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# The impact of Policy on Farm Conservation Incentives in Developing Countries: What can be Learned from Theory?

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# The impact of Policy on Farm Conservation Incentives in Developing Countries: What can be Learned from Theory?

**Abstract:**
The consequences of agricultural pricing reforms for the resource management of cultivated land have attracted attention in the literature. This paper reviews some of the theoretical studies on the subject and focus in particular on soil conservation incentives. In addition some empirical literature on the causes to land degradation processes are also surveyed. On the basis of this evidence a classification scheme for agricultural investments depending on both soil fertility and agricultural output are suggested. The role of various agricultural activities and their effects on soil conservation incentives due to policy reforms are then discussed. It is shown that the effects on resource management incentives in theoretical models depend on technology and the options available to a household. The presence and knowledge of soil conservation measures and win-win technologies are necessary conditions for the success of agricultural policy reforms which increase farm profitability.

**Keywords:** Policy reforms, soil management

**JEL classification:** Q12, Q20

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# 1. Introduction

Soil degradation involves many and complex processes such as soil mining, soil erosion, acidification, salinization and leaching. These processes affect soil depth, the physical and chemical properties of the top soil, moisture holding capacity, infiltration rates and the stock of nutrients available for future crop production. Any decline in such characteristics, ceteris paribus, will be reflected in lower yields. The degradation of soils are world-wide problems but, until recently, have been neglected by researchers with the exception of soil scientists. An increasing awareness of soil erosion and soil degradation has changed the notion of land among economists. The classical view in the economic literature of land as being bestowed upon certain soils once and for all is now replaced by the view that land is potentially exhaustible, partly renewable resource, rather than an inexhaustible one.

Soil scientists have been mainly concerned with measuring soil erosion in physical terms and identify the influence of different causal factors to land degradation. In the economic literature, the applied research activity has concentrated on at least four approaches. First, there are studies trying to measure on-farm and off-farm costs of soil erosion measured in terms of future productivity losses (see e.g. Pierce et al., 1983; Schertz et al., 1989; Holmes, 1988; Brekke et al., 1996). Second, there are studies assessing soil conservation practices by cost-benefit analysis (see Veloz et al., 1985; Magrath, 1989; and Lutz, Pagiola, and Reiche, 1994). Third, the incorporation of the economic effects of soil degradation into general equilibrium models, to take account not only of the direct costs associated with degradation processes, but also costs arising from interlinkages between agriculture and other sectors of an economy. Such integrated economy-environment macro analyses are recently conducted for several tropical countries (see Aune et al., 1994; Alfsen et al., 1995; and Alfsen et al., 1996). Fourth, there are dynamic programming models which derive optimal rules for soil and fertility losses and study how the optimal paths change for different values of parameters (see Burt, 1981; Taylor and Young ,1985; and Weisenel and Van Kooten ,1990).

Reardon and Vosti (1992) discusses the effects of policies implemented to protect the long-term fertility of top-soils in developing countries. They find that more need to be known about relationships between production choices and the rate at which soils are deteriorating, and that little empirical work on impacts of macro and sectoral policies on natural resource management for developing countries has been done. They further stress the need for policy analysts to focus on incentives at the household level to understand the consequences and implications of such policies. In particular, it is important to be aware of the similarities and distinctions among the sets of productivity and conservation investments which are available at the household level.

The empirical gap identified by Reardon and Vosti is also confirmed in many other studies (see Lutz, Pagiola and Reiche, 1994; Barbier and Burgess, 1992). In spite of the increasing awareness of degradation processes, there is still a need for more research, in particular in developing countries and on tropical soils (Aune and Lal, 1995). Data are sparse, not only because of the lack of resources, but also due to the inherent technical difficulties associated with measuring a complex set of interactions evolving randomly and slowly over time. As a consequence, it is difficult to obtain precise assessments and it is questionable if such data, when existing, can be generalised to other regions. In spite of the empirical gap, some understanding of how policies affect household behaviour can be gained from theoretical studies on soil degradation. There is a need to relate such studies casted in a purely theoretical framework to the issues raised by Reardon and Vosti. In doing so, this paper will also present hypothesis about the causal factors to land degradation processes in order to illuminate that they are many, intermingled, and sometimes indeterminate. A second purpose is to argue for the importance of classifying agricultural investments into three different categories all having different effects on output and future soil fertility. Furthermore, the listing up of causal factors will also act as a benchmark for comparing the justification of various theoretical models appearing in the literature.

The next section provides some evidence on how farm decisions may influence soil degradation processes. In section 3, a classification scheme of agricultural investment decisions is presented where the criteria applied are how various decisions differ with respect to their effects on current output and long-term soil fertility. The paper then moves to a discussion of common characteristics of theoretical dynamic models on natural resources and soil conservation. In section 5, soil conservation models are presented in more detail, with particular focus on how they are modelled and what distinguish them. In section 5 the key results arrived at, with respect to the effects from macroeconomic policies in such analyses, are presented. This paper focuses solely on farm behaviour and cropping activities.

## 2. Farm household behaviour that influences soil degradation processes

In order to produce agricultural outputs from a parcel of land, land clearing activities have to be undertaken which inevitably will reduce the fertility of top soils. People also affect the soil-plant system through land use choices, cultivation practices and input use, and together with physical factors such as topography, wind, rain, and soils, they determine how the natural fertility of soil develops over time. One often mentioned cause to the increased pressure on lands in Third World countries is the process of extensification. The expansion of agricultural production activities onto marginal and erosion-prone lands, often in response to a rapid population growth, is believed to speed up the rate at which soils are deteriorating (Blaikie and Brookfield, 1987; Ruddle and Manshard, 1981; Eckholm, 1976). Such processes are most likely to occur in frontier regions with an unclear specification of property rights and involve deforestation and bush clearing processes. Under extensification, cultivators may push out pastoralists, who often do not posses legal tenure rights to land, thus leaving them on a diminishing land area or forcing them to less fertile grassland. Such changes destabilise traditional ways of agricultural production and strain both former and remaining grassland.

However, the degradation of soils is also taking place over time within a given farm holding - on the intensive margin. Many studies report on malign consequences on the resource base from the intensification of agricultural production, often interpreted as increases in the input-land and output-land ratios. Below we review some of the literature on household decisions and how they interact with the soil-plant system. In particular, we present hypothesis and evidence on how cultivation practices and input use may affect soil degradation processes. The focus will be on how various agricultural activities influence both short-term production and long-term productivity of land. Such a distinction is the point of departure for much of the theoretical modelling of soil conservation problems. The same distinction is also applied by Reardon and Vosti when suggesting a typology of agricultural investments which is to act as a conceptual basis for analysing policy effects on land management incentives.

## A) Land use changes and cropland expansion

Even when property rights are completely specified and there are no possibilities of expanding agricultural production beyond a fixed area of land, soil degradation may be induced by various processes. Within a given holding, a farmer may speed up degradation processes by conducting land use changes. One often observed feature in agriculture is that land is shared among different agricultural activities like woodlots, cropland, fallows and pastures. By changing the relative land use patterns, for example by replacing a less erosive land use practice (grassland and woodlots) with more erosive activities (annual cropping), soil degradation will accelerate. Another example is rotating fallow, where parts of the cultivable land is left fallow for a period of time in order to regenerate soil fertility. If the area devoted to fallow is reduced and/or the time period a plot is left fallow is shortened, the overall pressure on the farm holding will increase. More intensive cultivation, e.g. by increasing the ratio of cropland to forage fallow, exhibits a trade-off between short-term output and long-term production. In some situations, parts of a holding is left unutilised, often because the returns from such lands are low (marginal) or because the costs in developing them are high (steep hillsides). If former unutilised land is put under the plough, farm output will increase, but soil's future productive capacity will be reduced.

## B) Cropping pattern

Crops, crop varieties, crop density and crop sequencing are also important for both short-run output and the long-term soil fertility. Some crop varieties are perceived as more erosive than others and crop density and row spacing determine how well crops protect the soil from the erratic attacks from wind and rain. In addition the crops themselves harvest nutrients, and the removal of harvested products means that nutrients will be lost for the soil (Aune et al., 1994). Continuos cropping of seasonal crops instead of crop rotations speed up soil degradation. Lal (1982) reports that run-off increases with continuos cultivation. Reardon and Vosti find that modern crop varieties depletes key soil nutrients.

## C) Irrigation

Many studies mention modern inputs or land saving technologies as potential contributors to soil degradation. LaFrance (1992) and Anderson and Thampapillay (1990) refer to numerous studies which points out possible malign consequences on the soil base from increased used of chemical fertilisers and irrigation. Below we present some of the literature referred to in their studies. Crop production will increase with irrigation due to a higher and more stable supply of water. However, possible side effects from water irrigation are erosion and soil salinization. The surface runoff from irrigation water often cause the loss of soil material through erosion. Irrigation can raise the water table and lead to soil salinization as dissolved salts in the groundwater are deposited in the root zone. Randall (1981) and Musgrave (1983) find that the underpricing of irrigation water in Australia contributes to the problems of soil erosion, sedimentation, and salinity. Nadkarni (1987) and Joshi (1987) have identified adverse effects on soil quality of excessive irrigation. Lughezzani (1996) reports for China that the use of water for irrigation leads to waterlogging, salinization and soil erosion. Peck, Thomas and Williamson (1983) have estimated land degradation damage costs as a consequence of irrigation.

## D) Chemical fertilisers

The application of chemical fertilisers will enhance soil productivity and thereby increase production through the adding of minerals and nutrients to the soil system. However, fertilisers may speed up various land degradation processes. Chemical fertilisers accelerate the natural process of soil acidification as nitrates and phosphates leach into the soil profile. The use of chemical fertilisers depletes the soil and leads to a deterioration of its structure (Lughezzani, 1996). Costin and Combes (1982) found that superphosfaete subsidies in Australia have led to heavy application and damaged the structure and reduced the overall quality of the soil. Similar findings for India are reported in Sing, Sing and Bal (1987) and Subba Rao et al., (1987). However, some studies on tropical soils stress the importance of fertilisers in arresting erosion. Fertiliser application will provide land with a denser vegetation and reduce the time needed to provide such a cover, thus providing a better protection of soils by intercepting falling raindrops (Aune and Lal, 1995; Roose, 1977). Logan and Lal (1990), in a study on the Dominican Republic, reports of a decrease in erosion with fertilisation due to greater vegetal cover provided by such input use[1]. It follows that there are several and possible ambiguous effects from the application of fertilisers on long-term soil fertility, and the overall effect will most likely depend on both location and physical factors such as soils, wind, and rain. Especially in regions with very erosive rain, the land cover effect from the use of fertilisation may be important.

## E) Seedbed preparation and tillage practices

A farmer influences both present and future soil fertility by the tillage practices applied. The tilling of soil is done in order to increase output, by bringing subsoils with a higher nutrient content to the surface, to conduct seeding at the appropriate depth, by rooting up weeds, and by improving the infiltration rate. A land manger can choose among a wide range of options which differ with respect to how much land is turned, how rough the soil surface is left and which tools are applied. «The type, frequency, and timing of tillage operations, influence porosity, roughness, cloddiness, compaction, these in turn affect water intake, surface storage, runoff velocity, and soil detachability all of which are factors in potential erosion» (Wischmeier and Smith, 1977, p.20). A farmer can apply no- or minimum tillage techniques or use more conventional deep ploughing methods. Whether or not to:

- plough along the contours instead of up and down the hill,
- leave the soil surface rough or smoothen it with secondary tillage operations,
- plant in small pockets by hand or to till by hoe, plough, and animal traction,

may all be decisive for run-off and soil losses experienced.

The literature suggests that minimum or conservation tillage methods reduce erosion losses compared to conventional tillage. Deep ploughing, discing and repeated tillage reduces the integrity of the soil by weakening the soil structure (see LaFrance, 1992; Reardon and Vosti, 1992; Lutz, Pagiola and Reiche,1994). Lal (1986) found that erosion losses from ploughed land were 5 to 400 times higher than for no-till. Other studies find that there is an yield penalty associated with conservation tillage (Walker and Young, 1986). Reduced and minimum tillage can lead to soil compaction, which interferes with sprouting, root development and the ability to plant seeds at the appropriate depth, all causing current yields to fall. Lal (1987) reports that no-till decreased maize yields due to nitrogen deficiency.

## F) Timing decisions

The timing of tillage operations, planting and harvesting dates may have consequences both for short-term output and for the future productivity from lands. Waiting to perform tillage operations and delayed planting decrease yields because of the shortening of the growing season (Lal,1987). However, such timing decisions can provide the soil with a better protection in periods when erosive storms are concentrated (Barber, 1984).

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[1] The same positive effect on soil depth may also arise from irrigation, since improved water management will increase output and thus strengthen the land cover effect (pers. comm. J.B. Aune).

### G) Crop residue management

The use of crop residues, organic manures and the decomposition of roots may be important for both present and future soil productivity. If residues are not removed from croplands but left on the soil surface throughout the year, they act both as fertilisers and as a vegetal cover against falling raindrops and wind. Crop residues can remain on the soil surface as left by harvesting operations, or being ploughed down. Crop stubble converted into compost and mulching (a method of using crop residues) provide an excellent cover of seedbeds and reduce soil loss rates (Lal, 1986). The effectiveness of crop residue management in intercepting falling raindrops and obstructing runoff, will depend on the amount of residue applied.

### H) Structural conservation measures

Structural conservation measures include both mechanical and vegetative conservation measures such as terraces, bunds, ditches, waterways, planting of trees, and live (hedges) and dead barriers (stone walls). Structural conservation measures are often built in order to reduce gravity and water run-off, to act as windbreaks, or to intercept and conduct the flow of water. Examples are canals and ditches constructed across the slope. However, such conservation activities involve costs beyond their construction costs (labour requirements, external input use, and investment in capital) in that they take up productive land. Both Lal (1987) and Lutz, Pagiola, and Reiche (1994) find that such measures reduce the productive land area by 10-15%. However, there are important secondary benefits associated with structural conservation measures, besides arresting the effective reduction in soil depth, like increased infiltration rates and an improved moisture availability (Bishop and Allen, 1989).

## 3. A classification of input use and cultivation practices

Both the typology suggested by Reardon and Vosti and theoretical models of soil conservation make use of a classification of agricultural activities by dividing them into two groups; productive investments and conservation investments. How to draw the line between these types of activities is not obvious. One way of thinking about what separates them, is to define productive investments as those activities which primarily aim at enhance short-run crop production (e.g. within a crop season). Conservation activities, on the other hand, aim primarily at arresting land degradation processes, thus being mainly concerned with the future returns from land. For purposes of clarity, I have chosen to classify productive investments (output increasing) and conservation investments (arresting soil degradation) into three different categories each, depending on their effects on long-term soil fertility and current output, respectively.

By following this procedure we end up with 6 different categories of agricultural activities (see Table 1 below). The classification scheme suggested is a stylised way of presenting many and complex processes, but will in the following sections act as benchmark for comparing the models of soil conservation appearing in the economic literature.

**Table 1. Classification scheme of inputs and cultivation practices**

| *Productive Investments* | *Conservation Investments* |
|---|---|
| **(I) Land Degrading** | **(IV) Output Decreasing** |
| - Cropland expansion, crops, new seeds<br>- Irrigation and chemical fertilisers<br>- Tillage practices and weeding<br>- Timing decisions<br>- Crop-fallow ratios | - Terraces and bunds<br>- Ditches and waterways<br>- Windshields<br>- Hedges and barriers |
| **(II) Land Neutral** | **V) Output Neutral** |
| **(III) Land Improving** | **(VI) Output Increasing** |
| - Pesticides, herbicides<br>- Chemical fertilisers, irrigation<br>- Crop residues and mulching | - Tied ridges<br>- Liming |

Some of the farm household decisions presented above can easily be categorised while for others the situation is more complex (see Table 1). The use of irrigation water for example is a productive investment and there is sufficient evidence for believing in malign long-run effects on the soil base from such input use. However, irrigation will increase output and thus represent an improvements in the land cover and in this way arrest erosion processes. As a consequence, water irrigation can be represented both by category I and III in Table 1. Most structural soil conservation measures belong to category IV. In spite of beneficial secondary effects from the adoption of such measures, it is unlikely that such factors immediately will offset output losses caused by the effective reduction in cultivated farm area. Cropland expansion, timing decisions and tillage practices can be considered both as productive or conservation investments depending on the perspective chosen. Here, I prefer to think about these groups of decisions as productive investments, since they all point to a conflict between output and future fertility. Crop/fallow ratios, area under permanent cultivation, crop season length, and seedbed preparation choices, are decisions which represent trade-offs in their effects on current output and the long-run productivity from soils (category I in Table 1).

Fertiliser use will enhance short-term output, but the future effects on the soil base are ambiguous. Depending on whether or not possible soil-acidification effects dominate possible erosion-preventing effects, they can be classified in category I or III. Crop residue management and mulching belong to category III or VI, depending on whether such practices/inputs are considered as productive or cultivation investments. Both categories can be denoted win-win practices, since when applied they increase both current output and reduce the rate at which soils are deteoriating. If we relate our classification scheme to the typology of Reardon and Vosti we find many similarities. What Reardon and Vosti denotes the «polar cases» are in Table 1 represented by category I and IV. Reardon and Vosti also introduces the concept of overlapping technologies, which are believed both to enhance short-run output and arrest soil degradation. They mention tied-ridges as one example of such technologies. Overlapping technologies coincide with one of the win-win categories presented in Table 1 (VI).

There are problems associated with a classification of various agricultural investments. First, we have the problem of ambiguous effects arising from the same activity, exemplified with chemical fertilisers. Second, cultivation practices can not be assessed in physical terms as is the situation for conventional inputs. Fertilisers, crop residues, and irrigation, can be thought of in physical units, thus a monotone relationship will apply between quantity and output, and quantity and the degree of soil degradation experienced. For cultivation practices, the situation is more complex. Such decisions often represent discontinuous choices and can be measured along many dimensions. One way out, is to rank every group of cultivation practices on a scale - from the least to the most degrading practice. However, the assumption of the ranking being related to output in a monotone way, need not always be valid, even though such a relationship seems relevant for many situations. For example, several studies are reporting on a yield penalty associated with no- or minimum tillage practices as compared to conventional tillage. Third, there is a conceptual problem associated with the distinction between productive and conservation investments. One example is conservation tillage, which according to our classification scheme is defined as a productive investment, while in most literature is referred to as a soil conservation technique. As a consequence, moving from conventional tillage to a reduced tillage system, is considered a less intensive productive investment rather than an increase in conservation activities[2]. Fourth, we have above considered input use and various cultivation practices independent of each other. In reality many such decisions are interrelated. Conservation tillage often involves the use of crop residues, and the tillage method implemented may have consequences for weeding requirements and the adoption of herbicides.

Some cultivation techniques and inputs are not mentioned in our above presentation. Examples are weeding practices, agrochemicals like pesticides and herbicides, liming and various agroforestry systems. However, it seems that most choices made by a farmer have consequences for both current output and the future fertility from lands, even though some effects may be minor and of little importance. Wischmeier and Smith (1977) find that weeding will increase output but increase erosion. Agrochemicals have consequences for plant growth, thus long-term soil productivity can be affected by land cover effects. Labour, the most important input in low-input agriculture has not been discussed so far. However, the role of labour is very much connected to cultivation practices and input use, and can not be judged as an independent factor when considering interlinkages between farming decisions and soil degradation processes.

## 4. Resource models in economics

Theoretical models in resource economics focus on renewable and non-renewable resources such as fisheries, groundwater, fossil fuels, minerals and forestry. Below I will present some common features of such models. In all dynamic formulations of resource extraction models there is a stock component representing the quantity of the resource which is constrained by natural endowment. The stock of the resource may or may not replenish itself and the stock dynamics is also governed by human actions. The revenues obtained by a resource manager is a function of the resource extraction rate (decision variable). For fishery models the extraction rate is the catch rate, in fossil fuel models it is drilled oil or gas, and in forestry models the amount of harvested timber. There are costs associated with the harvesting of the resource and for some models such costs are assumed to depend on the remaining

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[2] Mannering and Fenster (1983) define conventional tillage as the combined primary and secondary tillage operations performed in preparing a seedbed, while conservation tillage is any tillage system that reduces loss of soil or water relative to conventional tillage.

stock of the resource[3]. The resource manager is assumed to maximise a discounted income stream over a long horizon (finite or infinite), by deciding on an extraction path of the resource. The models apply the usual neo-classical assumptions of continuos and smooth functional relationships and in general abstracts from discontinuities and lumpy investments. The models may be viewed as planning models in the sense that the resource manager chooses an optimal resource extraction path over time. In deterministic analyses they have full information about relevant parameters like interest rates and future prices, about technological relationships, and about biological and ecological processes.

Resource models in economics abstract from many complex processes and focus attention on some features which are considered as important. As a consequence, a limited number of both stock variables and decision variables are specified. Such considerations also apply for models on soil degradation processes. Agricultural production systems involve complicated interactions between farmer behaviour and the physical factors which determine soil fertility. As a consequence, the modelling of farming systems need to be a simplification. Parsimonious models are beneficial in order to understand important processes and effects without getting lost in details.

An early contribution in economics on optimal soil conservation is Burt (1981). Here, a dynamic programming model is applied which derive optimal rules for losses of organic matter and soil, for different discount rates and output price levels. In this analysis all farming decisions are represented by the percent of land under wheat as compared to forage fallow. In recent years additional papers have emerged using optimisation models to study soil degradation and soil conservation issues. The methodology applied to analyse such inherent long-term relationships is intertemporal models, often specified in continuos time where the length of each time interval is arbitrarily short. The various analyses deal with problems of whether private soil loss rates are socially excessive or not and how planning horizons, discount rates, policy reforms and - distortions affect resource management decisions. The increased focus on pure theoretical modelling may reflect the complexity of addressing such issues in an empirical context. The lack of data is already mentioned, but in addition there are methodological problems associated with empirical testing of phenomena for which there are long time lags between cause and consequences.

In order to limit the number of stock variables in soil conservation models at least two approaches are observed. First, to focus upon one side of land degradation processes only, for example soil erosion, where soil depth is the only stock variable determining soil fertility (Barbier, 1990; McConnell, 1983; Barret, 1991,1996: Goetz, 1996). Second, by letting the stock variable represent an index of many characteristics of the soil like organic matter, soil structure, soil depth, mineral content and water holding capacity (LaFrance, 1992; Clarke, 1992, Ardila and Innes, 1993; Grepperud, 1996abc).

Most models on soil conservation, treat the soil base as a (slowly) renewable resource since top-soil posses the ability to regenerate itself. Examples are the natural additions to top-soils through soil formation and the regeneration of minerals through the decomposition of organic matter and nitrogen fixation (Ladd and Amato, 1985). In addition straw and roots contain nitrogen and when left on the croplands after harvesting they will be recycled to the soil (Aune and Lal, 1995)[4]. Soil can also be

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[3] In Hotelling models, extraction costs are assumed to be independent of both stock and extraction rate.

[4] If soil depth is considered the stock variable, the resource can be classified a slowly renewable resource (Barber, 1984). One compareable natural resource is ground water. Soil formation and groundwater recharge are

analysed as a renewable resource with a threshold value below which resource use becomes irreversible. There are especially two features that distinguish soil conservation models from other models in resource economics. First, that revenues or pay-off not only depend on the extraction rate (decision variable) but also on the stock variable, since the soil base itself (soil quality and soil depth) is a direct input variable in the production of agricultural outputs. Second, there are (often) more than one decision variable which have a direct effect on the evolution of the stock variable over time, and the direction of these effects contradict each other.

Compared to static analyses of farm household behaviour, a dynamic specification of agricultural production decisions introduces new rules for optimal behaviour. In a static framework, inputs are employed until their marginal benefit equates marginal variable costs. In a dynamic setting the concept of user cost (the shadow price) of soil is introduced. The multi-period formulation enable us to pay notice to the fact that any decision made in any period of time have future consequences on soil fertility. Herein lies the treatment and awareness of soil being a scarce resource. Depleting soil fertility represents an immediate benefit through higher yields, but involve future costs in the sense that soil fertility for future production are lost. An optimising farmer must pay attention to such considerations when allocating the use of the soil resource over time. As a consequence, there are additional costs in the production of agricultural outputs, beyond the variable costs associated with labour use and the purchase of external inputs. Land has become a production factor whose use implies a future production penalty. The shadow price of soil reflects this cost - the discounted value of the reduction in the production potential for all subsequent cropping periods.

# 5. Economic models of soil conservation

We will in the following review some of the soil conservation models appearing in the literature, and focus attention on how the relationships between the decision variables (control variables) and short-term output and long-term soil fertility are assumed to be. How these functional relationships are specified and their properties are important for the conclusions arrived at. The methodology applied in nearly all studies reviewed is optimal control theory, and most models abstracts from multiple outputs and focus on a single crop choice or a given crop mixture.

In order to clarify differences and similarities between the models commented upon a model is presented which encompass many of the models discussed below in that they appear as special cases of the benchmark model. In addition some of the results arrived at are summarised in Table 2 below. The maximisation problem for a rational farmer given the benchmark model is as follows;

$$\underset{Z,C,W}{Max}\int_{0}^{\infty}[PF(S,Z,C,W)-H(Z,C,W)]e^{-rt}\,dt \qquad (1)$$

$$s.t.\;\; \dot{S}=G(S,Z,C,W) \qquad (2)$$

The farmer maximises discounted net revenues over an infinite horizon (1) w.r.t. three different agricultural activities or input groups (Z,C,W), given a scarcity constraint represented by a dynamic equation describing soil fertility (S) or soil depth evolution (2). F(*) is a production function which depends on both the stock of soil fertility (S) and the group of agricultural decision variables (Z,C,W). H(*) is the input costs being a function of the three agricultural activities, while G(*) represents the

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both processes which take place slowly over time. If Nitrogen recycling is considered, soil as a renewable resource adjust more rapidly, within a time-scale relevant for short-term economic decision making.

rate of change in the stock of soil fertility (or soil depth) over time as a function of both the stock variable itself and the group of decision variables. P and r are the agricultural output price and discount rate, respectively. The assumptions on technology for each of the models discussed are presented below.

An important theoretical work on soil erosion is McConnel (1983), which determine when the private path of soil loss differs from the social optimal path. Two different models of the optimal control of soil erosion are presented in his paper, however only one of the frameworks is applied in the analysis conducted. In the first model, the decision variable is the soil loss rate itself, Z, where a higher soil loss rate is assumed to increase current production (category I in Table 1). McConnel is not very precise on the justification of the functional relationship assumed but mentions cropland expansion as an example «....for example output can be increased by cultivating land with greater slope, increasing soil loss» (McConnel, 1983, p.84). In addition an index of variable inputs is introduced, W, assumed to increase immediate output but have no effect on soil depth (category II). His model can be summarised as follows: $F(S,Z,W,\underline{C}) = f(S,Z,W)$, $H(\underline{Z},\underline{C},W) = qW$, $G(\underline{S},Z,\underline{C},\underline{W}) = M-Z$. q is the unit price of non-soil inputs (W) and M a constant representing natural additions to soil depth (S)[5]. Barrett (1991) applies the same model, but give a more elaborate justification of the model specification. The farmer can choose among different cultivation practices such as crop pattern, the extent of terracing, windshields and the amount of land covered with permanent vegetation. All such practices are collapsed into one decision variable (soil loss, Z) thus representing a trade-off (category I). The decisions made about the soil loss rate is to reflect a soil investment/disinvestment program. An index or vector of productive inputs is also present, and nitrogen fertiliser is mentioned as an example (category II).

When analysing the role of risk aversion in connection with soil depletion incentives, Ardila and Innes (1993) presents a land degradation model with one decision variable only, the output level. In this study a trade-off between current output and future output is assumed in that higher agricultural production is associated with more soil depletion (category I). In a recent study by Goetz (1996) the farm manager is allowed to choose between two crops, each with distinct erosion rates. In addition the farmer can control soil losses by the intensity of the use of inputs, where more input use means more erosion (category I)[6]. Larson and Bromley (1990), analyses the role of property rights in a fallow-rotation system and presents a model in which the household is to allocate labour and land between cropping and fallowing activities given constraints on time and labour. In this model land under fallow represents costs in terms of foregone since land under fallow is temporarily lost for crop cultivation. However, fallowing will improve the future fertility of soil and generate yields in terms of harvested trees. This model shares similarities with output-induced soil degradation models in that additional labour devoted to crop production will increase immediate output but lower the future fertility of land. Higher crop production can also be achieved by devoting more land to cultivation at the expense of fallowed land, a course of action which also cause a decline in future soil fertility.

In the analyses mentioned above there is only one decision variable influencing the evolution of soil over time for a given crop choice. However, other studies treat the soil base as being influenced by two or more decision variables, in the following denoted as general soil conservation models. The

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[5] Underlined variables will in the following denote variables appearing in the benchmark model which do not enter the functional relationship of the particular model discussed.

[6] In Goetz(1996) there are two decision variables determining the soil evolution since crop pattern is decisive for the degradation processes experienced.

second model suggested by McConnel (1983) belongs to this group. Here all inputs are of two types. First, a vector of productive inputs, Z, which increase current output when employed in larger quantities but increase soil loss (category I). Second, ameliorative inputs, C, which reduce soil loss but have no effects on current output (category V). The same model is applied by Barbier (1988, 1990) where the first «input package» includes productive inputs (and labour), crop varieties, and cropping patterns and techniques, while the second «input package» includes soil conservation methods such as bench terraces and agroforestry, assumed to arrest erosion when applied in larger quantities. The two models can be represented as follows; $F(S,Z,\underline{C},\underline{W})=f(S,Z,)$, $H(Z,C,\underline{W})=kZ+vC$, and $G(\underline{S},Z,C,\underline{W})=g(Z,C)$[7]. Where $g(*)$ is the net soil loss function in which Z is a negative argument while C enters as a positive argument. k and v are the units costs of productive and conservation inputs, respectively. Barrett (1996) extends the model in Barrett (1991) by introducing an additional control variable - conservation inputs (terrace construction) assumed to be output neutral (category V) - which together with the soil loss rate (category I) determines soil depth evolution over time. The third control variable, a vector of productive land-neutral inputs (category II - non-soil inputs in the terminology of Barrett), represents labour, fertiliser use, and irrigated water. The model can be described as follows; $F(S,Z,\underline{C},W)=f(S,Z,W)$, $H(\underline{Z},C,W)=qC+vW$, $G(\underline{S},Z,C,\underline{W})=M-g(C)Z$. q and v are the unit costs of conservation inputs and non-soil inputs, respectively. C is a negative argument in $g(*)$ so that more conservation effort reduces soil losses.

**Table 2. Modelling of agricultural investments in relation to land degradation processes**

| | | Categories | | | | | |
|---|---|---|---|---|---|---|---|
| | | Productive Investments | | | Conservation Investments | | |
| | | I | II | III | IV | V | VI |
| McConnel 1 | (1983) | x | x | | | | |
| McConnel 2 | (1983) | x | | | | x | |
| Barbier | (1990) | x | | | | x | |
| Barrett | (1991) | x | x | | | | |
| LaFrance | (1992) | x | | | x | | |
| Ardila and Innes | (1993)[1] | x | | | | | |
| Goetz | (1996) | x | | | | | |
| Grepperud | (1996a)[2] | x | | | (x) | (x) | (x) |
| Grepperud | (1996bc)[3] | x | | (x) | x | | (x) |
| Clarke | (1992) | x | | | | x | |
| Barrett | (1996) | x | x | | | x | |

*1) In Ardila and Innes (1993) output itself is the decision variable, thus inputs and/or farming decisions are suppressed.*
*2) In Grepperud (1996a) conservation investments are analysed as the build-up of conservation capital. The parentheses illustrates that the decision variable ( conservation capital) is allowed to have various effects on immediate output ( be both output-decreasing, output-neutral or output-increasing).*
*3) In Grepperud (1996bc) the model contains three decision variables all affecting the soil evolution over time. The parentheses illustrates that the win-win decision variable can be interpreted as belonging to both category III or VI in Table 1.*

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[7] The soil loss function presented is the one applied by Barbier. McConnels' specification is $G(\underline{S},Z,C,\underline{W})=M-g(Z,C)$, where M is a constant representing natural additions to soil depth due to soil formation processes and $g(*)$ is the soil loss function.

LaFrance presents a model on soil degradation with two control variables both having a direct effect on future soil fertility. The two decision variables are classified as crop-increasing/land degrading (Z; category I) or crop-reducing/land improving (C; category IV), which coincides with the «polar cases» of Reardon and Vosti[8]. LaFrance (1992) mentions fertiliser use, water irrigation, and ploughing as examples of the first input group (cultivation rate). The same arguments are applied by Ardila and Innes (1993) when justifying their model of output-induced soil depletion[9]. The second input group (conservation rate) of LaFrance reflects soil conservation measures like windbreaks, liming, and conservation tillage. A similar specification is applied by Grepperud (1996a), but the crop-reducing/land improving inputs are here replaced with conservation capital (stock of soil conservation capital), in order to reflect that many conservation measures have an effect beyond the crop season they are implemented. The model of LaFrance is as follows; $F(S,Z,C,\underline{W})=f(S,Z,C)$, $H(Z,C,\underline{W})=vZ+qC$, $G(\underline{S},Z,C,\underline{W}) =g(Z,C)$[10]. v and q are units costs of productive- and conservation inputs, respectively. The net change in soil fertility, g(*) depends negatively on productive inputs and positively on conservation inputs.

Grepperud (1996bc) presents a conservation model with three control variables all affecting the evolution of soil over time, when analysing the effects on soil conservation incentives from poverty and risk averse preferences. In addition to cultivation intensity (Z; category I) and conservation intensity (C; category IV), the third control variable is to represent a vector of win-win technologies, W, assumed to increase immediate output but also to arrest land degradation processes (categories III and VI). Here, each variable is assumed to include both input use and cultivation practices, and the costs associated with every activity include input purchase costs, opportunity costs of non-marketed inputs, and labour costs. The production function and the cost function are similar to the ones presented in the benchmark model and S, Z and W are all positive arguments in the production function while C is a negative argument. Input costs are assumed to increase with all three activities. The change in soil fertility is as follows; $G(\underline{S},Z,C,W)= M-g(Z,C,W)$, where M represents additions to soil fertility due to soil formation and/or the decomposition of crop residues.

Clarke (1992) presents a model with features similar to the one by LaFrance. The model contains two variable inputs; productive inputs (Z) and conservation intensity (C), where Z can represent any input such as land or fertiliser while C is investments in soil quality and can represent fertiliser or lime to soils, the application of drainage or leaching technology, the use of contour cultivation. However, the output level itself is assumed to influence soil quality (S). The model can be presented as follows; $F(S,Z,\underline{C},\underline{W})=f(S,Z)$, $H(Z,C,\underline{W})=vZ+qC$, $G(S,Z,C,\underline{W})=\alpha C-\beta S-\gamma f(S,Z)$. Note that the change in soil quality is positively related to conservation investments but negatively related to output. In addition soil quality also depends on an additional term, the stock of soil quality (S) multiplied to a constant $\beta$, meant to represent that soil quality regenerate or deteriorate (depending on $\beta$ is assumed positive or

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[8] The structure of the erosion model applied in McConnel (1983) and Barbier (1990) coincides with the soil degradation model of LaFrance (1992), with one exception. McConnel and Barbier assume conservation inputs to be output-neutral (V) while LaFrance models them as output-decreasing (IV).

[9] Ardila and Innes (1993) also argue for fallowing and cultivation practices as examples on output-induced soil depletion.

[10] In a mathematical appendix LaFrance also consider a model where the soil fertility evolution depends on the soil stock. In Grepperud (1996a) C is replaced with K (the stock of structures) thus an additional differential equation is introduced into the problem ( $\dot{K} = I - \partial K(t)$ ) compared with the model of LaFrance.

negative) in the absence of conservation technology. A higher rate of conservation intensity, C, will strengthen future soil quality but have no direct effect on immediate output. As a consequence C can be classified as an output-neutral conservation investment (category V). A higher level of Z increases immediate output and have an indirect effect on future soil quality since higher crop production reduces soil quality. As a consequence, Z can best be classified as a land degrading productive input in this model (category I).

Brekke et. al (1996) conducts a simulation study on a degradation model for Tanzania in order to investigate if current observed land degradation processes are optimal or not. In doing so they present a theoretical model which focuses on two land degradation processes, soil mining (the loss of nutrients) and soil erosion. As a consequence soil fertility becomes a function of two stock variables, stock of nutrients and soil depth. The two stock variables together with two input (decision) variables; capital and labour, are all arguments in the crop production function. A third decision (input) variable, fertiliser, is not an argument in the production function, but is assumed to add to the stock of nutrients, in this way contributing to higher crop production. As was the case in the models of Ardila and Innes (1993) and Clarke (1992), the output level itself has effects on future soil quality. In this model, however, the implications of higher output on future soil fertility are somewhat different. First, higher crop production and more erosion will both increase nutrient losses, as a consequence crop production in the future will be lower. Second, a higher production of crops is assumed to arrest soil erosion. In this model, fertilisers can be classified as a win-win input in that additional use of this input improves future soil quality by adding nutrients but also by arresting erosion (category III). The classification of capital and labour is not straightforward since they have opposite effects on the two stock variables appearing in the model. If only erosion processes are studied, both inputs are win-win inputs in that they contribute to a higher output and thus less erosion. As concerning the nutrient-cycle, both become land-degrading productive inputs (category I) since increased crop production imply more consumption of nutrient from the soil. This model however, does not consider the role of soil conservation technologies.

As seen from the above presentation, the decision variables appearing in most models are aggregates of various inputs and /or include several cultivation and cropping practices which share common characteristics with respect to their effects on immediate output and long-run soil depth and/or soil fertility. The specifications of the problem of soil conservation and the empirical justification of the functional relationships assumed and their properties, vary to some extent across the models considered. One example is chemical fertilisers, assumed to be soil degrading (I), soil neutral (II) or soil improving (III), depending on the study considered. There are several reasons to the observed disparities across the models. The empirical justification depends on whether all degrading processes are considered, or whether the perspective is more narrow, focusing on one process, only. Furthermore, the conceptual problems associated with the classification of productive and conservation inputs, and the general lack of empirical data, contributes to different approaches. In addition land degradation processes are site-specific phenomena, meaning that relationships between causes and consequences can be different across regions. In some respects land degradation is still an inadequately understood phenomena and there is still some controversy in the soil science literature both on the identification of separate causes and to what extent available evidence can be generalised.

A similarity between general soil conservation models, is the distinction made between productive and conservation investments. The resource manager has several options at his/her disposal which differ with respect to their effect on immediate output and on the future productivity from lands. The models do not view farmer choices as being a product of tradition, only, but emphasise the possibility of choosing among many activities all lying within their technological horizon. The land manager is aware of the relationships between the various agricultural investments made and their implications on their most important asset, top soils. The decision maker is continuously adapting to a changing environment in order to optimise the returns from lands. In the next section we will sum up the main conclusions arrived at in the theoretical studies. In particular, discuss how macroeconomic and sectoral policies can affect farm household resource decisions.

## 6. Macroeconomic policies and the incentives for soil conservation

Barrett (1996) discusses how macroeconomic and sectoral policies can affect the incentives for soil conservation at farm-level due to their effect on prices on agricultural outputs, inputs, and on discount factors, and provides a description on how various policy reforms are expected to influence these parameters. How they change depend on what policy reforms - exchange rate controls, quotas, output taxes, input subsidies, and industry protection - actually are considered and will not be discussed here. A second step, after the interlinkages between policy reforms and parameter changes have been understood, is to investigate how shifts in internal terms of trade affect soil conservation incentives. How will a land manager respond to changes in output prices, input prices, and discount factors changes which follows from macroeconomic and sectoral policy reforms? Such issues are addressed in Barbier (1990), Barrett (1991, 1996), LaFrance (1992), Clarke (1992), Goetz (1996) and Grepperud (1996a). In all papers parameters are assumed to be fixed and the implications of policy reforms are analysed as unanticipated permanent changes. Furthermore, all studies analyse the impacts of such changes in steady state, since it is the long-term effects on the resource base which are of primary interest[11].

A striking result from general soil conservation models is the indeterminacy with respect to the implications for the soil base from changes in any price and in the discount factor. This result apply independent of which of the above general models the analysis is conducted within. The main reasons for such conclusions are due to the stock of soil being a direct input in production and due to the evolution of the stock variable being governed by at least two choice variables with contradicting effects. The only way to arrive at unique conclusions is to make very restrictive assumptions on technology which can not be verified by evidence due to the very detailed information needed. If reasonable or intuitively appealing assumptions on technology are made, the inability to sign of the effects from such changes still prevails. One way out is to undertake model simulations. However, such a procedure necessities a detailed database for assigning the various numerical values.

Valuable insights on agricultural investment decisions can however be gained by studying the effects from each decision variable at a time. This is done by studying each agricultural activity, keeping the other(s) fixed at some level throughout the planning horizon (direct effects). Hence most indirect effects (represented by cross partial derivatives of the production function and the fertility loss function) which makes it difficult to sign the effects in a general setting disappears. Such a partial approach illuminates key differences between the different types of agricultural investments, thus creating a better understanding of important forces at play. Below we will pursue such an approach by

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[11] Short-term effects from changes in policy variables are analysed in LaFrance (1992) and Barbier(1990). The sign of the qualitative effects coincide with the long-run effects for both prices and discount rate changes.

focusing on the effects of the «polar cases»; land degrading productive investments (category I) and output decreasing conservation investments (category IV).

Let us first consider land degrading investments (category I), only, and price changes. A lower input price (e.g., productive input subsidies) will make it profitable for a farmer to apply more of this input which has become relatively cheaper. Thus, the incentives for soil conservation have weakened since increased input use speed up land degradation processes. The effect from a rise in the agricultural output price is more complex. A higher output price will increase the value of current yields from cultivation, thus acting as an incentive to invest more resources into productive land degrading activities. However, a higher (permanent) output price will also increase the future returns from productive activities; the shadow price of soil increase as a result of such an increase. This effect pulls in the opposite direction and constitutes an incentive for the farmer to «save» soil fertility for future production by deinvesting in degrading activities. It can be shown that the first effect dominates the second one, as long as there are increasing variable costs associated with a more «intensive» cultivation (see Grepperud, 1996a). As a consequence, a higher output price weakens the incentives for soil conservation when productive land-degrading investments are considered.

As was the situation for productive inputs (I), input subsidies on conservation activities (IV) will induce the farmer to apply more of such inputs, thus the long-term soil fertility will now be improved as a result of such actions. A higher output price will as before increase the shadow value of soil, but also represent higher immediate costs due to the reduction in cultivated area which arise from the application of structural conservation measures. A higher output price means that immediate costs in terms of foregone production have become significantly higher. The overall effect will be that higher farm-gate output prices will strengthen the incentives for soil conservation, as long as variable costs increase with such activities. It has become relatively more profitable for a farmer to invest in structural conservation measures.

It follows from the above discussion that the partial effect from each of the two agricultural investments on soil conservation incentives are opposite. A higher output price strengthens the incentives for a more intensive cultivation, but on the same time improves the incentives for devoting more resources to soil conservation. The reason for the opposing conclusions arises from the way variable costs are for the two agricultural activities analysed. For productive investments, soil conservation can only be achieved by reducing the intensity at which land is cultivated. To apply less of land degrading inputs means that less resources are needed. Considering conservation activities, more soil conservation means that more resources are needed to arrest land degradation[12].

The role of variable costs are crucial for the opposite conclusions arrived at in the partial models. The higher the costs associated with increasing the intensity of an activity are, the stronger will the effect be. If there are no variable costs associated with changing the intensity at which land is cultivated or conserved (fixed costs), then there will be no partial effect from a output price change. For conservation activities, the assumption of increasing variable costs, seems obvious. The same apply for conventional input use such as fertilisers and water irrigation, while for some cultivation practices a

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[12] In Grepperud (1996a) it is shown that a higher output price can in some situations reduce the incentives for applying structural soil conservation measures, in a partial model, if implementatition costs are assumed to decrease in the stock of structures (learning-by-doing effect). However, such an effect will not change the conclusion arrived at in a more general framework.

monotone relationship between costs and more degrading cultivation practices need not be the case. In the model specifications suggested by McConnel (1983) and Barrett (1991,1996), changing the soil loss rate is assumed to have no implications for costs. Whether or not the intensity at which land is cultivated is assumed independent of costs, will however not change the conclusion arrived at in general soil conservation models. In spite of the absence of a direct effect from cultivation intensity on the soil base and the existence of a direct land improving effect from soil conservation measures, the overall effect on soil conservation incentives can still go either way, due to the presence of indirect effects. However, the assumption of input costs being monotone in more erosive/degrading cropping practices seems to be the assumption which best capture the relationship between cultivation practices and variable costs. Cropland expansion, crop-season extension, weeding and more erosive tillage practices will often imply more input use both in terms of labour effort and cash expenditures.

The significance of indirect effects in a general setting is clearly seen when the consequences of higher discount rates on soil conservation incentives are studied. The qualitative direct effects from each of the two activities (partial effects) will now go in the same direction. A higher discount rate means that future benefits are valued less compared to immediate gains, thus the shadow price of land has decreased, thus the incentives for saving soil for future production have weakened. It becomes optimal to invest more in land degrading activities and less in conservation measures. In a general model, where both activities are considered simultaneously, it is surprisingly still not possible to arrive at a unique conclusion. However, all outcomes are not equally likely, most of the identified effects from a higher discount rate pulls toward a weakening of the incentives for soil conservation.

The partial effects from price changes on land neutral productive investments (II) and win-win technologies (III, VI) can easily be derived on the basis of the above discussion. A lower input price and a higher output price for land neutral productive inputs (II) will act as an incentive to increase the use of such inputs, since having no direct effect on the natural fertility of soils, they will not affect the incentives for soil conservation. However, in a general framework, the optimal use of other variables will change in response to such inputs changes. If these determine soil evolution, conservation incentives will be affected one way or the other. The role of win-win technologies which are assumed to arrest land degrading processes is discussed in Grepperud (1996a). For this group of agricultural investments, lower input prices and higher output prices, will increase the quantity demanded of such inputs, as a consequence conservation incentives have improved. The partial effects for win-win technologies coincide with those of soil conservation measures (IV, V). The fundamental reason for the identical conclusions arrived at is due to that more resources are needed to be invested for both activities in order to reduce the rate at which soils are deteriorating. For productive land-degrading inputs the situation is opposite - less resources need now to be devoted to this activity in order to weaken degradation processes. Including win-win technologies into a model where the polar cases already are modelled (see Grepperud 1996bc) will not change the conclusions arrived at in general conservation models. The final effect on the resource management incentives can still in principle go either way.

The conclusions arrived at in theoretical studies shed light on the issues raised by Reardon and Vosti. If farmers are not wed to a certain set of technologies but seek a combination of them, they will respond to changes in relative prices. How changes in household behaviour affect the incentives for soil conservation depend on the agricultural investments being within the technological horizon of the farm household considered. The theoretical studies further confirm, as pointed out by Reardon and

Vosti, that policy analysts need to be aware of in what way conservation investments differ from the more familiar productivity investments. Above we have illustrated that price changes have opposite partial effects for the «polar cases». Another conclusion is the importance of having access to conservation measures and win-win technologies since such measures enable the farmer to cope better with land degrading processes if profitability increases. The existence of such technologies makes a more sustainable use of the land resource more likely. The presence, knowledge and access to such technologies are crucial. Reardon and Vosti find that win-win inputs (overlapping technologies) in general are on the shelf, and that there is a pressing need to make them acceptable and attractive to farmers. However, the absence of soil conservation measures and win-win-technologies, does not necessarily mean that such technologies are beyond the horizon of a farm household, but can arise from such activities being resource-demanding or perceived as expensive. Crop residues and dung have an alternative use as fuel and fodder, structural soil conservation are costly both to install and maintain and involve heavy labour requirements and input use. An improvement in farm profitability will make the implementation of such measures more likely, however the same change may also induce the land managers to adopt more degrading farming practices.

# 7. Conclusion

The modelling of soil conservation problems must be a simplification of the complex interactions which matter between human and physical factors, in order to allow insights into economic forces and their relationship with resource management. Many of the simplifications are already mentioned, in addition most studies ignore the role of technological change and focus on decision makers who are fully informed about complex soil-plant processes and how cultivation practices and input use influence them. Also other relevant relationships are not considered. Soil depth and soil quality can influence production costs and the rate at which soils are regenerating, and various agricultural activities are often interlinked. However, including such properties is not likely to change the main conclusions arrived at. The same apply if a more detailed specification of agricultural inputs is undertaken, instead of grouping those with similar characteristics into vectors or indexes. An additional numbers of input variables will imply an increasing number of possible substitution effects.

Real life agricultural production systems involve numerous decisions. A farmer can arrest degradation processes not only by investing more effort into various soil conserving activities such as terraces, ditches and crop residue management, but also by abstaining from production in the short run. It is the possibility of multiple responses which makes it difficult to arrive at determinate predictions with respect to the effects of macroeconomic and sectoral reforms. As long as farmers have several options at their disposal to influence the rate at which land is deteoriating, it is not possible to predict parameter changes affect the incentives for soil conservation In addition, the effects are likely to be site-specific and depend on both physical conditions prevailing in a given region and on the technological horizon of the household considered. What are the options for a farmer when responding to changes in relative prices? How are the variable costs associated with such changes? To what degree are conservation measures and win-win technologies accessible? To arrive at probable predictions such issues need to be addressed.

We have identified some conceptual problems associated with defining agricultural investments, and shown that the empirical justification of functional relationships vary across the models appearing in the literature. However, the assumptions made are not crucial for the main conclusions arrived at. A robust conclusion seems to be that as long as a land manager can influence the soil resource by more than one strategy, the overall effect from policy reforms are indeterminate. Theoretical modelling act as a basis for understanding economic behaviour and enables us to identify factors which influence the incentives for resource management and what their underlying forces are. All insights, which may not have been identified in more detailed analyses.

The occurrence of high erosion rates or a rapid degradation of land does not imply that excessive degradation is taking place from the farmer's point of view. For the resource manager such a development could well be desirable. If however, the rate at which soils are degrading is excessive from society's point of view (e.g. due to off-farm externalities or imperfect markets), there is a rationale for social intervention. However, the implementation of various policy reforms will not necessarily bring the development in the desired direction. Another conclusion is that agricultural intensification - defined as an increase in input/land ratios - does not imply that land degradation processes are speeded up. The same ratio will rise as more resources are invested in soil conservation measures and win-win technologies. Furthermore, higher output/land ratios do not inevitable mean increased soil depletion, due to the presence of win-win technologies. Agricultural intensification can cause a more sustainable management of top soils.

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