO2eq). Knowing the acreage of trees, the annual sequestration can be assessed through Equation 17 as follows:

$$Seq(t) = \sum\nolimits_{cp.i.s.y} crbs(cp,i) * XP(cp,i,s,t) \tag{17}$$

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

$$Cbal(t) = Seq(t) - Emis(t) \tag{18}$$

$Cbal(t)$ 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 practising agroforestry is gotten by adding the value of CB to the net present value. This computation can provide better satisfaction to farmers (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. In the most ideal case, a valid model replicates each and every actual observation. However, this is very difficult to achieve because of the informational gap between the researcher and the decision maker. Thus, a more realistic 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 observations 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 and Troost (2012) used an average observed value from the literature review. For this study, the validation is done for the baseline scenario only.

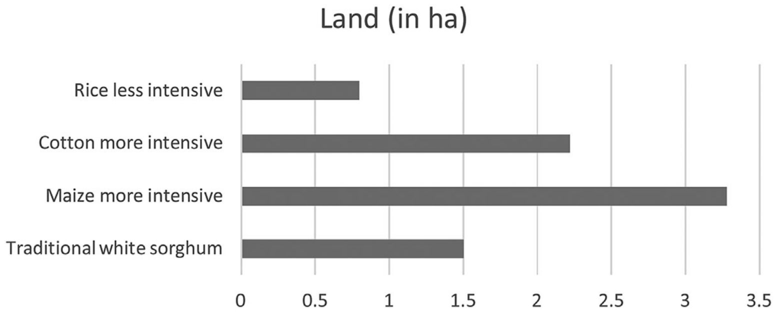
3. Results and Discussion

3.1 The Baseline Scenario

By doing the crop production as usual, the crop activities that raise maximum satisfaction to small farmers are shown in Figure 2.

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 in 2.21 ha on deep and thin upland soils. Shallows are used to produce rice.

Figure 2: Land allocation to different crops



Source: Authors' estimations.

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. 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 net cash income (NCI) obtained 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. By computing the NPV for 25 years' simulation, 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 US$1.25, equivalent of 750 local currencies (FAO, 2014). 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.

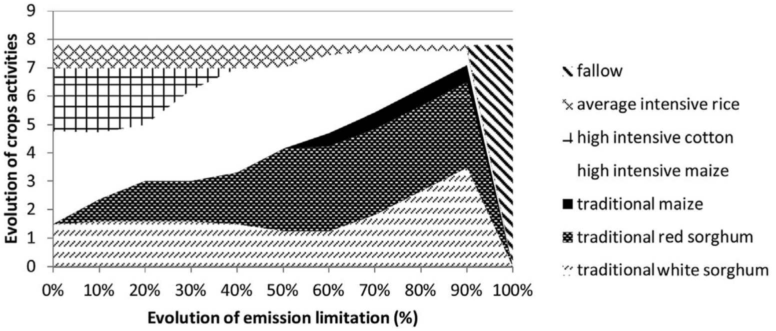
3.2 Scenario of Carbon Emission Limitation

This scenario consists of 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. According to 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 (Figure 3).

Without 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 per cent. After 50 per cent 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 per cent. 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 per cent. The farmer replaces these crops by low intensive rice, traditional maize and sorghum, whose share increases with an increase of the emission limitation.

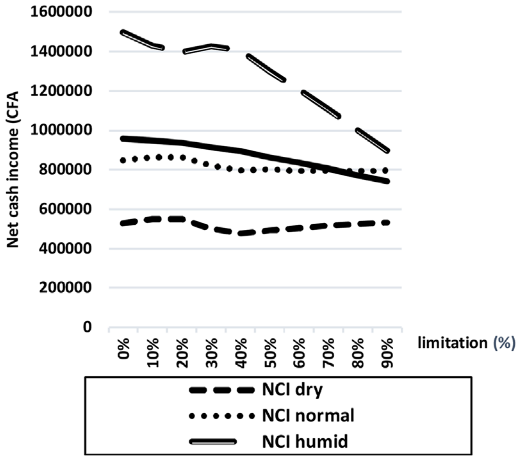
Globally, without any emission constraint, he produces crops with a high level of intensification, meaning crops with high levels of GHG emissions. When the GHG constraint is implemented or strengthened, he then is likely to replace the pollutant

Figure 3: Evolution of crop area with decreasing GHG emissions



Source: Authors' estimation.

Figure 4: Impact on NCI



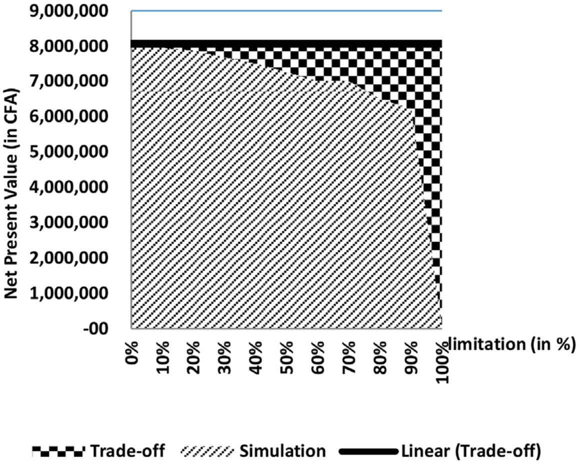
Source: Authors' estimations.

crops with the less pollutant. All crops activities emit at least a small quantity, that is the reason why the farmer does not realize any crops activity when the constraint is fixed at 100 per cent. In such cases, the cropland is laid to fallow.

Changing land allocation leads to change in the annual NCI from the crops activities, when the emission constraint becomes more and more strengthened (Figures 4 and 5).

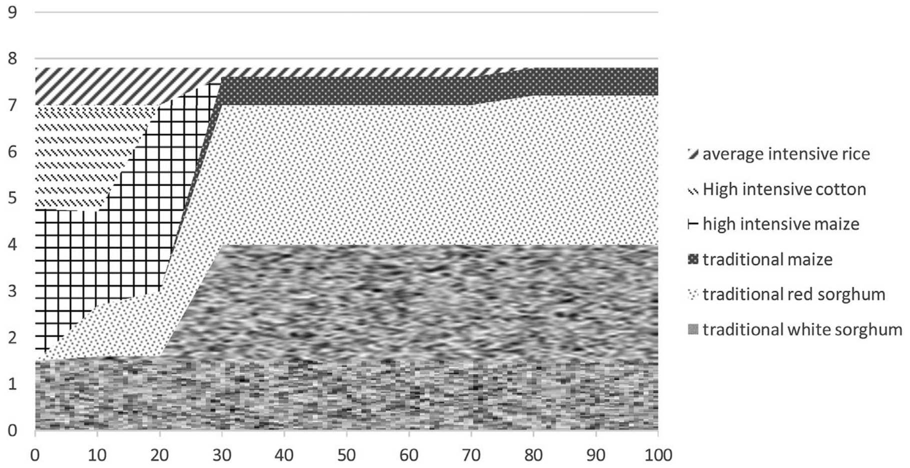
The evolution of the annual NCI varies according to the rainy season. In a dry rainy season, the amount is comprised between 400,000 CFA and 600,000 CFA. Until 20 per cent of emission reduction, the NCI remains stable (530,000 CFA), starts decreasing at 25 per cent, reaches the minimum amount (477,000 CFA) at 45 per cent and starts increasing again. When the rainy season is normal, the reduction makes decreasing effects at 15 per cent and remains stable after 25 per cent of emission reduction. In humid seasons, the amount decreases until the emission reduction reaches 25 per cent, makes a small increasing trend and falls back after 40 per cent. The NCI generated introducing risk on 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

Figure 5: Impact on NPV



Source: Authors' estimations.

Figure 6: Effects of taxes on land allocation



Source: Authors' estimation.

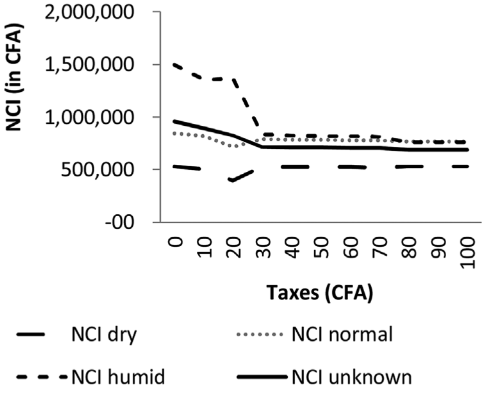
generated in the baseline scenario is 8,065,300 CFA. The NPV is decreasing when the limitation is strengthened, that involves a trade-off for small farmers.

3.3 Scenario of the Strategy of Taxation

As taxes increase, intensive crops are removed in favour of more traditional crops. To reduce costs linked to taxes, farmers have to abandon intensive cropping (Figure 6).

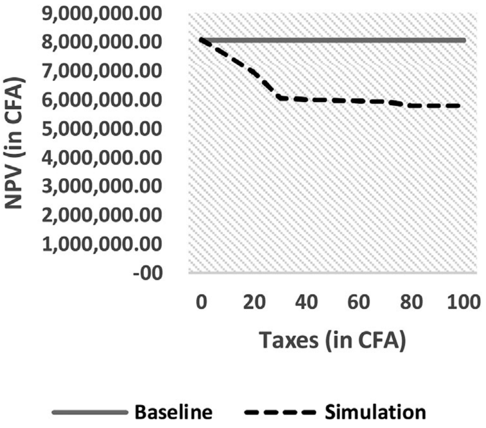
Without taxes, the farmers produce intensive crops such as cotton, maize, rice and a small quantity of traditional crops to satisfy food needs. With 10 CFA taxes per unit, the farmer reduces the production of cotton and increases the share of maize and sorghum. At 20 CFA of taxes, cotton production is stopped 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, that is: white sorghum (4 ha), red sorghum (3.2 ha) and traditional maize (0.6 ha). Variations in crops activities impacts the income generation (Figures 7 and 8).

Figure 7: Impact on incomes



Source: Authors' estimations.

Figure 8: Trade-off curve



Source: Authors' estimations.

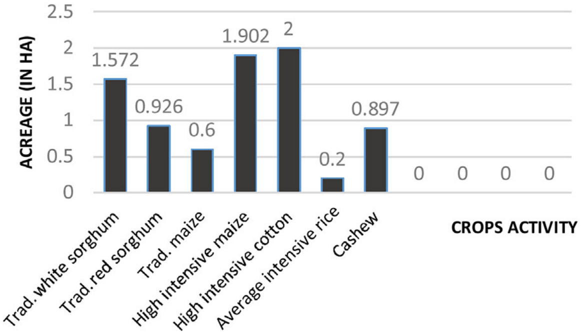
The seasonal NCI are decreasing. Decreasing magnitude is important for levels of taxes ranging between 0 CFA to 30 CFA. With more than 30 CFA of taxes, the magnitude is weaker, making the NCI stable for all rainy seasons except during the dry rainy season. During a dry rainy season, incomes decrease for a tax range of 0–15 CFA, and then start increasing again. This implies that the application of taxes higher than 15 CFA is beneficial for farmers during a dry rainy season, and a trade-off in normal, humid or risky rainy seasons. The NCI 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 affect 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 maximize the NPV. An efficient level of tax, amounting to 70 CFA in which farmers adopt these traditional crops activities with a mild reduction in NPV, is found. The global impact of taxes is negative. NPV of income 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 9).

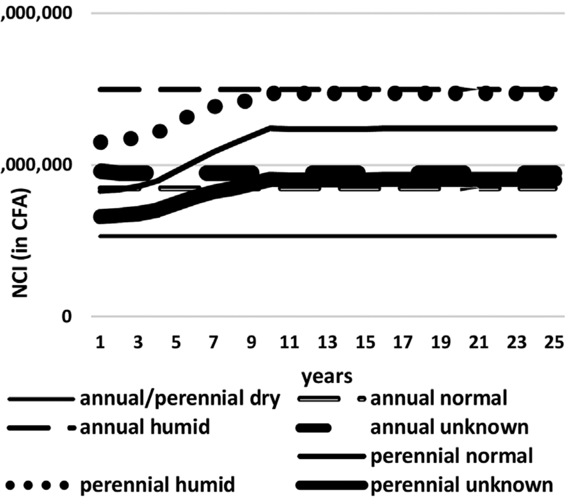
The farmer produces some traditional crops, sorghum and maize. The deep upland soils are used for intensive maize and intensive cotton production. Intensive rice is produced on the deep and thin upland soils while he produces sorghum on the thin upland soils; 0.89 hectares are allocated to plant cashew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

Figure 9: The land allocation among crop activities



Source: Authors' estimations.

Figure 10: Annual NCI (CFA)gr10



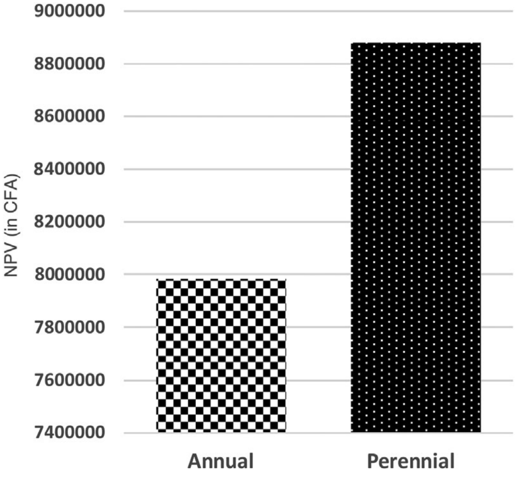
Source: Authors' estimations.

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 (Figures 10 and 11).

In the first four years in dry and normal rainy seasons, the NCI from agroforestry and annual crop activities seem to be the same, but in risky seasons, annual crops generate more NCI than the agroforestry. After four years, 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.

Farmer's NCI is increasing overall and reaches a maximal level at the thirteenth year. The NPV generated is 6,620,300 CFA, 8,921,000 CFA and 11,203,000 CFA in dry, humid and normal rainy season, respectively and 8,792,700 CFA in alternative ones. Household's individual and daily NCI are not enough to cover the expenses especially during the dry season

Figure 11: The NPV (CFA)



Source: Authors' estimations.

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 changes in the carbon balance. The results show that total annual emissions are decreasing while sequestration and carbon balance are improving. From the first six years, emissions exceed sequestrations, which makes the carbon balance negative. After six years, the carbon balance starts being positive and stays at a yearly amount of 7.618 tons carbon equivalent (tCO2eq). 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).

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 summarize, 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 baseline scenario. The conclusion is that there is win-win situation between annual crops production and agroforestry, because farmers obtain a 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. Beside the decrease, 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 fitted values and observed values in the study area, as well as to the general average values observed at the country level. Primary data collected are averaged in order to compare them to baseline results and other secondary data. The comparison of fitted and observed, both at national and regional levels, 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.

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: Authors' computation.

4. Conclusion

As mitigation strategies lead to additional costs but can also generates revenues. In the baseline scenario, the farmer produces intensified crop activities with a high level of emissions. When an emission constraint is set and implemented, polluting crops are replaced by the less polluting ones. Both scenarios of 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. This scenario improves annual incomes and the NVP and carbon storage.

Neither scenario of emission limitation and taxation is suitable for small households, but encourages them to shift to less polluting crops. These instruments can be additional policy ones 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 seeds and often use the channel of natural tree regeneration. Support is needed at this level to help them 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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