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Structural Adjustment Program and Soil Erosion: A Bio-Economic Modeling Approach for Northern Benin

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ABSTRACT

Macroeconomic policies may induce changes in the functioning of farming systems. The impact can be particularly important on soil degradation because inappropriate crop management is one of its major determinants. Furthermore, soil degradation is one of the most important problems of African agriculture and erosion is the main cause of this phenomenon. However, there is a frustrating lack of empirical evidence showing what effects, if any, policies have on the acreage, management of various crops, soil erosion, and crop productivity.

This paper uses a bio-economic model to assess the impact of the Structural Adjustment Program (SAP) on soil erosion in the Northern Benin. The main conclusion is that the implementation of the SAP appears to have led to a more sustainable agriculture in this cotton-producing region of Benin. However, this study has not quantified other sustainability indicators such as the soil nutrient or organic matter balance. But the results show that the reduction of soil loss was mainly due to an increased use of fertilizer, which may have had a positive effect on the soil nutrient balance. The better institutional framework under SAP may have contributed to this positive effect.

INTRODUCTION

Many African countries have engaged during the late 1980s in macroeconomic and sectoral reforms and Structural Adjustment Programs (SAP) to bring their economies back into line with international economies and to set the conditions for sustained long-term economic growth. Measures adopted included devaluation of national currencies, changes in trade and macroeconomic policies, reduction in government spending, changes in price and subsidy policies, and privatization and liberalization of domestic markets (for reviews see Heidhues and Knerr, 1994; Pintrup-Andersen and Pandya-Lorch, 1994; Michelsen, 1995; Heidhues and Michelsen, 1995). All these measures may induce change in the functioning of farming systems (cropping patterns, inputs use, labor allocation, etc.). The impact can also be important on soils because cropping pattern is one of the major determinants of soil degradation (Bonsu, 1981; Osteen, 1987; Grohs, 1994; Stocking, 1994; Quenum, 1995).

Erosion is one of the main causes of soil degradation in African agriculture (Upton, 1987; Ehui et al., 1990; Grohs, 1994). According to Bonsu (1981), soil erosion by water is one of the factors seriously affecting crop production in West Africa. A prolonged dry season, high intensity rains, overgrazing, uncontrolled grass burning and poor farming practices are some of the contributing factors to soil degradation.

Policies can affect soil erosion in two ways: first by modifying investments and input use (technologies) and second through its effect on the cropping pattern. A crucial issue for land degradation is the extent to which price-induced substitution encourages farmers to move away from less-erosive crops and cropping systems to more erosive crops and systems (Barbier, 1998). As a market oriented approach, economic reforms under (SAP) were intended to speed-up structural changes in the agricultural sector and to stimulate the export oriented sector; but improvement in the export-oriented sector in agriculture, in particular should have a trickle-down-effect on food production and food security. This means substitution within the cropping system and change in the soil degradation level. Many studies on the impact of SAP on agriculture have found out (or foreseen) a negative impact on the environment because of the increase of fertilizer price (de Haen et al., 1994; Kamajou, 1998; Nuppenau and Badiane, 1998). However, these results cannot be generalized because of two important reasons:

- Other factors such as the institutional framework play a central role in the availability of inputs and their use by farmers. Most small farmers in Africa appreciate the value of fertilizers, but they are seldom able to apply them at the recommended rates and at the appropriate time because of high cost, lack of credit, delivery delays, and low and variable returns (Badiane and Delgado, 1995).
- The evolution of single input-output prices ratios is not the only economic parameter influencing farmers' decision-making. The relationships governing their responses to relative crops prices are very complex and all the complexity should be taken into account when analyzing policy impact.

Conventional indicators of macro economic performance typically fail to reflect environmental degradation, and decision makers often neglect the environmental impact of economic policy (Reardon and Vosti, 1992). Whereas decision-makers in developing countries are aware of erosion, they lack detailed information on damages caused by erosion and the resulting costs to the economy (Grohs, 1994). Furthermore, there is a frustrating lack of empirical

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evidence showing what effects, if any, programs have on the acreage and management of various crops, soil erosion and crop productivity (Osteen, 1987; Reardon and Vosti, 1992). Especially, very little empirical work on impacts of the SAP on the household's natural resource base has been done in Africa.

The present study makes use of a bio-economic modeling framework to assess the impact of the SAP on soil erosion in Benin. The paper is structured in the following way. In section 2 the SAP is described and its potential impacts on agriculture and on soil are discussed. Section 3 presents the structure of the bio-economic framework. In section 4, the results of the case study situated in North Benin are presented. The paper closes with a summary and some concluding comments.

Structural Adjustment Program and environment

Two broad areas of adjustment policies can be distinguished (Heidhues and Knerr, 1994):

- *Stabilization*, also called macro-economic adjustment, refers to immediate changes of certain macro-economic parameters (eg.devaluation of exchange rate, tighter monetary policies, reduction of budget deficit) aiming at achieving short-term objectives (lowering of inflation, reduction of the balance of payment deficit). The measures primarily affect the demand side of the economy, which can be more easily, and quickly influenced than production, hence the gap between aggregate production and demand is narrowed by a cut in demand. Short-term macro-economic adjustment is primarily IMF's concern.
- *Structural adjustment* refers to fundamental changes of the way in which the economy operates. It involves market, trade, institutional and special sector reform measures (e.g. deregulation of markets and prices, reform of international trade policies, privatization, agricultural policies). The reforms aim at improving the production potential and efficiency of the economy, hence closing the gap between production and demand by increasing production in line with economic growth. This issue is especially of concern to the World Bank. As the structural adjustment policies need to be implemented in an appropriate sequence and require a certain time to materialize, they are, contrary to stabilization policies, of rather medium- to long-term nature. The short-term measures often had serious negative implications for employment, poverty alleviation, and food security.

In the area of agriculture, such policy reforms were aimed at correcting macroeconomic and sector-specific pricing and tax policies that had discriminated against agriculture. Examples of these policies were overvalued exchange rates, high levels of industrial protection and excessive direct and indirect taxation on agriculture from the imposition of export taxes, and low administered producer prices for exports and import-substituting food crops. These

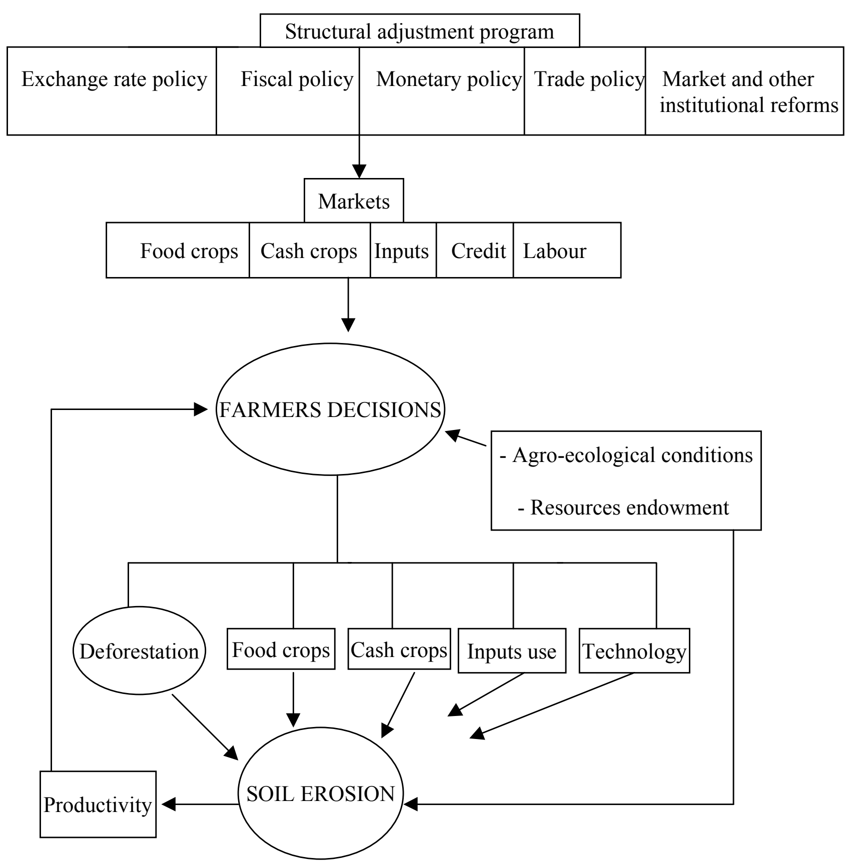

Figure 1. Main lines of impact of Structural Adjustment Program on soil erosion. Source: adapted from Thomson and Metz (1997).

policy measures significantly worsened the agricultural sector's terms of trade vis-a-vis industry and reduced production incentives. In addition, domestic policies for subsidizing food commodities and farm inputs and for stabilizing consumer and producer prices were held responsible for swelling fiscal deficits (de Haen et al., 1994).

In order to analyze the effects of SAP on the environment at the farm level, the relevant micro-macro linkages need to be detailed. Figure 1 presents a schematic framework of these linkages with special reference to the environment. The various policy spheres are listed in the upper boxes. Any macroeconomic policy is transmitted to the farmers through the meso-economy composed of markets, infrastructure and other institutions and results in the change of different outputs and inputs prices: foods crops, cash crops, production inputs. On the base of these incentives (or disincentives) and according to the agro-ecological conditions and their resource endowment, producers make their decision on crop allocation. They decide on the relative share of food and cash crops in the cropping pattern, the use of various inputs and technology. These choices have strong implications for the environment. Some crops and cropping systems are more erosive than others, some bring about more fallow clearing and deforestation than others, and the organic matter balance and the nutrient balance is not the same for all cropping systems. Other off-farm environmental effects can be mentioned: the cost/benefit which the eroded soils cause include the contamination of drinking water with nitrate, the siltation of rivers and dams, the dangers of insecticides to human health and the environment, etc. Even if these off-farm effects are important, this paper focuses on water erosion, which appears to be the most serious type of degradation in a tropical environment.

Benin has started its SAP in 1989. The main components of the program were: the reduction of the budget deficit, the liberalization of the economy, and other institutional reforms aimed at creating the conditions for a sustainable growth. All these measures have impact on the agricultural sector. For instance, the target of budget deficit reduction should be achieved through reduction of government (GOV) expenditures. At the beginning of the program, the lay-off of about 40% of the GOV employees in the agricultural sector was planned. There was also a cutting down on the expenditures for the health, research, education system and dismantling of parastatals. But these reforms affected only indirectly the farming systems; the most important change was the 50% devaluation in January 1994 of the CFA franc, the common currency of 15 West African countries. This devaluation led to a radical change of the farmers' economic environment (Senahoun and Heidhues, 1998).

Because of the economic importance of cotton for Benin, this crop is the one that benefits from well-organized commercialization and credit systems. Despite the SAP, its market is only partially liberalized and the government still fixes its prices. Thus, an active price policy for cotton is an important component of these economic reforms: Its price has been increased three times after the devaluation. Farmers have reacted positively, increasing cotton share in the farming systems and reducing food production. The food crops price index, compared to its values in 1993 has more than doubled (in 1996) in the urban centers of Benin. This inflation may be partially due to the farmers' reaction.

The bio-economic model

Bio-economic modeling procedures permit a simultaneous appraisal of adjustments in farm household resource allocation decisions that influence both household welfare and agro-ecological sustainability, in terms of soil erosion, organic matter and macro-nutrients balance. They have been developed to enable the integration of agro-ecological and socio-economic information to analyse the impact of agricultural policies and sustainable land use (Deybe, 1994, 1998; Barbier, 1998; Kruseman and Ruben, 1998). Currently available bio-economic approaches usually consist of the following four components (Ruben et al., 1998):

- Agroecological simulation models for agricultural activities that offer a wide range of technological (input-output) coefficients for current and potential activities , including indicators of their sustainability;
- Farm-household models that specify the underlying behavioral relations regarding farm household resource allocation and consumption priorities;
- Linear programming optimization procedures as a method for the appraisal of farm household response to policy instruments; and
- Aggregation procedures to address the effectiveness of policy instruments for sustainable land use and farmers' welfare at regional level.

The proposed model is a regional agricultural model, which integrates these four modules

General framework: objective function and constraints

Individual farm models are the microeconomic basis of the regional model. Farm households are classified according to the availability and use of resources (land, labor, capital, oxen and other animals). Physical, agronomic, socio-economic, and institutional aspects are integrated in the representation of the region. The model is based on a detailed description of farmers/breeders behavior. Three periods within the year are considered to better represent the constraints affecting crops, livestock, and consumption: seeding season, harvesting season and dry season.

Two goals are considered at the farm/household level: income maximization and food consumption sufficiency. Maximization of income is done on joint surplus[1] (aggregate farmers' surplus, which is defined by production less consumption) at the regional level subject to the constraint of individual self-sufficiency, either satisfied by household production or purchases.

Constraints which are linked with farmers' and global endowment of production factors include:

- Land for agricultural activities is constrained essentially by land availability. This constraint can be overcome by deforestation of common land, which obviously requires

[1]Compare the discussion on the aggregation issue in Hazell and Norton (1986), Bauer (1989), Deybe (1994), Brüntrup (1997).

labor. Deforestation is constrained at the regional level by availability of communal land.

- Labor used in the different activities is lower or equal to labor availability at the family level, plus or minus off-farm work, defined by period within the year.
- Production costs have to be lower or equal to cash availability. Farmers can borrow to compensate for a lack of cash. For some periods, they can also sell livestock to cover cash requirements. Credit is also limited. Cotton related credit is specified.

Risk related with the level of production and prices are considered with the «target MOTAD» method developed by Tauer (1983)[2]: several equations are introduced to represent several scenarios, with a minimal revenue constraint and a level of deviation authorized according to each farm characteristics.

Land use activities and indicator of sustainability

In order to avoid problems linked to the non-suitability of most crop growth simulation models to specific agro ecological conditions, the activities (actual and potential)[3] are defined based on statistical data (fertilizer use, yields, labor task times, climate, soil, etc) from farm surveys and local expert considerations. They are a set of points on a series of trans-log production functions. Thus, several technical schedules are considered, with different costs, labor requirements, and yields: Manure incorporation, animal traction, fallow, deforestation, different level of fertilizer use, etc.

The erosion impact of the different land use systems is the indicator of sustainability used in the model because of the importance of erosion in soil degradation in West Africa. Furthermore, in this agriculture with very low external input use, the trend in soil erosion may be correlated with an other indicator such as the nutrient balance: the use of fertilizer, for instance, leads to a better coverage of the soil and thus to less erosion and at the same time, it improves the nutrient balance.

Soil erosion depends on many factors, namely the vegetation, the slope, the climate aggressiveness, the existence of conservation practices. The first and the last one are the consequence of human action and, thus, they are affected by policy. Deybe (1994) suggests two methods to introduce soil erosion in a programming model:

- - as erosion trend counter, in order to compare among policies,
- - as a constraint or as a minimizing objective function in order to test utopian policies, useful to visualize the ecological optimum.

Here, the first approach is used by integrating the Universal Soil Loss Equation (USLE) in the model. The USLE, developed by Wischmeier et al. (1958) is the most common empirical-mathematical[4] model used to estimate soil erosion. It estimates average annual rates of sheet and rill erosion that are quantified in tons per hectare. It has been designed for soil loss prediction and control and is a function of natural and man-made factors influencing erosion. It allows prediction of erosion rates under proposed alternative management systems. All parameters of the equation have originally been estimated or calculated for the United States of America and have to be further modified if used elsewhere. Many efforts have been made to adapt the model to countries in the tropical zone. Roose (1977) adapted the USLE to West-African conditions based on extensive field erosion plots. Other adaptations of the USLE for Africa have been tried in Kenya, Mali, Lesotho and Zimbabwe (Grohs, 1994). Van Campen (1978) adapted the factors of the model for Benin and calibrated it for the most important crops of the country.

The USLE is introduced in our model as a erosion trend counter:

$$e_{ex,j,tec} = R * K * SL * C_{j,tec} * P * ter_{ex,j,tec}$$

where $e_{ex,j,tec}$ is the soil loss per farm type (ex), per crop (j) and technology (tec).

R = rainfall aggressiveness
K = soil erodibility
SL = topographic factor
$C_{j,tec}$ = cropping systems factor
P = conservation practices

Rainfall aggressiveness and soil erodibility depend on the region. It is also considered that the topographic factor is a regional parameter. Consequently, the USLE in our model is a modified one and can be assimilated to a simple erosion meter, which should provide qualitative information about soil erosion for comparison purposes only (see Senahoun, Heidhues and Deybe, 1999). The cropping system's factor depends on the farm type, the crops and on the technology used (fertilizer, animal traction, fallow, etc.). It is the single most important factor in soil erosion control in the tropics (Stocking, 1994). Because technology use and cropping pattern often change as a result of policies, erosion trend per farm type is endogenous in the model. This technique permits to capture the impact of different macro-economic measures on the soil. In spite of the availability of actual data from both pre- and post-SAP, it is important to use the simulated cropping pattern results to calculate erosion directly attributable to policy reforms only.

APPLICATION TO THE CENTRAL BORGOU REGION IN BENIN

Study area

The central Borgou region in Benin has been chosen to test the model for the following reasons:

- The Borgou Province, the most important cotton region of Benin, comprises 50% of the national territory, 17% of the population, and 60% of the cotton production.

[2]See the exhaustive discussion on the method in Hazell and Norton (1986), McCamley and Kliebenstein (1987).

[3]Alternative crop activities represent technically feasible production systems that are not widely practised by farmers and aim at sustaining land use.

[4]The most commonly used erosion surveys can roughly be distinguished according to the methodology involved: erosion surveys based on aerial photographs or satellite imagery and erosion surveys based on empirical-mathematical models (Grohs, 1994).

- It is also the province with the most important development of animal traction.
- Cotton, the most erosive crop is the most important monetary income source in the region and as mentioned above, the government still fixes its price.
- Thus, this region should offer the opportunity to observe and to analyze the phenomenon of substitution within the farming system and the impact of policies on food security, technology use and soil erosion.

The agroecological zonation (AEZ) is clearly the dominant factor inside the Borgou province to explain differences in farming systems, varying yield levels of crops, the potential regeneration and the management of soil fertility and, thus, the relative profitability of agriculture. The ecologically induced performance of crops also modifies the nutritional behavior of the in principal homogeneous ethnic groups and the gender-specific separation of tasks. The Borgou is subdivided in three AEZ, although in some studies the extreme South is partially subsumed under the southern zone. In this paper, only the region of the central Borgou is considered.

The central Borgou is characterized by a land use system based on yam, cotton, maize, and sorghum. The climate is of the soudanien type with only one rainy season (about five months) and 900-1300 mm rainfall. The soils are tropical ferralitic soils above crystalline base quite variable according to toposequence. They have average adequate chemical fertility, their major handicap for agriculture is the high percentages of coarse fragments with low water and nutrient absorption capacities. The most critical characteristic of soils for agriculture is their tendency to cementation. If cementation is near or at the surface, no agriculture is possible. Along the rivers, small hydromorphic alluvial belts are found with a very high nutrient content, but difficult physical properties (inundations, Vertisols). Soils, particularly the less developed, tend to degrade if no conservation measures are taken and mineral nutrients and organic matter maintained. In particular, water erosion is assumed to be very high in the region, with a higher proportion towards the north (Brüntrup, 1997).

Empirical Results

By factor analysis, three types of farms are distinguished in the region of central Borgou (Biaou, 1995). Farm 3 is a well endowed household with about 7 ha of crop land and animal traction, while farm 2 and farm 1 have respectively about 5 ha and 2.5 ha, both without animal traction.

- Several data sets are used for the calibration and the valid- a primary data set covering the period April 1991 to August 1992 available at the University of Hohenheim and collected in the Borgou (Brüntrup, 1997)
- A primary data set collected in 1994 by the UNDP and the Ministry of Agriculture of Benin in the framework of a study on the living conditions of the rural populations in Benin (ECVR) and covering all Benin
- A primary data set collected in 1994 by CIRAD for FAO and covering the whole country
- A primary data set collected by Senahoun in 1997 in the Borgou department.
- A secondary data set collected in different statistical offices in Benin.

As mentioned before, Benin has started its SAP in 1989, but the first reforms have affected only indirectly the agricultural sector. The 50% devaluation of the CFA in 1994 was the strongest and most direct measure affecting the farming systems. The above mentioned active price policy has also followed the devaluation: the cotton price has increased from 110 FCFA in 1993 to 140 FCFA in 1994, 175 FCFA in 1995 and 200 FCFA in 1996. Thus, it is assumed in this study that the impact of the SAP on agriculture and the resource base has started in 1994, and 1993 is considered as base year for the simulations.

The results are close to the land use and the technologies observed in the region: In 1993, cotton is the only crop which benefits from fertilizer use: about 100-150 kg per ha. Food crops are generally cultivated without fertilizer except maize, which receives a little fertilizer. The share of cotton area in the farming systems varies from about 15% to 30% according to farms. The total crop area is 2.9 ha, 4.96 ha and 8.58 ha respectively for farm1, farm2 and farm3 (Table 1). These results are very important for the following analysis because they constitute the base and show the ability of the model to capture the impact of policies on land use.

The input and output price changes resulting from the devaluation as well as the cotton price changes set by the government from 1993 to 1996 are simulated in the model. Results are summarized on Table 2 and Figure 2[5], which show that the average soil loss in the region has decreased continuously during this time period. Two important factors have contributed to this trend: the evolution of the cropping pattern and technological change by farmers.

From 1993 to 1994, just after the devaluation, the changing cropping pattern is the main cause of soil loss reduction. Farms 1 and 2 have reduced the share of cotton in favor of food crops, which are less erosive. The relative input/output price changes during this period did not allow the less endowed farms to increase cotton production: While the cotton price has increased by 27%, the labor price increased by 60% and the price of all imported foods almost doubled. For small farmers, because of their low labor and capital endowment, it is more profitable to increase food production in order to maintain calorie and protein intake. Fertilizer use decreased. Only Farm 3 has increased cotton production and fertilizer use in 1994, which is logical because it had more cash available.

In 1995, the GOV increased again the cotton price after the devaluation. The price (175 FCFA per kg) was high enough to incite all farms in the region to increase cotton production. It became more profitable to sell cotton and to buy food from the market. This situation led to a strong substitution inside the cropping pattern. Cotton (the most erosive crop) area has more than doubled in most farms. This evolution should normally increase soil erosion but it has decreased because of the simultaneous increase of

[5] The average soil loss per ha is the weighted average of the soil losses on the different farms types. The weights are represented by the total number of each farm type in the region.

Table 1. Simulated and observed land use in the region.

	simulated(†)	observed(‡)
FARM1		
food crops area (ha)	2.35	2.21
cotton area (ha)	0.55	0.15
total cropped area (ha)	2.90	2.36
FARM2		
food crops area (ha)	3.92	3.43
cotton area (ha)	1.04	1.00
total cropped area (ha)	4.96	4.43
FARM3		
food crops area (ha)	6.89	6.16
cotton area (ha)	1.69	2.20
total cropped area (ha)	8.58	8.36

Sources : (†) model ; (‡) Biaou (1995).

Table 2. Summary of main farm indicators.

	1993	1994	1995	1996
FARM1				
food crops area (ha)	2.35	2.48	2.08	2.08
cotton area (ha)	0.55	0.43	0.81	0.81
total cropped area (ha)	2.90	2.91	2.89	2.89
soil erosion by food crops (t/year/ha)	12.42	12.34	12.17	12.17
soil erosion by cotton(t/year/ha)	13.02	13.01	12.72	12.72
average soil erosion (t/year/ha)	12.52	12.44	12.33	12.33
fertiliser use (kg/ha)	26.50	20.56	39.33	39.33
farm income (FCFA)	252119	195836	522743	522743
FARM2				
food crops area (ha)	3.92	4.2	2.16	2.16
cotton area (ha)	1.04	0.64	2.83	2.83
total cropped area (ha)	4.96	4.84	4.99	4.99
soil erosion by food crops (t/year/ha)	12.42	12.15	11.9	11.9
soil erosion by cotton(t/year/ha)	13.01	13.01	12.3	12.3
average soil erosion (t/year/ha)	12.54	12.27	12.14	12.14
fertiliser use (kg/ha)	29.40	18.56	79.38	79.38
farm income (FCFA)	407554	279734	1154716	1154716
FARM3				
food crops area (ha)	6.89	5.48	4.77	4.77
cotton area (ha)	1.69	1.96	3.82	3.82
total cropped area (ha)	8.58	7.44	8.59	8.59
soil erosion by food crops (t/year/ha)	12.48	12.24	12.13	12.13
soil erosion by cotton(t/year/ha)	13.01	12.95	12.52	12.52
average soil erosion (t/year/ha)	12.59	12.43	12.31	12.31
fertiliser use (kg/ha)	27.54	36.90	62.43	62.43
farm income (FCFA)	608886	548623	1593831	1593831

Source: Model

fertilizer use, which allows a higher biomass and better soil cover. These results show the limitation of the studies based only on the change in cropping pattern to forecast soil erosion. They have to be treated with caution due to the lack of empirical data on erosion generated by different cropping systems.

A new cotton price increase in 1996 did not provoke any change in the model. The farms cannot further increase their cotton production due to limitations of resources: First, all the cropland has been used and it is not possible to deforest for more cotton production because of the high cost of this activity and the limitation of labor. Second, farmers cannot substitute further the food crops area in favor of cotton because of consumption sufficiency constraints.

The only difference between the evolution forecasted by the model and the actual situation in Borgou is that farmers continued to react to the cotton price increase in 1996; but because of the limitation of resources (explained by the

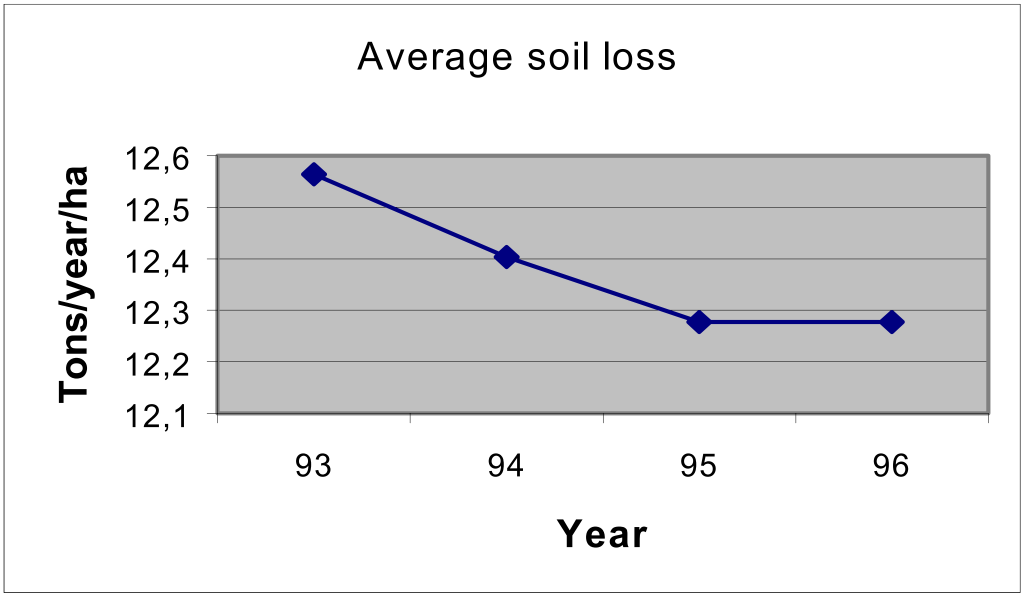

Figure 2. Soil loss evolution. Source: Model.

model), they were not able to manage all the cropped area. The consequence was a very low yield and decrease in local food supply. This situation may have contributed to the high inflation in the food sector observed in the country. The food crops price index, compared to its values in 1993 has more than doubled (in 1996) in the urban centers of Benin.

Globally, the model has indicated realistically the same trend in farmers' response to changes in their economic environment. Consequently, the measured positive impact on soil erosion can also be taken for granted.

One condition underlying this positive impact of the SAP on soil erosion is the existence of an institutional framework, which guarantees the timely availability of inputs. The Borgou is the most important cotton producing region in Benin and thus the region with the best infrastructure for fertilizer and credit supply. The SAP has strengthened this relatively good institutional framework through the partial liberalization of the input market, the decentralization of input commercialization, the involvement of farm organizations. These conditions have contributed to a more sustainable agriculture in spite of farmers' low-income level and input price increases.

CONCLUSION

This paper has used a bio-economic model to assess the impact of structural adjustment policies (SAP) on soil erosion in Northern Benin. The proposed model is an analytical tool, which can help estimating the impact of economic policy measures on the farming system and the environment. The main conclusion is that the implementation of the SAP appears to have led to a more sustainable agriculture in this cotton-producing region of Benin. However, this study is limited to the erosion aspect of sustainable land use and has not quantified other sustainability indicators such as the soil nutrient or organic matter balances. However, the results have shown that the reduction of soil loss was mainly due to an increased use of fertilizer, which may have had a positive effect on the soil nutrient balance. The SAP induced improvements of the institutional framework for input supply and credit may have contributed to this positive effect.

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