STRUCTURAL ADJUSTMENT PROGRAMS AND SOIL EROSION : A BIO-ECONOMIC MODELLING APPROACH FOR NORTHERN BENIN

1. 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 privatisation and liberalisation of domestic markets (for reviews see 14, 21, 18, 15). All these measures may induce changes in the functioning of farming systems (cropping patterns, inputs use, labour allocation, etc.). These changes can be important for soils because cropping pattern and input use are major determinants of soil degradation (5, 20, 10, 28, 22). Thus, a bio-economic modelling approach seems most appropriate to analyse the interactions between economic policy and soil degradation.

Erosion is one of the main causes of soil degradation in African agriculture (31, 9, 10). According to Bonsu (5), 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 (2, p 255). As a market oriented approach, economic reforms under (SAP) were intended to speed-up structural changes in the agricultural sector and to stimulate export oriented sectors; productivity improvements in the agricultural export sector can have significant positive effects on food production and food security. However, this means substitution within the cropping system and change in the soil degradation level. Many studies of the impact of SAP on agriculture have found out (or foreseen) a negative impact on the environment because of increased fertiliser price (11, 19). These results however can not be generalised for two important reasons:

- other factors such as the institutional and infrastructural framework play a central role in the availability of inputs and their use by farmers. Most smallholder farmers in Africa appreciate the value of fertilisers, 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 uncertain returns (1) ;
- the input-output price ratio, although important, is not the only economic parameter influencing farmers' decision-making. The factors and relationships governing their responses to relative crop prices are complex and situation-specific, which needs to be taken into account when analysing 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 (23). Often decision-makers in developing countries are aware of erosion, but they lack detailed information on damages caused by erosion and the resulting costs to the economy (10). Furthermore, there is a frustrating lack of data and empirical evidence showing what effects, if any, programs have on the acreage and management of various crops, soil erosion and crop productivity (20, 23). Especially, very little empirical work on the impacts of the SAP on household's natural resource base has been done in Africa.

The present study makes use of a bio-economic modelling 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.

2. Structural Adjustment Program and Environment:

Two broad areas of adjustment policies can be distinguished (30, p 112):

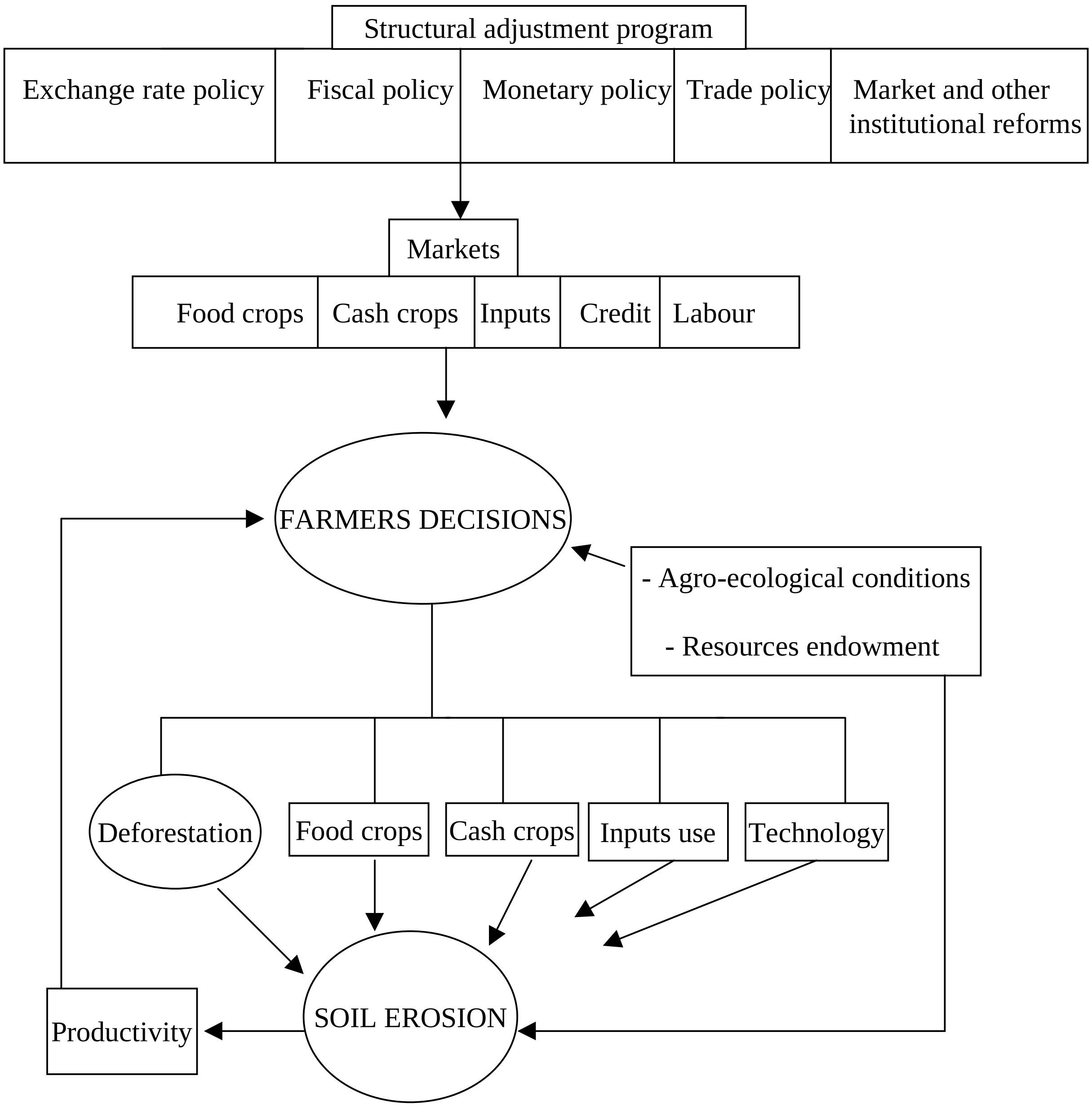
- *Stabilisation*, also called macro-economic adjustment, refers to immediate changes of key macro-economic policies, e.g. devaluation of exchange rate and tighter monetary and fiscal policies. These measures focus on achieving short-term objectives particularly on controlling inflation and lowering the budget and balance of payment deficits. They affect primarily the demand side of the economy which can be more 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 of primarily concern, to the IMF.

- S*tructural adjustment* refers to fundamental changes of the way in which the economy operates. It involves market, trade, institutional and sector reform measures e.g. deregulation of markets and prices, reform of international trade policies, privatisation, agricultural policy changes. 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 specially of concern to the World Bank. Structural adjustment policies need to be implemented in an appropriate sequence and require a certain time to materialise. They are, contrary to stabilisation policies, of rather medium- to long-term nature.

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 of agriculture through the imposition of export taxes and administered low producer prices for exports and import-substituting food crops. These 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.(11, p 196).

In order to analyse 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. The results are changes of different output and inputs price. On the base of these incentives (or disincentives) and according to the agro-ecological conditions and their resource endowment, producers make their decision on factor 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 can have strong implications for the environment. Some crops and cropping systems are more erosion prone than others, some bring about more fallow clearing and deforestation than others and the organic and mineral balances are not the same for all cropping systems. Other off-farm environmental effects can occur: the damages/benefits which the eroded soils may cause include the contamination of drinking water with chemicals, the siltation of rivers and dams, the dangers of insecticides to human health and the environment, etc. Even though these off-farm effects may be important, this paper focuses on water erosion which appears to be the most serious type of degradation in tropical environments.

Figure 1 : Main lines of impact of Structural Adjustment Program on Soil Erosion



Source: adapted from Thomson and Metz (1997).

Benin has started its SAP in 1989. The main components of the programs were: the reduction of the budget deficit, the liberalisation of the economy, and other institutional reforms aimed at creating the conditions for a sustainable growth. All these measures have an impact on the agricultural sector. For instance, the target of budget deficit reduction is to be achieved through reduction of government (GOV) expenditures. At the beginning of the first program, the lay-off of about 40% of the GOV employees in the agricultural sector was planned. Also the expenditures for the health, research, education system and for parastatals was cut down. While these reforms affected the farming systems indirectly, the most important change was the 50% devaluation of the CFA franc in January 1994, the common currency of 15 West African countries. This devaluation led to a radical change of the farmers' economic environment (26).

Because of its economic importance, the cotton sector is only partially liberalised and the government still fixes cotton prices. An active price policy for this crop is an important component of these economic reforms: Its price has been increased three times after the devaluation. Also it benefits from well organised commercialisation and credit systems Farmers have reacted positively, increasing the 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 centres of Benin (26). This inflation may be partially due to the farmers reaction.

3. The Bio-Economic Model

Bio-economic modelling procedures permit a simultaneous appraisal of adjustments in farm household resource allocation decisions that influence both household welfare and agro-ecological sustainability, particularly soil erosion, organic matter and macro-nutrients balances. They have been developed to enable the integration of agro-ecological and socio-economic information to analyse the impact of agricultural policies on sustainable land use (7, 8, 2, 16).

Currently available bio-economic approaches usually consist of the following four components (24, p 336) :

- 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 behavioural 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, labour, 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 behaviour. 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 maximisation and food consumption sufficiency. Maximisation of income is done on joint surplus [i] (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 labour. Deforestation is constrained at the regional level by availability of communal land.
- Labour used in the different activities is lower or equal to labour availability at the family level, plus or less 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 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 to the level of production and prices are considered with the « target MOTAD » method developed by Tauer (29)[ii]: several equations are introduced to represent different scenarios, with a minimal revenue constraint and a level of deviation authorised according to each farm characteristics.

Land Use Activities and Indicator of Sustainability

To avoid problems of non-suitability of crop growth simulation models to specific agroecological conditions, the activities (actual and potential)[iii] are defined based on statistical data (fertiliser use, yields, labour task times, climate, soil, etc) from farm surveys and local expert evaluations. They are a set of points on a series of semilog production functions. Thus, several technical schedules are considered, with different costs, labour requirements and yields: Manure incorporation, animal traction, fallow, deforestation, different level of fertiliser use, etc.

The extent of erosion of the different land use systems is the indicator of sustainability used in the model. Furthermore, in West African agriculture with a very low external input use, the trend in soil erosion may be correlated with other indicators such as the nutrient balance: the use of fertiliser, 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 anti-erosive measures. The first and the last one are the consequence of human action and, thus, they are affected by policy. Deybe (7, p 115) suggests two methods to introduce soil erosion in a programming model:

- as erosion trend counter, in order to compare different policies,
- as a constraint or as a minimising objective function in order to test utopian policies, useful to visualise 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.* (32) is the most common empirical-mathematical model used to estimate soil erosion. It estimates average annual rates of sheetwash 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 to predict erosion rates under proposed alternative management systems. It 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 = anti-erosive practises

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 (27). The cropping system's factor depends on farm type, crops and the technology used (fertiliser, animal traction, fallow,...etc.). It is the single most important factor in soil erosion control in the tropics (28). Because technology use and cropping pattern often change as a result of policies, the erosion trend per farm type is endogenous in the model. This technique permits to capture the impact of different macro-economic measure on soil erosion.

4. Application to the Central Borgou Region in Benin

4.1.Study Area

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

- The Borgou Province is the most important agricultural region of Benin ; it comprises 50% of the national territory, 17% of the population and 60% of the cotton production.
- It is also the province with the most advanced development of animal traction.
- Cotton, an erosion prone crop, is the most important monetary income source in the region ; as mentioned above, the GOV still fixes its price.

- This region offers the opportunity to observe and to analyse 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 (6, p 25). The province is subdivided in three AEZ. In this paper, only the region of the central Borgou is considered.

The central Borgou is characterised 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 a crystalline socle quite variable according to toposequence. They present on average good chemical fertility, their major handicap for agricultural use is the high percentages of gross material with low water and nutrient absorption capacities. The most critical characteristic of soils for agricultural use is their tendency to concrete. If concretion 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 anti-erosive measure are implemented and mineral nutrients and organic matter are restituated. In particular water erosion is assumed to be very high in the region, with a higher proportion towards the north (6 p 439).

4.2. 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 validation of the model :

- a primary data set covering the period April 1991 to August 1992 available at the University of Hohenheim and collected in the Borgou (6)
- 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 above, Benin has started its SAP in 1989, but the first reforms have affected the agricultural sector only indirectly. 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 in effect started only in 1994 ; 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 fertiliser use: about 100-150 kg per ha. Food crops are generally cultivated without fertiliser except maize which receives a little fertiliser. 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 important for the following analysis because they constitute the base and inform about the ability of the model to capture the impact of policies on land use.

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).

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 summarised on Table 2 and Figure 2 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.

The comparison of 1993 and 1994 shows the short-term effect of the devaluation , which took place in January 1994. The changing cropping pattern is the main cause of reduced soil losses. Farms 1 and 2 have reduced the cotton area in favour 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 labour price increased by 60% and the price of all imported foods almost doubled. For small farmers, because of their low labour and capital endowment, it was more profitable to increase food

Table2 : 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	560558
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	1290827
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	1775149

Source : Model

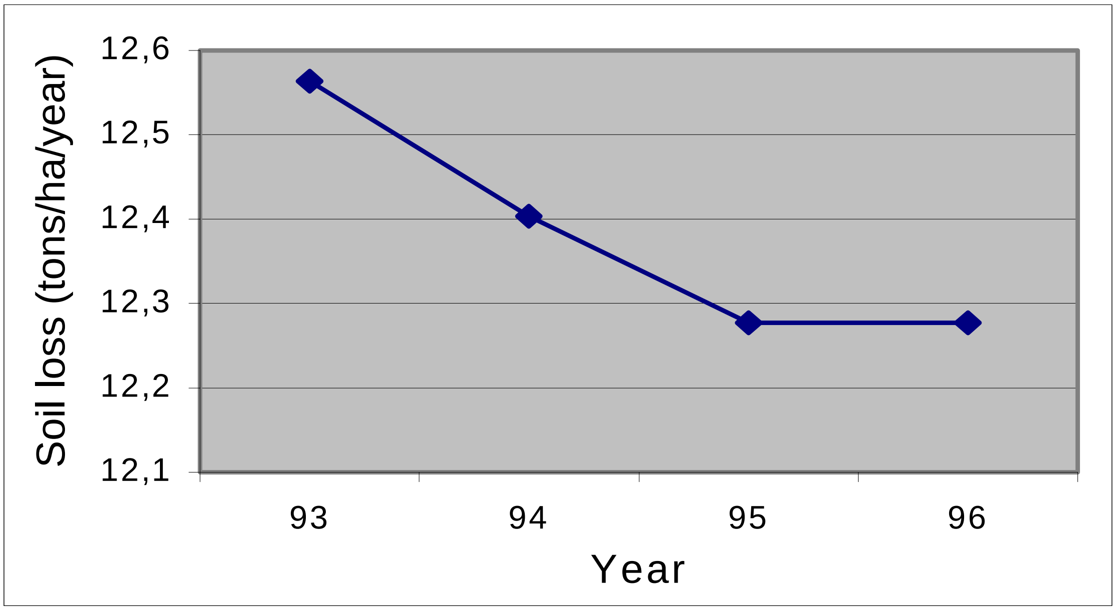
production in order to maintain calorie and protein intake. Also, fertiliser use decreased in 1994. Only farm 3 has increased cotton production and fertiliser use in 1994, which was possible because liquidity was less of a constraint.

In 1995, the GOV increased the cotton price a second time after the devaluation. The price with now 175 FCFA per kg was 25% above the 1994 level and high enough to incite all farms in the region to increase cotton production. It became more profitable to sell cotton and to buy foods from the market. This situation led to a strong substitution inside the cropping pattern. The area under cotton (the most erosive crop) more than doubled in most farms. This evolution would normally increase soil erosion but the simultaneous increase of fertiliser use which allows a higher biomass and better soil cover resulted in a decreased soil loss. These results show the limitation of the studies based on the change in cropping pattern only to forecast soil erosion. They have to be treated with caution due to the lack of empirical data on erosion generated under different intensity (fertiliser use) levels in changing cropping systems.

A new cotton price increase in 1996 didn’t provoke any change in the model. The farms could not further increase their cotton production due to limitations in land and labour availability: first, all the crop land available has been used. Also, it is not possible to deforest areas for raising cotton production because of the high cost of this activity and the limitation of labour. Second, farmers are not prepared to substitute more food crop area in favour of cotton because of the priority they attach to consumption sufficiency.

A key difference between the evolution forecasted by the model and the actual development in Borgou is the farmers' continued reaction to the cotton price increase in 1996; however, due to the limitation of resources (explained by the model), they were not able to intensively cultivated all the cropped area. The consequence was a low yield and decrease in local food supply. This

Figure 2 : Average Soil Loss Evolution in the Central Borgou Region



Source : Model

situation contributed to the high inflation in the food sector observed in the country. The food crops price index, compared to its values in 1993 more than doubled in 1996 in the urban centres of Benin.

In summary, the model seems to indicate realistically the trend of farmers' responses to changes in their economic environment. It appears that SAP induced improvements in the policy framework result in a positive impact on soil erosion.

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 fertiliser and credit supply. The SAP has strengthened this relatively good institutional framework through the partial liberalisation of the input market, the decentralisation of input commercialisation and the involvement of farm organisations. These conditions have contributed to a more sustainable agriculture in spite of farmers' low income level and input price increases.

5. 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 ; it has not quantified other sustainability indicators such as the soil nutrient or organic matter balances. But the results have shown that the reduction of soil loss was mainly due to an increased use of fertiliser, which may have had a positive effect also 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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Notes :

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[i] Compare the discussion on the aggregation issue in (12), (3), (7), (6).

[ii] See the exhaustive discussion on the method in (12) and (17).

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

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