POLICY REFORMS AND NATURAL RESOURCE MANAGEMENT

WEEK 3: DAY 2

SOIL MANAGEMENT IN SOUTHERN MALI

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1. INTRODUCTION

Land use practices in Southern Mali are characterized by high nutrient depletion, runoff and erosion that severely limit agricultural production and yields. Due to high population growth, pressure on land rapidly increased during the last decades, resulting in an over-exploitation of fragile natural resources. As land has become a scarce factor, emphasis should be given to technologies that enable a higher production per unit area. Given the prevailing market and institutional environment, farmers tend to retain their currently used non-sustainable practices, since an important part of their income depends on soil mining. They can only be expected to adjust their farming systems when positive income and expenditure effects are warranted.

Agrarian policies for sustainable land use thus require the selection of appropriate incentives that induce farmers towards appropriate resource allocation decisions. Since final decisions on crop and technology choice are made by individual farm households, an analytical framework that adequately captures the relationship between macroeconomic or sectoral policy measures and the adjustments in the farm household production structure due to modifications in the market or institutional environments, is required. Therefore, attention has to be devoted to different farm household preferences (e.g. profit, leisure, risk) and resource constraints (land, labour, capital) that influence the decision-making processes regarding crop and technology choice.

Farm-household modelling procedures can be applied to identify microeconomic supply response reactions to various policy measures. Production and consumption decisions are analyzed, permitting an appraisal of adjustments in land use in accordance with farm-household welfare objectives. Different types of farm-household will be identified according to their resource endowments and objective functions to acknowledge different directions of supply response reactions. Policy instruments are analyzed with respect to their effectiveness to induce producers decisions towards more sustainable land use at farm and regional level. Trade-offs between farm-household welfare and agro-ecological sustainability criteria can be acknowledged and policy options are identified that permit reconciliation of both objectives.

Analysis of sustainable land use asks for an analytical framework that takes into account the technical possibilities and limitations for land use in the long run, and the socio-economic incentives available for possible short-term adjustments in the production structure of farm households (Hengsdijk and Kruseman, 1992). The former component of such a framework makes trade-offs between different priorities of agricultural development explicit (Rabbinge and Van Latesteijn, 1992). The latter analysis is more suitable to identify policy instruments for modifying land use through their impact on the socio-economic environment in which farm-households make their allocational decisions (Kruseman *et al.*, 1995). This chapter focuses on the latter issue, making use of a bio-economic modelling approach to analyze the response of farm households in the short and medium term (1- 5 years) to well-defined changes in the production conditions. Agrarian policy formulation can be improved considerably when the impact of policy instruments can be predicted with reasonable accuracy. Such an integrated framework for the appraisal of the effectiveness and feasibility of policy instruments is required to support policy makers in selecting appropriate instruments to attain the agrarian development objectives pursued.
Bio-economic models are based on the integration of data sets from agro-technical and socio-economic sources. Actual and alternative (sustainable) cropping and livestock activities are defined

according to soil and weather conditions, production techniques and soil management practices, and their consequences for soil-nutrient and carbon balances. Farm-household resource endowments and expenditures guide the allocational procedures. Dynamic properties are incorporated into the model through savings and investment, while a time discount rate accounts for risk behaviour. Diversity in farm household supply response reactions is warranted. Factor and commodity prices are considered as exogenous variables that are given for individual producers. Food and labour balances are identified for the appraisal of market interactions and exchange among farm types. The effects of modifications in market prices of food and cash crops, input prices, transaction costs, credit supply and land policy are demonstrated, and trade-offs between objectives of farm-household welfare and sustainable land use are acknowledged.

The integrated farm household-region modelling approach to be presented analyzes the impact of policy instruments in the Koutiala *Cercle* in southern Mali. Due to high population growth, pressure on natural resources rapidly increased and traditional fallow periods are strongly reduced. Traditional transhumant grazing systems meet difficulties due to the increasing number of animals and the competition with arable farmers, affecting the availability of rangelands. Regional agricultural development is constrained by decreasing soil fertility and limited access to productivity enhancing techniques. As further options for extensive growth become limited, more attention should be dedicated to improvement of factor productivity and input efficiency (van Keulen and Breman, 1990). Technical options for intensification of land use and suitable policy measures to induce farmers to adopt more sustainable production systems must be identified. This study contributes to the policy agenda, identifying suitable instruments that permit farmers to modify their production system in more desired directions.

The rest of this chapter is structured along the following lines. Section 2 gives a short introduction to the agrarian production structure and prevailing soil mining practices in the Koutiala *Cercle*. Section 3 offers a review of the policy framework and an inventory of available policy instruments. In section 4, the bio-economic modelling approach is presented, followed by the description of the different components of the modelling framework. In section 5, results of the analysis of supply response reactions for different sets of policy instruments are presented. Section 6 discusses the feasibility of these outcomes against the background of national development policies and international literature, and mentions some options for further refinement of the methodological framework.

2. LAND USE AND SOIL MANAGEMENT PRACTICES IN SOUTHERN MALI

The *Cercle* of Koutiala is located in the southern part of Mali and has a superficies of 9,100 km^2. Population consists of 46,320 farm households (DNSI, 1991b) and has an annual population growth rate of 3.3 percent. Agricultural production in Koutiala *Cercle* is based on rainfed food crops (maize, millet, sorghum and cowpea), cash crops (cotton and groundnuts) and livestock. Average annual rainfall is about 780 mm. Soils can be characterized as loamy sand (50 % of all soils), gravelly (40 % of all soils) and clay depression (10 % of all soils) with low organic matter contents. Runoff and erosion of the former two types of soil are considered as major problems (Berckmoes *et al.*, 1990).

Cultivated area of food crops strongly increased during the last decades, while cotton area remained reasonably stable. Food security levels are fairly beyond minimum requirements, and locally produced surpluses of maize and millet are transferred to other regions. Livestock population more than doubled during the last decade, causing an increased pressure on available pasture areas. Availability of rangeland is becoming a limiting factor. Investment of cotton revenues for the purchase of livestock caused an increase in stocking rate up to 0.32 UBT ha^{-1}, beyond the carrying capacity of 0.15 UBT ha^{-1} (Bosma *et al.*, 1993). Moreover, livestock ownership is transferred from traditional herders to arable farmers, traders and urban bureaucracy (World Bank, 1994). These actors increasingly acquired control over the livestock sector for rent-seeking purposes, using cattle as a hedge against inflation.

Crop activities account for 35 percent of current land use, while pastures occupy more than 62 percent of available land (see Table 1). Fallow is almost eliminated and land has become a scarce factor. Current agricultural activities guarantee full absorption of regional labour force, of which 7.7 percent is used for livestock herding and almost 90 percent is used for cropping activities. Family labour represents a major part of all labour, but wage labour is gradually becoming more important (DNSI,1991b).

Table 1. Cercle of Koutiala : Agrarian Production Structure (1992/93)

Activity	Area (ha)	Area (%)	Employment (10^3 labour days)	Employment (percent)
Millet/Sorghum	154,054	17.2	9,705.4	38.0
Rice	2,190	0.3	175.0	0.7
Maize	36,329	4.1	2,361.4	9.3
Cowpea	24,831	2.8	1,117.4	4.4
Cotton	59,057	6.6	8,799.5	34.5
Peanut	21,045	2.4	1,031.2	4.0
Other crops	13,203	1.5	n.d	n.d
Livestock	533,891	62.3	1,964.7	7.7
Fallow	24,900	2.8	—	—
Unemployment	—	—	64.1	1.4
Total	869,500	100	25,518.9	100

Source : based on DNSI (1994)

Population and income growth caused a substantial increase in cultivated crop area (see Figure 1) at the expense of fallow and also lead to reduced availability of common property natural pasture areas. Simultaneously, livestock numbers have increased (see Figure 2), both to enable more mechanical land preparation and to maintain livestock as a reserve for adverse circumstances. Consequently, rising stocking rates are observed at the risk of severe pasture degradation.

Figure 1. Koutiala: changes in land use (1975-1993)

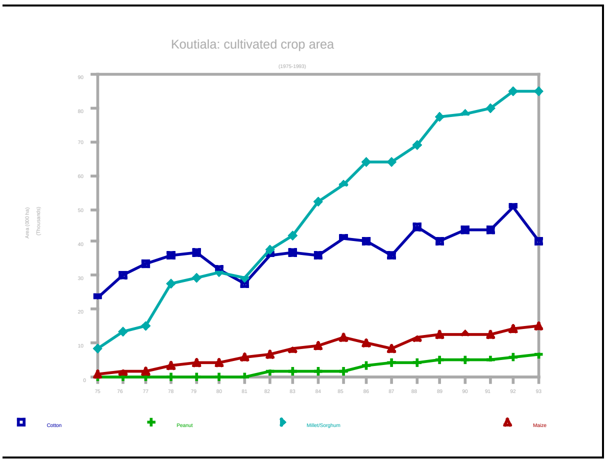
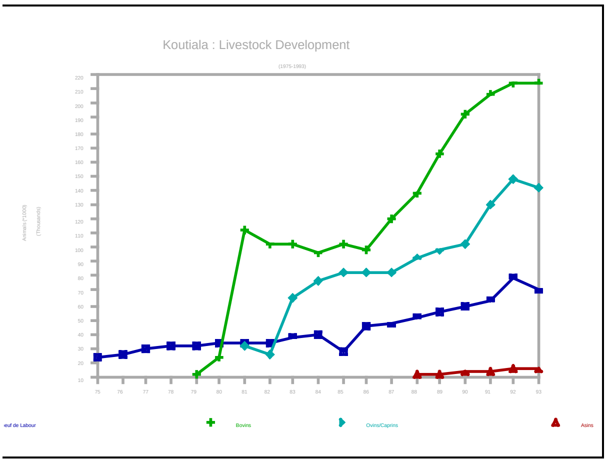


Figure 2. Koutiala: livestock development (1975-1993)



Current land use practices essentially rely on nutrient depletion and soil mining. Negative nutrient balances for Nitrogen, Phosphorus and Potassium in major land use activities in Southern Mali valued at replacement costs are estimated by van der Pol (1992) at an amount equal to 40 percent of farmers' total income from agricultural activities. These estimations (see Table 2) refer to the difference between the nutrients exported from the cultivated fields (extraction by crops, leaching, erosion, volatilization, and denitrification) and the imported nutrients (through chemical fertilizers, organic manure, restitution of crop residues, and biological nitrogen fixation). For most cropping activities, Nitrogen and phosphorus availability and soil organic matter contents (influencing nutrient efficiency) are considered as major constraints. We therefore focus attention on these elements in the subsequent discussion.

Table 2. Nutrient balances for N, P and K (kg/ha) in Southern Mali

	Millet	Sorghum	Maize	Cotton	Groundnut	Cowpea	Fallow
N-inflow	16.4	12.9	55.3	56.2	38.5	39.6	24.8
N-outflow	63.4	45.1	83.9	77.6	78.7	60.5	29.5
N balance	-47.0	-32.2	-28.6	-21.4	-40.2	-20.9	- 4.7
P-inflow	3.0	3.0	9.8	15.9	2.6	2.1	4.8
P-outflow	6.2	5.7	9.7	8.6	5.6	6.3	4.4
P-balance	- 3.3	- 2.7	0.1	7.3	- 3.0	- 4.2	0.4
K-inflow	26.8	19.3	42.0	45.5	8.3	10.1	26.0
K-outflow	64.1	45.8	59.3	54.6	47.2	52.0	32.9
K-balance	-37.3	-26.5	-17.3	- 9.1	-38.9	-41.9	- 6.9

Source: van der Pol (1992).

Different technological options could be made available to reduce soil erosion or nutrient depletion while maintaining or increasing productivity. These options include:

- Improved fallow (*jachère amelioré*) through stubble grazing and manure recycling;
- Simple or tied ridging in cropping systems to improve surface water storage capacity, increase the amount of water available, and reduce soil erosion;
- Mulching in cropping systems, based on recycling of crop residues to supply organic matter to the soil;
- Pasture improvement, reducing biomass loss and improving above-ground biomass of the herb layer through improved grazing strategies; and
- Fodder crops; production of cowpea straw (with manure and fertilizers) for high quality feed purposes, thus diminishing the pressure on common pastures.

Technological options for sustainable soil management are basically founded in a better integration of cropping and livestock activities, relying on recycling of manure for soil nutrient management, the use of animal traction to improve land preparation, and the use of crop residues for livestock feeding. Moreover, attention should be focused on the investment into physical soil management practices based on different types of ridging. Finally, alternative technologies could be made available to control pasture degradation through better rangeland management and the supply of fodder crops and crop residues.

These improved or alternative technologies imply in practice **intensification** of production through reliance on (chemical) fertilizers and sometimes also of labour. Nutrient balances are expected to be in equilibrium, and higher physical yields should compensate for input use. These nutrient balances are based on single cropping activities. Table 3 provides a comparison of actual (depleting) and alternative (non-depleting or sustainable) millet activities.

Table 3. Comparison of actual and alternative millet activities

		Actual	Alternative
Outputs	Marketable produce (kg/ha)	631	870
	Crop residues (kg/ha)	1,894	2,611
	Carbon balance (kg/ha)	-1,474	0
	N-balance (kg/ha)	-38	0
Inputs	Manure (kg/ha)	0	2,011
	Nitrogen (kg/ha)	7	120
	Labour (mandays/ha)	81	127
	Oxen draught power (animals/ha)	14	24

Source : Hengsdijk *et al.* (1996)

3. ECONOMIC POLICIES: OBJECTIVES AND INSTRUMENTS

Socio-economic development prospects for Mali are highly dependent upon the performance of the agricultural sector. Objectives of employment creation, poverty alleviation, food security, foreign exchange earnings, and government finance require substantial attention for agricultural growth (Ministère du Plan, 1988). Moreover, control on resource degradation is necessary to maintain the medium and long-term agricultural production potential. Different objectives with probable conflicting consequences result in trade-offs among these goals. Prioritization of objectives and assessment of the impact of policy instruments is required to permit sustainable patterns of economic growth.

Structural Adjustment started in Mali in 1988, giving priority to economic recovery within the framework of food self-sufficiency. Therefore, incentives are required to guarantee regular revenues to farmers and for mobilizing rural savings to finance regional development. Decentralization of allocative decisions was promoted in order to increase flexibility in resource use and improve market response reactions. The Malian government restricted its role to enhance technical support and infrastructural facilities that permit efficient resource allocation and mobilization, leaving room for local development of institutional mechanisms for resource conservation. Structural Adjustment was thus directed towards demand management with restrictive budgetary and monetary policies, and progressive price liberalization to improve supply response. Major instruments include market development to enhance productivity in the private sector, and decentralized resource management at lower levels of public sector absorption (World Bank, 1994).

Policy guidelines for rural development are specified in the *Schema Directeur du Secteur Developpement Rural* (MAEE, 1992). Main objectives include: economic stabilization based on diversification and intensification of cash crop production and integration of livestock production systems through market incentives and decentralized agencies (*contrats plan*); reinforcement of food security through improvement of agricultural productivity, investment in rural infrastructure (*désenclavement*) and restructuring of cereal markets; and sustainable rural development, based on rehabilitation of productive infrastructure and control of soil erosion, through legal codes and decentralized administration (*Gestión et Aménagement des Terroirs Villageois*).

The Malian Government defined the following specific development objectives for Koutiala *Cercle* (MAAE, 1992):

(a) stabilization of cultivated area under cotton and intensification of cotton production techniques, permitting area expansion only in the southern part of the region;
(b) improvement of integration between cropping and livestock activities;
(c) control of erosion and soil conservation;
(d) intensification of livestock production systems, i.e. increase of value added per animal;
(e) crop and income diversification; and
(f) promotion of local village-management of natural resources and decentralization of productive services towards village associations.

The rural sector is broadly acknowledged as a major engine for economic growth, requiring well functioning factor and commodity markets. Within the framework of the ongoing structural adjustment programme, available policy instruments to influence economic development and sustainable land use in Koutiala *Cercle* can be classified according to the following (Ellis, 1992): price policies to adjust relative prices of inputs and/or outputs; market development programmes to adjust transaction costs or to relieve market constraints; and definition of property rights to control access to depletable resources (especially common property pasture areas).

Price policies. Efficiency and sustainability of agricultural production systems could be enhanced through selective price policies of factor or product markets. Both input and output prices for food and cash crops are subject to policy reform, within the framework of market liberalization. Modifications of market prices directly influence cost/benefit relations of agricultural activities, and also have an indirect effect on net farm household revenues through different discount rates. Model simulations are executed for the following instruments: (i) increase or decrease of cereal prices, (ii) increase of cotton prices, and (iii) fertilizer price subsidy.

Market development. Effective supply response at farm household level depends on the development of the marketing system. Government investment in infrastructure may support the functioning of commodity markets. The development of factor markets for capital (banking system as alternative insurance mechanism) and savings offer alternative outlets for capital investment, controlling for inappropriate livestock expansion. Off-farm employment may also favour prospects for farm-level intensification. Model simulations are executed for the following instruments: (i) decrease in transaction costs, and (ii) increase in credit supply.

Property rights. To control for nutrient depletion on common property resources, clear definition of rights on common pasture land and forest areas (*droit foncier*) is required. Specific mechanisms for land allocation and distribution can be defined within the framework of territorial planning, taking into account both efficiency (resource allocation) and welfare (income distribution) aspects. Model simulations are realized for two specific instruments: (i) land tax per hectares of common pastures used, and (ii) head tax according to the number of animals using common pastures.

The impact of price policies on agricultural income depends strongly on the net supply or demand position of rural households (Budd, 1993). If priority is given to self sufficiency, food prices will have only a marginal impact on family income, although distributional effects may occur since budget shares for food expenditure vary among households. Households that are net buyers of cereals could benefit from lower food prices, but net suppliers are harmed by such policies (Weber *et al.*, 1988). Changes in the marketable surplus can be realized also with other methods, like infrastructure improvement, taxation or improved input provision (Ellis, 1992).

As for certain production factors (e.g., capital and land), no effective markets exist and so shadow prices have to be used for an evaluation of the possible impact of market development policies. For a number of commodities (cotton, livestock, fertilizers, cotton cake) prices are defined exogenously or through institutional mechanisms. In these cases, the effect of price changes due to market regulation or liberalization will be analyzed, and the effects of exchange rate adjustment on relative prices can be evaluated.

Modifications in relative prices are expected to influence the choice of production technologies. Intensification of cropping systems can be attained through improved access to animal traction and increased use of fertilizers. Crop diversification is in general considered as a risk reducing strategy (Reardon *et al.*, 1988), while investment in livestock represents an additional insurance mechanism. Integration of livestock and cropping activities includes the use crop residues (fodder) for high quality feed, and manure for organic matter and nutrient recycling in cropping activities, thus allowing mutual benefits. However, even in such integrated systems the supply of fertilizers is a prerequisite to sustainable production. The implications of these different policy instruments for resource allocation at farm household and regional level are reviewed in section 5, making use of an integrated bio-economic modelling framework that is explained in the next section.

4.POLICY ANALYSIS: OUTLINE OF A BIO-ECONOMIC MODELLING APPROACH

The bio-economic approach is based on a combination of two modelling frameworks: the analysis of the production side is based on a *Multiple Goal Linear Programming* (MGLP) framework to determine crop and technology choice, while a *Farm-Household Modelling* (FHM) approach is used for the assessment of impact of modifications in prices on farm profits, factor allocation, and land use.[1] The result is a recursive modelling framework in which econometrically specified (non-linear) behavioural relations are used to guide the procedures for linear programming optimization of the production structure (Ruben *et al.*, 1994; Kuyvenhoven *et al.*, 1995). The modelling framework is used for two subsequent optimization procedures: (i) definition of the initial production structure and allocation of savings (base run) under average weather conditions and given market prices (ii) identification of the modified production structure with different price conditions.

Four farm-household types are identified according to their initial factor endowments and related objective structure. Bigger farm types A and B possess more land, cattle and implements for oxen traction compared to smaller farm types C and D. Moreover, as farms mutually exchange resources,

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[1] The present contribution offers a summary of research conducted within the framework of cooperation among the Wageningen based cooperative research project '*Sustainable Land Use and Food Security*' (DLV) and the AB-DLO/IER/WAU based '*Projet Production Soudano-Sahélienne*' (PSS) in Mali. The mathematical presentation of the farm household model (written in GAMS) is published in Kruseman *et al.* (1997). The technical coefficients for cropping and livestock activities are documented in Hengsdijk *et al.* (1996).

each farm type is distinguished into two subtypes for closed and open resource situations (i.e., in- and out-hiring of labour and animal traction). Variations in performance of farm households can be explained by differences in available resources and environmental constraints. It also depends on institutional features, such as use-rights for common pastures and arrangements to guarantee access to animal traction (interlinked with labour services). Finally, relations with factor and commodity markets are specified, as rural households become integrated into cereals and labour markets, both for food security and income generation, as well as for input purchase. Therefore, options for intensification of farming systems depend on opportunity costs and risk behaviour (Reardon *et al.*, 1994; Fafchamps, 1993).

The basic structure of the farm-household model is schematically presented in Figure 3. The model consists of seven separate modules for (i) farm household stratification, (ii) objectives, (iii) arable cropping (LUST) and animal production (APST) activities, (iv) resource endowments, (v) prices, (vi) expenditures, and (vii) savings and investments. This modular structure permits the linkage of data sets from agro-technical and socio-economic sources and simple adjustments of individual modules without having to change the complete model structure. Moreover, various farm households can be characterized directly through different initial resource endowments and defined parameters for the savings coefficient and the time discount rate, that result in a different allocation of income among consumptive expenditures and savings/investments.

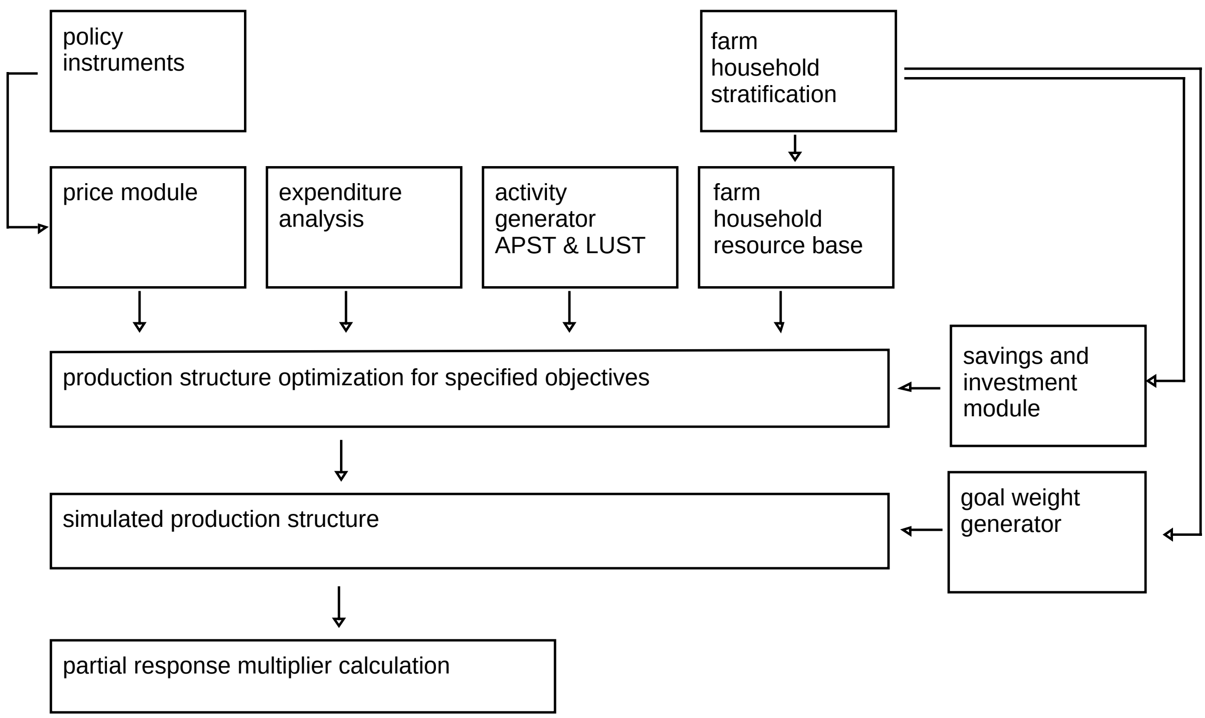

Figure 3. Structure of the farm household model

Dynamic properties are incorporated into the model through the savings and investment module, permitting adjustment of the resource base in subsequent years. The different modules are combined into a multi-objective optimization procedure and outcomes are derived with respect to (changes in) the selected production structure and related agroecological nutrient and carbon balances and socio-economic balances for labour and food. Since decisions on production are influenced by consumptive choice and leisure preferences, households can adjust their optimum choice through selective engagement in market exchange (Singh *et al.*, 19986).

Results of the modelling approach are presented in the form of *response multipliers*, indicating a percentage adjustment in factor allocation (land use, labour intensity, input use) as induced by discrete parametric changes in market prices. Effects of modifications in commodity prices, transaction costs (e.g. public investment in infrastructure), credit supply and land policy are determined at farm level. Finally, trade-offs between objectives of economic welfare and agro-ecological sustainable land use are acknowledged, and suitable incentives are identified that permit a sustainable use of natural resources while maintaining food security prospects.

The different components (modules) of the farm household model have the following characteristics :

Farm-household stratification. Measurement of farm level reactions to modifications in policy incentives requires a specification of farm households according to homogeneity in expected response to policy interventions. Different criteria for definition of homogeneous farm households can be used, based on variations among farm households with respect to (i) resource endowments and equipment level (Brons *et al.*, 1994), (ii) production systems and farm management practices (Bosma *et al.*, 1993), and (iii) farm performance (Leesberg *et al.*, 1990; van der Pol, 1993).

In the Koutiala *Cercle* farm-households are classified by the regional development agency *Compagn ie Malienne pour le Développement des Textiles* (CMDT) into four farm household types (CMDT, 1994). This classification is mainly based on the availability of animal traction at the farm households, as prospects for agricultural intensification depend to a large extent on access to animal traction and related equipment. The possession of oxen teams is of foremost importance for timely land preparation and to increase labour productivity. Other variables like farm size, labour availability, farm size and land-use are highly correlated with animal traction as shown by Brons *et al.* (1994).

Table 4. Farm Household Characteristics

Criterion	Type A	Type B	Type C	Type D
Family Size (persons)	25.1	11.9	8.5	5.5
Labour Force (persons)	11.8	5.7	3.9	2.5
Land (ha)	17.8	10.1	5.8	3.3
Cattle (UBT)	23.1	3.0	0.6	0.1
Oxen (units)	5.8	2.7	1.0	0.2
Ploughs (units)	4.2	2.2	0.9	0.1
Number (N)	9100	7900	2380	400

Source : CMDT (1994) Annuaire Statistique - Résultats de l'Enquête Agricole Permanente 93/94.

Four types of farm households are identified with characteristics as shown in Table 4. Farm types A and B, the largest farm households, represent 46% and 40%, respectively, of the number of farms in Koutiala. They combine food and cash crop production, making use of their labour surplus to generate savings. Food security is guaranteed through own production and income growth is attained through investment in cattle and/or intensification of cropping activities (van der Pol, 1993). The smaller households with less equipment (type C and D) have less diversified production systems and depend on purchase of food to guarantee self sufficiency. These households rely on hiring of animal traction against payment with labour. Major constraints for farm development include management and technical knowledge, equipment for medium- and large-sized (A and B) households, and labour availability and purchasing power for smaller (C and D) farm-households (Toulmin, 1994; Leesberg *et al.*, 1990).

Cotton production influences the overall farm strategy for all other crops because it is the major farm income source which is used to finance inputs for other crops. Cotton revenues are also used to expand livestock activities. Fertilizers, supplied by the CMDT and meant for cotton production, are applied to other crops directly or indirectly by making use of the residual effect of fertilizer nutrients in the soil. Moreover, crop rotation requirements imply that cotton can only be growing to a quarter of the farm area.

Objectives. Model optimization takes place for objectives of net expected full income and consumption utility. Consumption utility is derived from the expenditure module (see below). Full income is defined as the difference between net revenue and the monetary value of nutrient losses (van der Pol, 1992). The model determines the optimal production structure for the weighted combination of these goals, and calculates the value of net revenue and savings under these optimum conditions.

Objective values depend on both the weather type in the preceding year, determining the available savings, as well as on the actual weather type that determines labour requirements and attainable yields. Different savings coefficients for each type of farm-household guarantee different allocation of savings, preferring acquisition of livestock (in case of risk avoidance), purchase of equipment (in case of risk neutrality) or investment in land improvement (in case of risk acceptance). Moreover, different time discount rates for each farm types are taken into account for the valuation of nutrient losses.

A specific procedure has been used to generate goal weights, that permits specification of the relative importance of each objective for all farm types. These goal weights are determined through a confrontation of the objective values under partial optimization as generated in the base run with actual production activities and current prices with the actual objective values as derived from farm survey data (Romero, 1993). This calibration compares the selected production structure with field survey data for farms with the same resource endowments (DRSPR, 1992; Brons *et al.*, 1994). Relative goal weights of .75 for consumption utility and .25 for full income (including monetary value of nutrient losses) provided a good fit for the model.

Production activities. In the production activity module, well-defined mixtures of inputs are converted into agricultural outputs. These outputs include for example harvestable yields for human consumption and crop residues for fodder purposes, as well as side-effects of the production process such as soil

erosion. Input requirements include labour for cultivation practices, animal traction, implements, fertilizers and manure. For labour and animal traction, specific time periods are distinguished to account for peak activities.
Land use systems and technologies (LUST) for cropping activities are defined for millet, sorghum, maize, cotton, cowpea and peanut, while animal production systems and technologies (APST) are defined for cattle, goats, sheep and oxen used for animal traction. Moreover, pasture activities are defined to quantify the agricultural output of natural rangeland in Koutiala as one of the feed sources for the various livestock activities. For cotton a rotation constraint of 4 years is maintained. Different crop activities are defined according to soil type, rainfall type, production techniques, utilisation of crop residues and type of anti-erosion measures.

Because agricultural production is also determined by the prevailing environmental conditions. Five soil types are identified that differ in texture, available rooting depth and presence of gravel. These characteristics influence the water availability and thus to a large extent the production potential of crops. On the basis of rainfall collected during the period 1950-1981 at the Koutiala meteorological station three types of rainfall years are identified, a 'dry', a 'normal' and a 'humid' year, representing the 10% driest, the middle 45% and the wettest 45% of the rainfall years, respectively. The combination of the soil types and rainfall years forms the basis of the agro-ecological characterization that determines the production potential at different soils under various rainfall years. For each crop activity four production techniques are defined, of which the main criteria are the application of fallow periods and the use of animal traction and implements.

Agro-ecological sustainability is operationalized in the crop production activities in four ways: (i) Soil erosion measures are defined to reduce soil loss, (ii) soil management measures are defined, which improve the surface water storage capacity and increase the amount of water available for crop production (iii) a carbon balance is defined for each crop activity that monitors the annual organic carbon supply in the soil and the organic matter composition of the soil, (iv) a nutrient balance for N, P and K is defined to monitor the annual supply and withdrawal of these nutrients from the system.

For livestock activities, sustainability implies a stable herd of each type of animal. The production of pasture activities is calculated according the method described by Breman and de Ridder (1991) and equals a fraction of the total annual biomass production that does not affect the exploitation of rangelands in the long run. For each animal type, four production levels with different feed rations are defined, each combined with two marketing strategies depending on the age at which offspring is sold. For pasture activities, three different exploitation regimes are defined for grazing only during the rainy season, year round grazing, and grazing during the dry season.

Two types of arable crop activity are defined: (i) activities that represent the actual production techniques in Koutiala, and (ii) agro-ecological sustainable activities that are technically feasible but not yet widely applied in the region. Actual activities are in general characterized by negative carbon and nutrient balances and high soil erosion losses. The underlying data for the quantification of these actual activities are derived from a detailed farm survey (DRSPR, 1992). Agro-ecologically sustainable activities are based on attainable yield levels of which the maxima are determined by the available amount of water. These activities are defined in such a way that the annual decomposition of soil organic matter is compensated by a supply of crop residues, manure, or fallow periods, while the nutrient output of the system is compensated by the application of manure and, if necessary, additional fertilizers.

It must be noted that not every combination of criteria is feasible so that the number of crop activities could be reduced to manageable proportions. The activity module includes a total number of 1,400 actual and 3,120 alternative crop activities, as well as 9 livestock activities with 34 different feed rations.

Resource endowments. Farm households are defined according to their initial resource endowments of land, labour force, livestock and equipment. Each farm household is characterized by different coefficients for savings (see below). Land for cropping activities is limited to the available land (see Table 4) with prevailing soil characteristics (Hengsdijk *et al.*, 1995). Soil types are distributed over the farm households proportional to the regional soil type distribution. For cotton, the annual production is limited to one third of the total farm household area to control the occurrence of soil born diseases. The availability of common pastures is only limited at regional level. Use of wage labour is constrained by limits on working capital. The initial production structure for each farm household is determined in a base run, with only actual activities available and under given market prices.

Prices. The model makes use of expected market prices, based on a weighted average of farm-gate prices during the last three years, with coefficients of expectation set at levels of 0.5 for year t-1 and 0.25 for years t-2 and t-3 respectively. Transaction costs are defined as a margin between farm-gate and market price, subject to available transport infrastructure and market information. Hedonic price analysis is applied for the estimation of these margins at a 50 % level. The impact of an adjustment in the general price level due to, for example, a devaluation of the exchange rate can be determined by using different sets of prices.

Statistical records of market prices are only available for tradeable commodities. Prices for non tradeable commodities (land) and the terms of trade for reciprocal exchange transactions (family labour, animal traction) are based on implicit prices (Goetz, 1992). Therefore, so-called *virtual markets* have been defined that permit the identification of these price relations.

Expenditures. The relationship between household income and consumption utility is estimated directly from a cross-sectional budget survey (DNSI, 1991a) for Mali. Marginal utility of consumption for different expenditure categories (cereals, meat, milk, non-agricultural commodities) is converted into utility, making use of a negative exponential function (Ruben *et al.*, 1994). Linearizati on of this function is carried out using the convex combination constraint (Hazell and Norton, 1986).

Coping strategies to declining food production under adverse weather conditions depend on the available options for savings under more favourable production conditions. Moreover, rural incomes and consumption patterns are sensitive to prices, not just from the supply side, but also from the demand side (Reardon, 1993). As cereal consumption represents between 34 and 77 % of the household budget, reproduction costs of labour as well as animal feed costs depend on the level of grain prices. High cereal prices will thus be favourable for net-supply households, and lower prices within the framework of import liberalization would yield positive welfare effects for net-demand households.

Leisure time should be considered as a normal good in the utility function, as the cost of labour equals the marginal utility of foregone leisure. In this specification of the model, leisure is only taken into account as an incentive for hiring out animal traction in the absence of a local labour market. Receiving labour services from other households permit an increase of leisure consumption.

Savings and Investment. The savings and investment module permits a dynamic analysis of farm-household behaviour. The recursive modelling framework allows for a separate specification of production and investment decisions. Production decisions are made on the basis of the availability of resources and specified fixed and transitory savings coefficients. Fixed savings vary among farm-household types and are dependent on the income level. Transitory savings are defined as 80% of the difference between the expected income under 'average' rainfall conditions and the effective income under real weather conditions.

Investment decisions are modelled in a separate way. Transitory savings are used for the purchase of livestock as a buffer stock for motives of so-called consumption smoothing (Deaton, 1990; Rosenzweig and Wolpin, 1993). Fixed savings are used to enhance the resource base through the purchase of additional livestock, the purchase of equipment, or investment in anti-erosion measures, such as tied ridging. Returns to alternative allocations of savings are discounted and compared among farm households.

This procedure permits a clear distinction between different purposes for the maintenance of livestock for precautionary motives, and other investments that can be used to improve the resource base. The fixed type of savings can be considered as an insurance to maintain expenditures in periods of adverse weather conditions, while the transitory savings are required to assure expenditures in the long run. Off-farm labour (or migration) offers an alternative mechanism to finance farm investments and variable inputs. When rural credit market do not function adequately, off-farm labour becomes a substitute for lending (Reardon *et al.*, 1994). Allocational priorities depend on the available alternatives offered by local markets and institutions.

4.POLICY SIMULATIONS

The bio-economic modelling framework can be used for the assessment of the potential impact of economic policies on land-use and welfare at farm-household level. Resource allocation is analyzed as a result of production, consumption and investment decisions, and trade-offs between welfare effects and sustainability criteria are simultaneously addressed. Differences among farm types with respect to their net demand or supply situation on local cereals and labour markets are highlighted, since elasticity of supply response depends on the effective functioning of these markets (de Janvry *et al.*, 1991). Three separate model simulations are presented:

·a **base run**, where only actual activities and current prices are used to evaluate actual land use;
·a **technology scenario** where both actual and alternative (sustainable) activities are introduced under current (unmodified) prices; and
·a number of **policy scenarios** with both actual and alternative production activities under modified prices, permitting an identification of feasible instruments to enhance the adoption of more sustainable technologies.

Base run

Table 5 gives the results of the base-run for each farm type under current market prices and with actual activities, as determined by the initial resource endowments (see Table 4) and the selected objectives for optimization. This model run indicates the direction of change of the farm household production system under unchanged circumstances within a medium-term time frame of 5 years.

All farm types dedicate a substantial proportion of resources to cash crops (cotton and peanut), but only farm types A and B are able to maintain a net cereal surplus. Cowpea is selected by all farm types to guarantee livestock feed requirements. Fallow disappeared with the exception of a small portion of land in farm type A. The reliance on common pastures is dependent on the size of livestock and the available biomass from cropping activities. Production activities selected under the base run include mainly cotton to the maximum of the rotation constraint, and cereals (sorghum and millet). Millet production is concentrated in farm types A and B. Farm types C and D produce groundnuts for sale in order to provide additional income to buy food, since these households have a negative food balance.

Objective values for utility and full income are decreasing from farm types A and B to farm types C and D. Net revenues and fixed savings follow the same tendency, but the difference between net revenue and full income is less on smaller farm types due to the higher time discount rate for soil depletion on these types of farms. Nutrient balances for N, P and K and carbon balance are negative under the selected production structure, and all farms suffer serious soil erosion. Farm types C and D are net buyers of cereals and reach a low level of cereal self-sufficiency, due to limitations of land and preference for cash crop production. The labour balance, the share of available household labour required for agricultural activities during the peak period, is negative for farm type B only, indicating that for all other farm types labour exchange is not necessary. Livestock has a positive growth rate for all farm types, as savings are used for precautionary purchase.

Table 5. Base run: Objective Values and Production Structure

Indicator	Unit	Farm Type A	Farm Type B	Farm Type C	Farm Type D
Consumption Utility	Utility per capita	611,501	598,481	546,688	525,893
Full Income	FCFA per capita	68,681	53,306	32,921	25,416
Net Revenue	FCFA per capita	81,493	61,419	36,546	26,848
Savings	FCFA per capita	16,299	6,142	1,827	269
C-Balance	ka/hectare	- 1,127	- 1,193	- 1,323	- 1,182
N-Balance	kg/hectare	- 42	- 48	- 47	- 44
P-Balance	kg/hectare	2	0	- 2	- 1
K-Balance	kg/hectare	- 19	- 20	- 10	- 10
Erosion	MT soil loss/ha	34	42	50	48
Labour Balance	Peak period labour use (%)	95	- 5	93	90

Cereal Balance	KG cereals/capita	133	246	- 79	- 118
Cereals	hectare	10.8	6.6	2.1	1.2
Cash Crops	hectare	4.5	2.5	2.5	1.4
Cowpea	hectare	1.6	1.0	1.3	0.8
Fallow	hectare	1.0	0.0	0.0	0.0
Pastures	hectare	132.0	23.0	11.0	3.0
Livestock	annual growth rate (%)	7	5	2	4

Technological Change

Introduction of alternative (sustainable) cropping activities into the model under current prices permits only a partial improvement of the nutrient and carbon balances, while net returns increase between 15 and 29 percent (see Table 6). Although alternative activities are technically more efficient, an important part of actual activities is still maintained as economic efficient options, especially on smaller farm types C and D. Supply of alternative techniques may lead to substitution of crops and/or adjustment of technology choice. Farm types A and B can rely on the first strategy and increase their cash crop production as their food balance was already positive, while food deficit farm types C and D give preference to improve cereal production.

For all households there is a shift in cotton production from actual to alternative technologies, because the differences in costs between actual and alternative technology are not great, while the benefits in terms of carbon balance are important. For farm types C and D a mixture of actual and alternative technology occurs because their time discount rates are higher that render positive effects on the carbon balance less important. Where farm type A shifts toward extensive cereal production while diminishing the total cropped area, farm types B and D give priority to more intensive production technologies. Moreover, while farm type A shifts towards sorghum production, farm types B and C shift towards millet production that makes labour requirements in the peak periods coinciding with cotton production. Changes in cropping patterns with respect to cereals can be explained by a number of factors of which differences in labour availability is the most important.

Table 6. Response Multipliers for the Technology Scenario

Indicator	Farm Type A	Farm Type B	Farm Type C	Farm Type D
Consumption Utility	2	4	4	2
Full Income	34	39	36	18
Net Revenue	18	28	29	15
Carbon Balance	65	44	32	33
N Balance	59	48	29	22
P Balance	51	45	42	40
K Balance	65	56	15	12
Erosion	- 28	- 33	- 18	- 37
Labour Balance	53	- 42	- 79	48

Food Balance	- 122	- 16	92	- 10
Alternative activities	61	53	33	21

Note : response multipliers indicate the percentage change in the value of the goal indicators compared to the base run. For positive nutrient and C-balances the percentage change should be higher than 100 %.

It should be noted that these technological improvements do not take into account the costs of adjustment of cropping and livestock practices. Some specific practices might be adopted more easily by farmers, while other techniques require more knowledge and investments. Therefore, these shifts only indicate the technically feasible options for intensification, without considering their attractiveness from the farm household viewpoint.

Policy Instruments

Making alternative production techniques available through research and extension can be considered as an option to enhance resource use efficiency, but economic incentives for adoption will still be rather limited, as adjustment costs may fully offset marginal income increase. Therefore, additional price policies could be evaluated that permit a more substantial improvement of net revenues.

For this purpose, policy simulations are executed with the following instruments (see Section 3): (i) increase in food prices, (ii) increase in cotton prices, (iii) decrease in transaction costs (due to infrastructure investment), (iv) fertilizer price subsidy, (v) credit market development, (vi) land taxation or (vii) head tax on common pasture use. Response reactions are presented in Table 7, for each individual farm-type as a percentage change in the value of the indicator for a 1 percent upward or downward change in prices. Attention is now focussed on the trade-off between farmers net revenue and soil-carban balances, taking into account that shortage of organic matter is considered as the main limitation for sustainable intensification.

Several price policy measures permit an improvement of net revenues at farm-household level, but elasticity of these reactions differ among farm types. Increase of output prices for cotton or cereals has a general positive impact, while input prices and transaction costs yield substantially lower supply response reactions. Most response reactions are due to small shifts in cropping patterns, both in terms of shifts between crop groups (cereals, cash crops, fodder crops) and in terms of shifts between cereal crops, and substitution of technologies within crop groups.

Increase in food prices has a general positive effect on the food balance, due to the substitution of cash crops by cereals and/or the selection of more efficient cereal production techniques. Most substantial increase is reached in farm type C, where further intensification and specialization in millet production occurs. Household type B was already the top of the league with respect to food balance, and increasing food prices only strengthens that position. Household type A intensifies production of cereals in response to food price increases.

Fertilizer subsidies encourage farm types C and D to adopt more alternative cotton activities. For farm type C, the potentially positive effect on the carbon balance is offset by the choice of more soil depleting cereal activities. For farm type D the shift towards alternative technology is so small that the effect is negligible. The negative impact of fertilizer price subsidies on the carbon balance can be understood as a disincentive to improve input efficiency at farm-household level.

Market development policies provoke somewhat stronger reactions for several farm-types. Reduction of transaction costs is especially relevant for the more commercially oriented farm types. The negative effect on the carbon balance in farm type B is caused by the adoption of more intensive cereal production techniques. Improved credit facilities only provokes major reactions in farm type D, that uses additional resources to increase the cereal area and reduce livestock, both with adverse effect for the carbon balance. For all other farm types, the availability of internal savings proved to be a sufficient device for consumption smoothing purposes.

Different policies regarding property rights proved to have a limited or even negative impact on the carbon balance. Introduction of a head tax (250 FCFA UBT^{-1}) does not lead to adjustment of livestock production, as objectives of consumption smoothing and manure requirements outweigh short-term revenue effects. Introduction of a land tax (250 FCFA ha^{-1} pastures) results in a marginal decrease in farm-household revenues, but negatively affects the carbon balance as reliance on crop residues for livestock feeding increases. Moreover, the effect of a land tax on the use of common pastures leads to less intensive use of these resources. The secondary effect is a shift towards the use of fodder available at farm level, leading to adverse effects on the carbon balance.

Table 7. Response Multipliers for Different Price Instruments

Indicator	Level	Food Price	Cotton Price	Transaction Costs	Fertilizer Price	Credit supply	Land Tax	Head Tax
	Farm Type A	0.05	0.05	0.03	0.01	0.01	-0.01	0.00
Net Revenue	Farm Type B	0.04	0.05	0.01	0.02	0.00	-0.01	0.00
	Farm Type C	0.04	0.06	-0.02	0.01	0.01	-0.01	0.00
	Farm Type D	0.09	0.02	0.01	0.02	0.10	0.00	0.00
	Farm Type A	0.11	0.01	0.06	-0.01	0.03	-0.12	0.00
Carbon	Farm Type B	-0.02	-0.01	-0.08	-0.02	0.00	-0.15	0.00
balance	Farm Type C	0.07	0.06	0.06	-0.03	0.02	-0.02	0.00
	Farm Type D	0.01	0.11	0.06	0.00	0.03	0.00	0.00

Improvement of the carbon balance can be reached through modification of the relative price relation between cereals and cash crops. Only farm type B suffers a lower carbon balance when food or cotton prices increase due to limited labour availability that inhibits the selection of more intensive cropping techniques. Fertilizer price subsidies will lead in all cases to adverse effects on the carbon balance, as the increasing use of fertilizers is accompanied by higher extraction rates and thus incentives for efficient use are diminishing.

Complete equilibrium of the carbon balance cannot be reached with any of the indicated policy instruments. The calculated effects on the carbon balance through policy intervention are relatively small compared to the impact of technology. Policy interventions cause small shifts in allocative efficiency, whereas technology change as defined in this model leads to substantial shifts in technical efficiency. In situations where differences between actual and alternative activities are rather substantial, the welfare consequences of intermediate technology options are to be evaluated with special attention.

Intensification of cropping systems can be attained through better access to animal traction and more use and improved efficiency of fertilizers. Crop diversification is in general considered as a risk reducing strategy, while investment in livestock represents an additional insurance mechanism (Rosenzweig and Wolpin, 1993). Integration of livestock and cropping systems include the use of crop residues for high quality fodder, and manure for organic matter and nutrient recycling in cropping systems, thus allowing mutual benefits. However, even in such integrated systems, the supply of chemical fertilizers is a prerequisite to sustain production.

Variations in performance among farm households can be explained by differences in available resources and environmental constraints. The impact of price policies on agricultural income depends finally on the net supply or demand position of rural households (Budd, 1993). Taking into account the relationship between production and consumption decisions, changes in the market surplus or net revenues are somewhat dampened by adjustments in home consumption (Singh *et al.*, 1986) If priority is given to self sufficiency, food prices have only a marginal impact on household income, although distributional effects can be important. In this case, changes in the marketable surplus can be realized better via market development policies. Budgetary consequences of both alternatives need to be reviewed for a final evaluation.

Market policies enhance the tradability of different commodities and thus increase supply response reactions. Non-tradable items are actually demand constrained. Cereals are locally traded, but marginal budget shares are high and demand is rather inelastic with respect to income (Delgado *et al.*, 1994). By consequence, multipliers of regional income growth due to increased spending on locally tradable goods are generally high. These demand linkages permit in turn adoption of production techniques that favour factor productivity and sustainable land use. Aggregate supply response is also dependent on the availability of incentive goods (Bevan *et al.*, 1989). Therefore, higher cash crop prices only lead to increased production if sufficient consumer goods are available to absorb additional income. Perverse responses may occur due to shortages in supply. Joint application of different price and structure policy instruments (e.g. fertilizer subsidies and credit supply ; price policies and infrastructure investments) will then offer a feasible alternative (see Bade *et al.*, 1997).

Finally, institutional features, such as use-rights for common pastures, exchange arrangements to reach economies for animal traction, and specially options for off-farm employment can be considered as important additional devices to enhance supply response (Debrah and Sissoko, 1990). As rural households become more integrated into factor and product markets, both for income generation and for input purchase, options for intensification of farming systems depend on opportunity costs and risks. Off-farm employment becomes possible once labour productivity enhancing technical options are accessible. Otherwise, off-farm income may be equally important to finance input purchase and capital investment and thus may favour farm intensification (Reardon *et al.*, 1994; Fafchamps, 1993).

6. DISCUSSION AND CONCLUSIONS

The major policy problem to enhance intensification of African Sub-Saharan agriculture refers to low supply response reactions, causing market policies to be largely ineffective to promote economic growth and sustainable land use (Delgado *et al.*, 1994). Therefore, it has been argued that structural policies (rural infrastructure development, input delivery systems, research and extension, etc) are required to promote technological innovation.

The farm-household modelling approaches used within bio-economic research offers a framework for the analysis of the impact of different policy incentives on farm-household welfare and sustainable land use. The present model approach takes into account multiple objectives and differences in resource endowments among farm-types. Technical relations between cropping and livestock activities at farm level, as well as market relations for inputs and commodities are explicitly integrated into a modelling framework that permits an appraisal of their interactions. The preliminary results of the modelling exercise presented here are especially suited to identify main bottlenecks of both price policies as well as technology diffusion. Based on these conclusions refinements can be made for further analysis of the possibilities to enhance food security and more sustainable land use. Exploration of the possibilities of technological change indicates that with full knowledge of alternative (sustainable) technology and in the absence of adjustment costs, nutrient and carbon balances improve somewhat but do not reach equilibrium. Given the farm household's resources, their goals and aspirations and the subjective time discount rate, soil mining practices are maintained in terms of allocative efficiency. Modification of output prices tends to yield higher response reactions than input price adjustment. Both fertilizer subsidies and instalment of a head tax for livestock lead to diminishing incentives for efficient resource use. Structural policies addressing transaction costs and financial markets seem to offer better prospects to enhance tradeability and reinforce intersectoral growth linkages.

These results offer compatible outcomes with other research concerning the structural determinants for the intensification of production systems, involving both characteristics at farm-household level, as well as regional parameters. Following Delgado *et al.* (1994) the positive impact of factors like transaction costs, off-farm income, and the availability of credit can be confirmed. With respect to price policies different hypothesis are used to identify the driving forces that stimulate intensification of land use. Higher food output prices may offer incentives to improve factor productivity for producers that are net suppliers, but maintaining low food output prices tends to reduce opportunity costs for farm-households that are net buyers. Intensification can thus be associated with both higher and lower food prices, but especially with more stability in income patterns in order to reduce the costs of smoothing consumption. With respect to export crops, government price control or export taxation may result in a rationing of peasants' demand for consumer good and eventually lead to reduced supply response (Bevan *et al.*, 1987).

Some major shortcomings of bio-economic modelling approaches should be explicitly acknowledged. As the calculated response multipliers reflect short and medium term reactions, adjustment costs are not taken into account. Different time-lags in adjustment behaviour can be expected for consumption and investment. Moreover, the procedures for the adoption of technological innovations are strongly linked with farm size and resource endowments, while modern literature also points to a broad number of other household characteristics (e.g. education, gender, age) and copying procedures that determine innovation adoption. Finally, linkages with the non-agricultural sector and relations with other regions are not taken into account, in order to acknowledge the possible contributions of remittances and off-farm employment.

Perspectives for further research based on this type of bio-economic modelling include a further refinement of the activity generator for multiple cropping and crop rotations, recognizing also dynamic properties of soils along different crop cycles. Aggregation requires a specification of the supply and demand conditions on factor and commodity markets to derive prices endogenously. Aggregate response tends to be less sensitive to prices, as market failures inhibit adjustment within certain farm types (de Janvry *et al.*, 1991). Moreover, calibration of the model parameters for risk and savings should be based on econometric estimations that require the availability of a farm-household data base that permits cross-section and time series analysis. Finally, changes in the structural composition of the number of farms within each farm-types should be analyzed by means of a farm (dis)continuation module making use of Monte-Carlo simulation (Wossink, 1993).

EXERCISES:

1. We are looking for agrarian policy instruments that effectively influence farm household resource allocation towards more sustainable land use. Could you make a comparison between the **effectiveness** of policies of adjustment of (i) input prices or (ii) output prices with respect to farm household response reactions ?

2. The effectiveness of agrarian policy instruments proved to be rather different for each of the farm household types. What specific farm household characteristics do you consider to influence the **adoption** of sustainable soil management practices.

3. Price and public investment policies also have profound budgetary implications. Which of the above-mentioned policy instruments do you consider to be the most **cost-effective** ?

4. Agrarian policies might work out differently for richer and poorer farmers. Which policy instruments do you consider most appropriate for **targeting** poorer farm households (Type C and D) ?

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Figure 1. Koutiala: changes in land use (1975-1993)

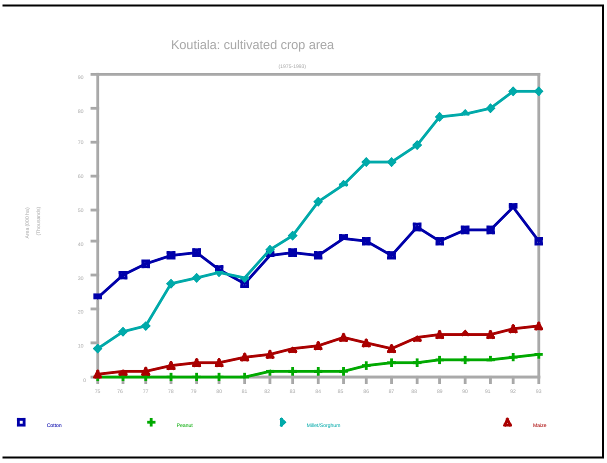
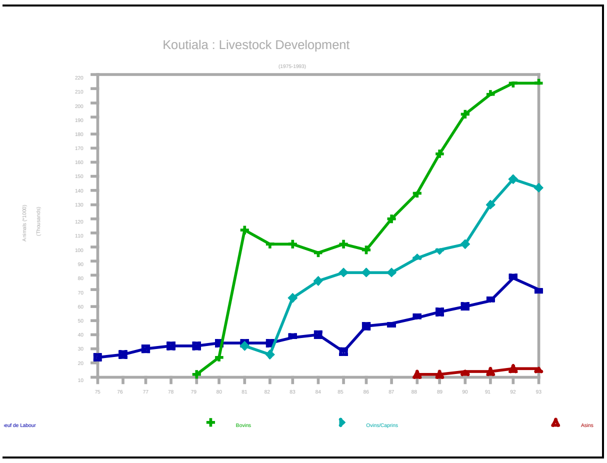


Figure 2. Koutiala: livestock development (1975-1993)



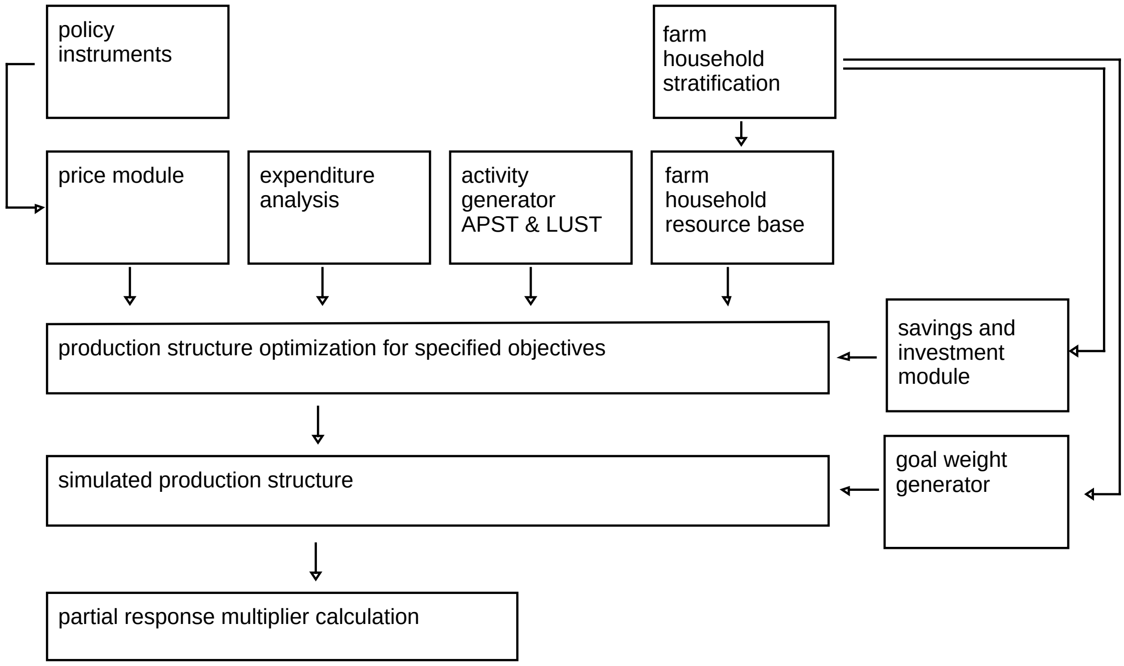


Figure 3. Structure of the farm household model

Table 1. Cercle of Koutiala : Agrarian Production Structure (1992/93)

Activity	Area (ha)	Area (%)	Employment (10^3 labour days)	Employment (percent)
Millet/Sorghum	154,054	17.2	9,705.4	38.0
Rice	2,190	0.3	175.0	0.7
Maize	36,329	4.1	2,361.4	9.3
Cowpea	24,831	2.8	1,117.4	4.4
Cotton	59,057	6.6	8,799.5	34.5
Peanut	21,045	2.4	1,031.2	4.0
Other crops	13,203	1.5	n.d	n.d
Livestock	533,891	62.3	1,964.7	7.7
Fallow	24,900	2.8		
Unemployment			64.1	1.4
Total	869,500	100	25,518.9	100

Source : based on DNSI (1994)

Table 2. Nutrient balances for N, P and K (kg/ha) in Southern Mali

	Millet	Sorghum	Maize	Cotton	Groundnut	Cowpea	Fallow
N-inflow	16.4	12.9	55.3	56.2	38.5	39.6	24.8
N-outflow	63.4	45.1	83.9	77.6	78.7	60.5	29.5
N balance	-47.0	-32.2	-28.6	-21.4	-40.2	-20.9	- 4.7
P-inflow	3.0	3.0	9.8	15.9	2.6	2.1	4.8
P-outflow	6.2	5.7	9.7	8.6	5.6	6.3	4.4
P-balance	- 3.3	- 2.7	0.1	7.3	- 3.0	- 4.2	0.4
K-inflow	26.8	19.3	42.0	45.5	8.3	10.1	26.0
K-outflow	64.1	45.8	59.3	54.6	47.2	52.0	32.9
K-balance	-37.3	-26.5	-17.3	- 9.1	-38.9	-41.9	- 6.9

Source: van der Pol (1992)

Table 3. Comparison of actual and alternative millet activities

		Actual	Alternative
Outputs	Marketable produce (kg/ha)	631	870
	Crop residues (kg/ha)	1,894	2,611
	Carbon balance (kg/ha)	-1,474	0
	N-balance (kg/ha)	-38	0
Inputs	Manure (kg/ha)	0	2,011
	Nitrogen (kg/ha)	7	120
	Labour (manday/ha)	81	127
	Oxen draught power (animals/ha)	14	24

Source: Hengsdijk *et al.* (1996)

Table 4. Farm Household Characteristics

Criterion	Type A	Type B	Type C	Type D
Family Size (persons)	25.1	11.9	8.5	5.5
Labour Force (persons)	11.8	5.7	3.9	2.5
Land (ha)	17.8	10.1	5.8	3.3
Cattle (UBT)	23.1	3.0	0.6	0.1
Oxen (units)	5.8	2.7	1.0	0.2
Ploughs (units)	4.2	2.2	0.9	0.1
Number (N)	9100	7900	2380	400

Source:CMDT (1994) Annuaire Statistique - Résultats de l'Enquête Agricole Permanente 93/94.

Table 5. Base run: objective values and production structure

Indicator	Unit	Farm Type A	Farm Type B	Farm Type C	Farm Type D
Consumption Utility	Utility per capita	611,501	598,481	546,688	525,893
Full Income	FCFA per capita	68,681	53,306	32,921	25,416
Net Revenue	FCFA per capita	81,493	61,419	36,546	26,848
Savings	FCFA per capita	16,299	6,142	1,827	269
C-Balance	ka/hectare	- 1,127	- 1,193	- 1,323	- 1,182
N-Balance	kg/hectare	- 42	- 48	- 47	- 44
P-Balance	kg/hectare	2	0	- 2	- 1
K-Balance	kg/hectare	- 19	- 20	- 10	- 10
Erosion	MT soil loss/ha	34	42	50	48
Labour Balance	Peak period labour use (%)	95	- 5	93	90
Cereal Balance	KG cereals/capita	133	246	- 79	- 118
Cereals	hectare	10.8	6.6	2.1	1.2
Cash Crops	hectare	4.5	2.5	2.5	1.4
Cowpea	hectare	1.6	1.0	1.3	0.8
Fallow	hectare	1.0	0.0	0.0	0.0
Pastures	hectare	132.0	23.0	11.0	3.0
Livestock	annual growth rate (%)	7	5	2	4

Table 6. Response multipliers for the technology scenario

Indicator	Farm Type A	Farm Type B	Farm Type C	Farm Type D
Consumption Utility	2	4	4	2
Full Income	34	39	36	18
Net Revenue	18	28	29	15
Carbon Balance	65	44	32	33
N Balance	59	48	29	22
P Balance	51	45	42	40
K Balance	65	56	15	12
Erosion	- 28	- 33	- 18	- 37
Labour Balance	53	- 42	- 79	48
Food Balance	- 122	- 16	92	- 10
Alternative activities	61	53	33	21

Note: response multipliers indicate the percentage change in the value of the goal indicators compared to the base run. For positive nutrient and C-balances the percentage change should be higher than 100 %.

Table 7. Response multipliers for different price instruments

Indicator	Level	Food Price	Cotton Price	Transaction Costs	Fertilizer Price	Credit supply	Land Tax	Head Tax
Net Revenue	Farm Type A	0.05	0.05	0.03	0.01	0.01	-0.01	0.00
	Farm Type B	0.04	0.05	0.01	0.02	0.00	-0.01	0.00
	Farm Type C	0.04	0.06	-0.02	0.01	0.01	-0.01	0.00
	Farm Type D	0.09	0.02	0.01	0.02	0.10	0.00	0.00
Carbon balance	Farm Type A	0.11	0.01	0.06	-0.01	0.03	-0.12	0.00
	Farm Type B	-0.02	-0.01	-0.08	-0.02	0.00	-0.15	0.00
	Farm Type C	0.07	0.06	0.06	-0.03	0.02	-0.02	0.00
	Farm Type D	0.01	0.11	0.06	0.00	0.03	0.00	0.00