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Technology, market policies and institutional reform for sustainable land use in southern Mali

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Abstract

To identify appropriate interventions that support sustainable land use, a farm household modelling approach is applied to analyze micro-economic supply reactions to various policy measures. The modelling framework links agro-technical and economic data, and takes both production and consumption decisions into account, allowing land use and production technology adjustments in accordance with farm household objectives. Different types of farm households are distinguished on the basis of their resource endowments, savings coefficients and time discount rate. Actual and alternative (sustainable) cropping and livestock activities for different weather regimes are defined for southern Mali. The effects on sustainable land use and expected farm household welfare of adopting alternative technologies and modifying prices, transaction costs, access to credit and land taxes are demonstrated. Even with full information on sustainable technologies, strong policy interventions are required to halt soil degradation. Structural policies proved to be more effective than price policies to reduce soil degradation while maintaining positive income effects. When prices are determined endogenously, structural policy loses some effectiveness as an incentive for sustainable land use due to the effect of additional supply on local cereal and meat prices.

Keywords: Farm household modelling; Sustainable land use; Intensification; Policy interventions; Mali

1. Introduction

Growing awareness and concern about the necessity to slow down land degradation in developing countries while maintaining food security call for deliberate public action to influence private behaviour. Identifying policy options to achieve this requires an analytical framework that takes into account (1) the technical possibilities and limitations for land use given the resource base, and (2) possible adjustments in the production structure of farm households due to modifications in the market or institutional environment (Reardon and Vosti, 1992). The effectiveness of policy instruments to influence farm household behaviour is conditioned by possible trade-offs between different productive and consumptive objectives, as well as different supply response reactions due to uneven levels of market integration and attitudes towards risk (Kuyvenhoven et al., 1995; Kruseman et al., 1995).

Agrarian policy formulation can be considerably improved when the impact of policy instruments on farm household allocative decisions could be pre-

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dicted with reasonable accuracy. To that effect, a recursive linear programming and farm household modelling approach is developed to analyze short- and medium-term reactions of farm households to well-defined changes in production conditions. The present methodology permits policy makers to select appropriate instruments to attain agrarian development objectives.

The integrated farm household modelling approach is applied to assess the impact of market policies and institutional reform in the Koutiala *Cercle* in southern Mali. Due to high population growth, pressure on natural resources is rapidly increasing as traditional fallow periods are strongly reduced. Traditional grazing systems meet with difficulties due to an increasing number of animals and competition with arable farmers, affecting the availability of rangelands. Agricultural development is constrained by decreasing soil fertility and limited access to productivity enhancing techniques. As further options for extensive growth are disappearing, attention now focuses on the improvement of factor productivity and input efficiency (van Keulen and Breman, 1990) With technical options for intensification of land use increasingly available (Breman and Sissoko, 1997), the question of how to induce farmers to adopt more sustainable production systems becomes pertinent.

After a review of major market and institutional constraints for sustainable land use and food security in sub-Saharan countries in Section 2, the policy environment in Mali is outlined in Section 3. The methodology of the integrated bio-economic farm household model and its major components are explained in Sections 4–6. Results of the policy impact analysis for key economic and agro-ecological indicators are presented in Section 7. In Section 8, induced effects of increased production on market prices are introduced, giving rise to modified response reactions. The paper concludes with a brief discussion of the major findings.

2. Market and institutional constraints

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). An emphasis on structural policies (rural infrastructure development, input delivery systems, development of rural financial markets, and property rights) is therefore required to promote access to technological innovations.

Adjustment of farming systems and adoption of new technologies based on more intensive use of land, labour or capital will only take place when factor proportions are constrained (Hayami and Ruttan, 1985). Government efforts to accelerate this process often meet with limited success due to widely occurring market and institutional failures (de Janvry et al., 1991).

Efficiency and sustainability of agricultural production systems can be enhanced through selective price policies in factor or product markets. The effectiveness of price policies on adjustment in factor use depends on: (i) the market environment, (ii) the tradeable character of the products, and (iii) the prospects for factor substitution. Especially food deficit households in drought affected regions are reluctant to respond to price incentives. Low supply response is usually related to failures in market infrastructure and associated high risks that induce farm households towards income diversification and safety-first strategies (Reardon et al., 1988). Modification of market prices directly influences cost-benefit relations of agricultural activities, creating a producer's surplus that can be mobilized to adjust factor proportions. Model simulations are therefore conducted for the following instruments: (1) higher cotton prices, and (2) lower fertilizer prices.

Limitations within the institutional framework may also severely hamper the process of agricultural intensification. Incentives for capital investment to maintain or improve the quality of fixed resources depend on the availability of external infrastructure and services. Efficient systems for timely and continuous delivery of inputs, based on public investment in transport networks, are critical in determining input costs at farm level, as well as to reduce uncertainty. Government investment in infrastructure support the functioning of commodity markets (Binswanger and Kandler, 1993).

Access to financial markets and attitudes towards risk are factors that determine the allocation of income among consumption and savings. Extensive use of rangelands is strongly related to the objective of transitory savings for consumption smoothing, and intensification of land use can only be expected to take place within a context of (i) development of rural financial markets (Udry, 1994) and/or (ii) income diversification (Reardon et al., 1994). Both mechanisms permit the generation of savings that can be mobilized to enhance on-farm investment. Moreover, they represent risk-coping strategies that control for the variability of income streams.

Absence of clearly defined property rights, limited access to financial resources, and high sensitivity for risks have a direct impact on farmers' willingness to invest. Massive adoption of technological innovations can only be expected if demands made on available household resources substantially exceed returns from other potential uses.Within this framework, model simulations are conducted for the following policy instruments: (3) lower transaction costs, and (4) improved credit supply.

Control of nutrient depletion requires a clear definition of rights on common pasture land and forest areas (*droit foncier*). Specific mechanisms for land allocation and distribution can be defined within the framework of territorial planning, taking into account both efficiency (resource allocation) and equity (income distribution) aspects. Model simulations are realized for two specific instruments: (5) land tax per hectare of common pastures used, and (6) grazing fee or head tax according to the number of animals using common pastures.

The effectiveness of price vs. structural policies to enhance sustainable land use and farm household welfare is a major issue in the current debate on the most suitable incentives to improve supply response in West African agriculture (Beynon, 1989). Adoption of more sustainable technological options cannot be expected unless farm households are able to reap the fruits in terms of higher utility and reduced uncertainty. Price policies can be made more effective if applied in combination with institutional development.

3. Mali's policy environment

Socio-economic developments in Mali are dominated by the performance of the agricultural sector. Reflecting the economic reforms of the late 1980s, policy guidelines for rural development (MAEE, 1992) emphasize: (a) 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*); (b) reinforcement of food security through improvement of agricultural productivity, investment in rural infrastructure (*désenclavement*) and restructuring of cereal markets, and (c) sustainable rural development, based on rehabilitation of productive infrastructure and control of soil erosion, through legal codes and decentralized administration (*gestion et aménagement des terroirs villageois*).

The rural sector is acknowledged as the major engine for economic growth, requiring well functioning input and output markets. The model simulations in this article address price policies for cereals, cotton and fertilizer, lower transaction costs, increased credit supply, and land and head taxes. The model is applied to the *Cercle* of Koutiala in southern Mali, which covers 9100 km^2 and counts 46,320 farm households. More than 90% of the labour force in the area is working in agriculture. Agricultural production is based on rainfed food crops (maize, millet, sorghum and cowpea), cash crops (cotton and groundnuts) and livestock. Average rainfall is just under 800 mm annually. Soils are subject to runoff and erosion and suffer from low organic matter content.

4. Model approach and methodology

The methodology used combines two modelling approaches: for the analysis of the production side a multiple goal linear programming framework is applied to determine crop and technology choice, while a farm household modelling approach is used to assess the impact of price modifications on farm profits, factor allocation and land use. The result is a recursive modelling framework in which econometrically specified relations are used to guide the procedures for a linear programming optimization of the production structure (Ruben et al., 1994; Kuyvenhoven et al., 1995). Kruseman et al. (1997) present the full mathematical description of the model. The

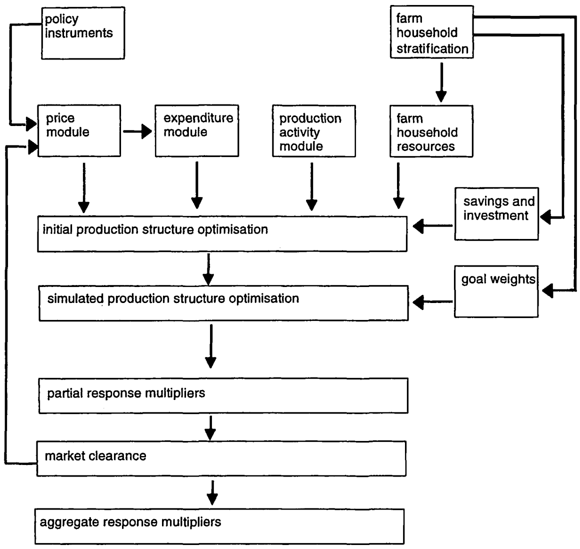

Fig. 1. Modelling structure.

analysis is conducted for three different types of farm households.

The structure of the farm household model consists of seven separate modules for (i) goal weights, (ii) farm household stratification, (iii) production activities, (iv) resource endowments, (v) prices, (vi) expenditures, and (vii) savings and investment (Fig. 1). At aggregate regional level, a module for market clearance is added to make prices endogenous. This structure enables the linkage of data sets from agrotechnical and socio-economic sources.

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; outcomes are derived with respect to (changes in) the selected production structure and related agro-ecological nutrient and carbon balances and key economic variables (labour and food).

Model optimization takes place for objectives of (i) adjusted net income and (ii) consumption utility. Consumption utility is derived from the expenditure module. Adjusted income is defined as the difference between net revenue and the replacement value of nutrient losses (van der Pol, 1992). The latter objective is introduced to account for sustainability at the farm household level. Time discount rates reflecting differences in time preference for each farm type are taken into account for the valuation of nutrients. 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 available savings, and the actual weather type giving attainable yields and labour requirements.

Calibration of the model is based on a comparison of the land use pattern that results from the base run of the model under current prices and actual activities with field survey data for farms with the same resource endowments (DRSPR, 1992; Brons et al., 1994). Following the procedure of Romero (1993), relative goal weights of 0.75 for consumption utility and 0.25 for adjusted income give a reasonably good fit for the model (Bade et al., 1997).

Model results are presented in the form of response multipliers, indicating adjustment in factor allocation (land use, labour intensity, input use) as induced by parametric changes in market prices and institutional features. Effects of modifications in input and commodity prices, transaction costs, credit supply and land policy for farm household welfare and sustainable land use are evaluated at farm and regional level.

5. Farm households and production activities

Farm households are defined according to their initial resource endowments of land, labour force, livestock and equipment. The possession of oxen teams is of foremost importance for timely land preparation and to increase labour productivity. Soil types are distributed over the farm households proportional to the regional soil type distribution. Annual cotton area is limited to a quarter of the total farm area to control for the occurrence of soil born diseases. Cotton production influences the overall farm strategy because it is the major cash income source, which is used to finance inputs for other crops. Cotton revenues are also used to finance expansion of livestock activities, thus, increasing pressure on pastures. Use of hired labour is constrained by limits on working capital.

Based on CMDT (1994) data, three types of farm households are identified. Farm types A and B, with the largest farm households A twice the size of B, represent the bulk of the farms in Koutiala. They combine food and cash crop production and reach food security through own production, while income growth is attained through investment in cattle and/or intensification of cropping activities. The smaller household type C with less equipment also has a less diversified production system, having to devote a large share of the available area to cereals production in order to guarantee food self-sufficiency. This household relies on hiring animal traction against payment with labour. Savings coefficient (increasing with farm size) and time discount rates (higher for smaller farms) are used to express vulnerability of the food balance and limited access to land and capital markets that especially face smaller households (Table 1).

In the production activity module, crop simulation procedures and expert knowledge are used to define input combinations required for various agricultural output levels (Hengsdijk et al., 1996). These outputs include, e.g., harvestable yields for human consumption and crop residues for fodder purposes, but also side-effects of the production process such as soil erosion. Input requirements include labour for cultivation practices, animal traction, implements, fertilizers and manure. The defined technological options include changes in production methods that can be practiced with currently available resources and knowledge. They combine productivity increases (due to higher quality feed rations and better use of manure and fertilizers for arable cropping) with conservation measures (i.e., tied ridging to reduce erosion and improved water storage capacity; mulching to compensate the annual withdrawal of soil organic matter, etc.). For each of these practices, labour- and animal-traction specific time periods are distinguished to account for peak activities. Pasture activities are defined which quantify the agricultural output of natural rangelands in Koutiala as one of the feed sources for the various livestock activities.

Table 1
Farm household resource endowments and savings parameters

Resource	Farm type A	Farm type B	Farm type C
Land (ha)	17.8	10.1	5.8
Family size (persons)	25.1	11.9	8.5
Labour force (persons)	11.8	5.7	3.9
Cattle (TLU)	23.1	3.0	0.6
Oxen (units)	5.8	2.7	1.0
Ploughs (units)	4.2	2.2	0.9
Savings coefficient (%)	20	10	5
Time discount rate (%)	5	10	18
Number (N)	9092	7905	2383

Source: CMDT (1994), Annuaire Statistique—Résultats de l'Enquete Agricole Permanente 93/94. Suivi Evaluation CMDT, Bamako, Mali.
Savings coefficients are estimated from data on available assets made from past savings (Brons et al., 1994).
Note: TLU=Tropical Livestock Units.

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 to improve the surface water storage capacity, and for each crop, a (iii) carbon balance for organic C and a (iv) nutrient balance for N, P and K is defined. The importance of the carbon balance as an indicator of sustainability refers to the soil–nutrient interaction that determine fertilizer efficiency. Different crop activities are specified according to soil type, weather conditions, production techniques, utilisation of crop residues, and type of anti-erosion measures. Weather risks related to the variability in rainfall are taken into account by making a difference between dry, normal and wet years that occurred during the last three decades in a proportion of 10–45–45%.

Broadly, two types of arable crop activities are defined: (i) activities that represent the current production techniques in Koutiala, and (ii) agro-ecological sustainable activities that are technically feasible but not yet widely applied in the region. Current activities are in general characterized by negative carbon and nutrient balances and high soil erosion losses as shown by farm surveys (DRSPR, 1992). Agro-ecologically sustainable activities are based on attainable yield levels of which the maxima are determined by the available amount of water. For livestock activities, sustainability of pasture activities is calculated according the method described by Breman and de Ridder (1991). In total, the activity module includes 1400 actual and 3120 alternative crop activities, and distinguishes nine livestock activities with 34 different feed rations.

6. Prices, expenditures, savings and investment

The model makes use of expected market prices, based on a weighted average of farm-gate prices during the last 3 years. 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).

The relationship between household income and consumption utility is estimated from a cross-sectional budget survey (DNSI, 1991). Marginal utility of consumption for different expenditure categories is converted making use of a negative exponential function (Ruben et al., 1994). Coping strategies to declining food production under adverse weather conditions depend on the available options for savings under more favourable production conditions.

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 based on the availability of resources and specified permanent and transitory savings coefficients. Permanent savings of farm household types are dependent on their average income level. Transitory savings represent 80% of the difference between (i) the expected income under 'average' rainfall conditions, and (ii) the actual 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 consumption smoothing (Deaton, 1990; Rosenzweig and Wolpin, 1993). Permanent savings are used to enhance the resource base through the purchase of additional livestock, the purchase of equipment, or investment in anti-erosion measures. Returns for alternative allocations of savings are discounted and compared between farm households.

7. Policy impact analysis

The farm household model is applied in the Koutiala region of Mali to assess the potential impact of sustainable intensification and economic policy on land use and welfare at the 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 derived. Differences among farm types with respect to their net demand or supply situation on local cereals and labour markets are highlighted, since the elasticity of supply response depends on the effective functioning of these markets (de Janvry et al., 1991).

For *prevailing market prices and technology*, optimization under initial resource endowments shows that all farm types dedicate a substantial proportion of their resources to cash crop production, and farm type C is expanding the cropping area to reinforce its net cereal surplus. Cowpea and groundnuts are selected by all farm types to guarantee livestock feed requirements. Reliance on common pastures is dependent on the size of livestock and the available biomass from cropping activities. Millet production is concentrated on farm types A and B. Farm type C produces groundnuts for sale in order to provide additional income. Nutrient balances for N, P and K and the carbon balance are negative under the selected production structure, and all farms suffer serious soil erosion. Livestock increases for all farm types because savings are used for precautionary livestock purchase.

The introduction of *sustainable cropping activities* into the model under prevailing prices only results in a partial improvement of the nutrient and carbon balances. Net revenue increases causing adjusted income to rise even faster (see Table 2). Although alternative

Table 2
Response to adopting sustainable intensification

Indicator	Farm type A	Farm type B	Farm type C
Adjusted income	95	71	79
Net revenue	52	51	63
C-balance	45	20	18
N-balance	40	22	17
Erosion	28	13	9
Labour balance	3	1	−1
Food balance	−85	−51	−12
Alternative activities	47	32	20

Note: response multipliers indicate the percentage change in the value of the indicators compared to optimization under prevailing technology. For making positive the N- and C-balances, the percentage change should be higher than 100%.

Table 3
Response multipliers for different policy instruments (in percentages)

Indicator	Farm type	Cotton price increase	Fertilizer price decrease	Transaction costs decrease	Credit supply i ncrease	Head tax	Land tax
Scenario		I	II	III	IV	V	VI
Net revenue	A	5	6	2	3	−2	−1
	B	5	4	2	0	−1	−1
	C	8	6	3	1	−1	1
Carbon balance	A	3	9	5	−2	0	1
	B	0	−5	1	0	−2	−1
	C	−1	0	−1	−1	0	−1

Note: response multipliers indicate the percentage change in indicator value compared to the intensification scenario in Table 2 resulting from: a 10% change in input or output prices (scenario I–II), half the difference between market and farm-gate price (scenario III), additional credit up to the amount of available household savings (scenario IV), a head tax of 1000 FCFA for large ruminants and 250 FCFA for small ruminants (scenario V) and a land tax of 250 FCFA per hectare of pastures (scenario VI).

activities are technically more efficient, an important part of the current activities is still maintained as economically efficient options, especially on the smaller farm type C. Supply of alternative techniques may lead to substitution of crops and/or higher intensification. Farm types A and B rely on the first strategy and increase their cash crop production as their food balance is already positive, while farm type C has to give preference to improved cereal production in order to free land for cash crops. All households shift their cotton production from actual to alternative technologies because differences in costs between the two are small, while the benefits in terms of improved carbon balance are substantial. For farm type C, a mixture of actual and alternative technology occurs because the higher time discount rates reduces the positive effects on the carbon balance.[1] Where farm type A shifts toward extensive cereal production, farm type B gives priority to more intensive production technologies.

Making alternative production techniques available through research and extension clearly enhances resource use efficiency, but without special incentives for adoption adjustment costs may well offset marginal income increases. Therefore, additional *policy interventions* are considered that permit a further improvement of net revenues. Results of these policy simulations are presented in Table 3.

Several price policy measures cause an improvement of net revenues, but response multipliers differ among farm types. Most reactions are due to shifts in cropping pattern and substitution of technologies within crop groups. Increasing cotton prices generally leads to intensification of cotton production by applying tied ridging and mulching. Farm types B and C are, however, not able to improve their carbon balance due to a simultaneous shift towards more extensive cereal activities. A carbon balance decrease is registered in farm type C where further specialization in sorghum production occurs in order to satisfy food security and to guarantee animal feed requirements.

Fertilizer subsidies encourage the adoption of more alternative cotton activities. For farm type B, the potentially positive effect on the carbon balance is offset by the choice of more soil depleting cereal activities. For farm type C, 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 different reactions for different farm types. Reduction of transaction costs (half the difference between market and farm-gate price) is especially relevant for the more commercially-oriented farm types A and B. The negative effect on the carbon balance in farm type C is

[1] Testing the model for its sensitivity with respect to the discount rate indicates that changes in the objective values are modest. Model runs for farm type C with an almost halved discount rate of 10% (as used for farm type B) decreases net revenue with 7% and adjusted income with 9%. Further reduction of the discount rate to 5% (as used for farm type A) only results in a decrease of net revenue with 1% and adjusted income with 2%.

caused by the adoption of less intensive cereal production techniques. Improved credit facilities only induce major reactions in farm type A, which uses the additional resources to increase the cereal area, while farm type C increases livestock production, both with an adverse effect on the carbon balance. For all farm types, the availability of internal savings proved to be sufficient for consumption smoothing purposes.

Policies regarding property rights result in negative income effects and have a limited or even negative impact on the carbon balance. Introduction of a head tax does not lead to substantial adjustment of livestock production, as objectives of consumption smoothing and manure requirements outweigh short-term revenue effects. Introduction of a land tax results in a small decrease in 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, causing a shift towards the use of fodder with adverse effects on the carbon balance.

8. Aggregate response

Because the introduction of new, sustainable production technologies results in changes in aggregate supply, market prices for locally traded commodities are likely to change. Market clearing prices for cereals and meat are calculated making use of aggregate demand functions (Bade et al., 1997). Demand elasticities are estimated for cereals at −0.50 and for meat at −1.32, in line with earlier estimates by Tsakok (1990). These elasticities are used to determine the adjustment of meat and cereal equilibrium prices that result under different policy scenarios (see Table 4).

Cereal prices rise sharply when policy instruments are applied that favour expansion of cash crop production (e.g., increase of cotton price, decrease of fertilizer price and reduction of transaction costs). Since the demand for cereals is fairly inelastic, a reduction of total cereal production results in a substantial price increase. Since local demand for meat represents only a small share of total trade, meat prices hardly change in response to market policies.

Application of different policy instruments under conditions of endogenous price formation reinforces the effectiveness of price instruments. While higher cotton prices and reduced transaction costs stimulate expansion of cash crop production at the expense of cereals under partial optimization, cereal production increases again if the induced effect of higher market prices is taken into account. Changes in the carbon balance are, however, less profound and sometimes even negative, especially for the smaller farm types. The income effect of fertilizer price subsidies is somewhat smaller at the aggregate level, since farm households are less inclined to substitute food crops by cash crops. Moreover, higher cereal prices prove to be an incentive for the application of fertilizers in food production.

Table 4
Market clearing prices and aggregate response (in percentages)

Indicator	Farm type	Cotton price increase	Fertilizer price decrease	Transaction costs decrease	Credit supply increase	Head tax	Land tax
Scenario		I	II	III	IV	V	VI
Meat price	(100)	100.0	100.0	99.8	99.8	97.5	99.8
Cereal price	(100)	116.5	116.5	113.9	76.5	96.6	98.6
Net revenue	A	7	4	5	−1	−3	−2
	B	9	4	4	−6	−2	−1
	C	10	6	4	−9	−2	1
Carbon balance	A	1	5	3	−27	0	1
	B	−2	0	−2	−26	−1	−2
	C	−4	7	−6	−7	−5	−3

Note: clearing prices give the adjustment of market equilibrium compared to the prices under the technology scenario (index=100). Response multipliers indicate the percentage change in the value of the indicators due to different policy instruments (see footnote Table 3). Improvement of net revenue and C-balance is denoted with a positive sign; deterioration with a negative sign.

Land policies also yield higher response reactions at the aggregate level. Although demand for meat products is fairly elastic, regional supply is most influenced when a head tax is introduced that stimulates early slaughtering and the sale of cattle. Carbon balances, however, do not improve as cereal prices also decrease, making the adoption of more sustainable cropping technologies less attractive. This spillover effect occurs because the lower farm household income inhibits further intensification of agricultural production.

Expansion of credit supply has a profound negative income effect that results from the intensification of cereal production with corresponding higher output levels. As a result, food prices strongly decline, while carbon balances are negatively affected by the disincentive to shift towards more efficient and sustainable production technologies.

9. Discussion and conclusions

Summarizing the results, two major conclusions stand out. First, intensification of cropping systems can be attained through better access to animal traction and more and improved use of fertilizers. Crop diversification is in general considered as a risk reducing strategy, while investment in livestock represents an additional insurance mechanism (see also 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, allowing mutual benefits. However, even in such integrated systems, the supply of additional fertilizers is a prerequisite to sustain production. Variations in response and performance among farm households with respect to sustainability and food security justify a distinction by major farm type.

Secondly, exploration of the possibilities of technological change indicates that with full knowledge of sustainable technology and in the absence of transition costs, nutrient and carbon balances improve but do not reach equilibrium. Given the farm household's resources, goals and risk perception, soil mining practices are maintained in terms of allocative efficiency. Modification of output prices can further reduce nutrient depletion. Both fertilizer subsidies and the instalment of a head and land tax result in diminishing incentives for efficient resource use. Structural policies addressing transaction costs and financial markets offer prospects to enhance tradeability and reinforce intersectoral growth linkages, with favourable effects on supply response and sustainable practices. At aggregate level credit policies result, however, in a sharp decline of cereal prices that affect farmers' income and organic matter balances. Especially for farm types that heavily depend on subsistence production, credit subsidies should therefore be avoided.

The results are comparable with other research concerning structural determinants for the intensification of production systems (Reardon and Vosti, 1992; Delgado et al., 1994). The positive impact of factors like crop diversification, yield-enhancing external inputs, transaction costs, credit availability, and well-functioning marketing channels are confirmed. Low supply response in sub-Saharan Africa causes market policies alone to be ineffective in promoting agricultural development and sustainable land use. Structural policies and institutional changes are indispensable to support the required technological innovation.

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