LEEC PAPER 89-08

Optimal Soil Conservation and the Reform of Agricultural Pricing Policies

SCOTT BARRETT

IIED

INTERNATIONAL INSTITUTE FOR ENVIRONMENT AND DEVELOPMENT

IIED/UCL LONDON ENVIRONMENTAL ECONOMICS CENTRE

The IIED/UCL London Environmental Economics Centre

This Centre was established in 1988 and is a joint venture by the International Institute for Environment and Development (IIED) and University College London (UCL). Its aims are the furtherance of policy relevant research in the field of environmental and natural resource economics, particularly in the context of developing countries.

The Author

Scott Barrett is a Lecturer in Economics at the London Business School, and an Associate Fellow of LEEC.

Contact Addresses

The author may be contacted at:

London Business School
Sussex Place
Regent's Park
London NW1 4SA
England, UK.

Tel: 01 262 5050 ext. 398 Telefax: 01 724 7875

or via,
IIED/UCL London Environmental Economics Centre
IIED
3, Endsleigh Street
London WC1H ODD, UK.

Tel: 01 388 2117 Telefax: 01 388 2826

OPTIMAL SOIL CONSERVATION AND THE REFORM OF AGRICULTURAL PRICING POLICIES*

Scott Barrett

London Business School

April 1989

Abstract. Soil degradation is often blamed for the poor performance of agriculture in developing economies; so too are policies which keep the prices of both outputs and inputs artificially low. Some economists have argued that pricing reforms will encourage soil depletion; others say that such reforms will encourage soil conservation. To evaluate these claims, this paper develops models of the optimal control of soil erosion and soil fertility. It is shown that the effect could go either way but that there are strong reasons for suspecting that pricing reforms will not affect soil conservation dramatically.

*This paper is a shortened version of a chapter of my London School of Economics PhD thesis. I have benefited greatly from discussions with Partha Dasgupta and David Pearce. David de Meza commented on an earlier draft. Financial support for my graduate studies in the form of a scholarhsip from the American Friends of the LSE and an Overseas Research Student award from the Committee of Vice-Chancellors and Principals of the Universities of the United Kingdom is gratefully acknowledged.

Address. Scott Barrett, Lecturer in Economics, London Business School, Sussex Place, Regent's Park, London NW1 4SA, England.

Blame for the poor performance of agriculture in many low-income countries is believed to lie partly with policies which keep prices of both outputs and inputs artificially low (World Bank, 1986)[1] and partly with inadequate soil conservation [see, e.g., USAID (1988) and Warford and Ackermann (1988)]. Two important questions for policy are whether low prices encourage farmers to deplete soil, and whether the suggested reforms will do much to reverse the trends of stagnant or declining productivity by providing farmers with greater incentives to conserve soil.

Gray (1913) was perhaps the first economist to claim that higher output prices would encourage soil conservation. More recently, Repetto (1987, p. 45) has argued that as a consequence of keeping agricultural output prices artificially low in developing countries

> "...returns on investment in farmland development and conservation are depressed. Farmers are discouraged from levelling, terracing, draining, irrigating, or otherwise improving their land. The loss of land productivity through erosion, salinization, or nutrient depletion is less costly relative to other values in the economy. In general, depressing agricultural prices depresses farmer incentives for soil conservation."

Superficially, Repetto's claim might seem plausible. But Lipton (1987, p. 209) argues precisely the opposite case:

> "...as a rule, 'the environment' responds badly to the normally advised, and otherwise often desirable, price reforms. Better farm prices now, if they work as intended, will encourage 'soil mining' for quick, big crops now....The corrections that pricists advocate, while generally justified, will not produce earthly or even environmental paradise, but will normally have damaging environmental side-effects, requiring preventive or corrective action by the state."

I am not aware of any empirical study which has attempted to establish a direct link between price and soil conservation. However, research has shown that the *aggregate* production impact of price policy changes in many low-income countries is slight.[2] Bond (1983) estimated the relationship between aggregate output and price for nine sub-Saharan countries, and found that in only two of these countries was the relationship significant. Perhaps just as important is her finding that the long-run response to a price change is the same as, or not much greater than, the short-run response. If soil conservation responds positively (negatively) to price increases one would expect the long-run elasticities to be significantly larger (smaller) than the short-run elasticities. Of course the fact that they are not does not necessarily mean that soil conservation is unresponsive to price; many other factors are involved [see, e.g., Streeten (1987)]. But the evidence at least suggests that reform of agricultural pricing policies will be inadequate to the task of significantly raising agricultural output in sub-Saharan countries.

In this paper I attempt to sort out the opposing views on the relationship between price and soil conservation. I consider two soil conservation problems: the control of soil erosion; and the control, by natural means, of soil fertility. I begin by modifying McConnell's (1983) model to characterize an optimal soil erosion control program. I then show that changes in either the output price or the input price may not affect the erosion control decision directly. However, an indirect effect is possible: if soil conservation appears more attractive when more of a non-soil input is used, then the price change may encourage soil conservation by inducing farmers to use more of the non-soil input. The problem is that the price change may well encourage further erosion. The sign and magnitude of the indirect effect are matters for empirical estimation.

The above model suggests that unless additional non-soil inputs such as fertilizer are employed, the effect of a price rise on soil conservation may well be nil. But farmers in low-income coutries often control soil fertility by natural means--especially by adjusting the length of fallow periods. Another important question for policy, then, is whether a price rise will encourage farmers to improve fertility by lengthening fallow periods. In Section 3 I construct a model of optimal shifting cultivation, and show that price increases will have no effect on soil fertility if only traditional production techniques are employed.

Taken together, these results suggest that pricing policy reforms may have little effect on soil conservation--or perhaps even output; alternative polcies will be required to encourage greater erosion control and soil fertility maintenance.

1. The Optimal Control of Erosion

The control of erosion represents a classic problem of balancing the immediate gains of an action with the associated long-term losses. Soil depth has a positive effect on output because in deeper soils there is more room for plant roots to take hold, and more nutrients available for plant growth. But conservation of soil nearly always requires sacrifices in output in the short run. Agricultural production can be increased in the near term by clearing and cultivating on hillsides. But unless terraces are built, such gains will be short-lived, for the soil will be quickly eroded away. Similarly, wind breaks, strip cropping and conservation tillage can extend soil productivity in the long run, but only at the expense of foregone near-term output. How should these gains and losses be balanced?

Following McConnell (1983), let the dynamics of soil depth (S_t) be described by

$$\mathring{S}_t = M - R_t, \; M > 0, \qquad (1)$$

where M represents naturally occuring additions to the topsoil and R_t is soil loss attributable to cultivation. Soil forms naturally at rates of about 0.01-0.5 mm per year (Myers, 1988). If the soil is covered with natural vegetation, soil loss will occur at a rate of about 0.02-1 mm per year. M here is taken to be the *net* rate of natural renewal. When the land is cultivated, the net overall rate of soil loss can be positive. When grassland is converted to row crops, for example, erosion increases by a factor of 20-100; when a forest is converted, this figure rises to 100-1,000 (Myers, 1988).

What determines soil loss? As recognized by the Universal Soil Loss Equation (Crosson and Stout, 1983; Unger, 1984), the amount of soil eroded by water depends on a number of factors. Some of these, such as rainfall, are determined by nature. Others depend on the actions of farmers. All else being equal, the rate of soil loss by water will be greater: (i) the steeper is the slope of land brought under cultivation, (ii) the smoother is the tillage, and (iii) the larger is the area planted with row crops such as corn instead of grasses. The rate of soil loss by water also depends on whether contour tillage, strip cropping on the contour, terracing and conservation tillage are practiced, and on the extent and nature of crop rotation.

A similar equation describes erosion by wind as a function of variables under the influence of both nature and farmers (Unger, 1984). All else being equal, erosion by wind will be greater: (i) the smoother is the soil surface, (ii) the smaller is the amount of land sheltered by wind breaks, and (iii) the smaller is the amount of land covered in vegetation.

Both relations indicate that the rate of soil loss is subject to partial control by farmers. The nature of the control is indirect: farmers choose a cultivation practice--that is, they decide which crops to plant, the crop rotation and pattern, the extent of terracing, the amount of land covered in vegetation, the type of tillage, etc.--and a certain amount of erosion results. For our purposes, we might as well assume that farmers choose R_t directly.

Provided we assume that a single crop is produced and that labor supply is fixed, efficient agricultural output may be expressed as a function of both soil depth and the rate of soil loss attributable to cultivation. Denote this function $F(R_t,S_t)$. When only a single crop is produced, choice of a cultivation practice in period t will determine output in period t, given soil depth. If land is taken out of permanent vegetation, or if trees which shelter the fields from wind are cut down, R_t will rise; and so too will current output (assuming that the cleared land is put into crop production), the extent of the rise being larger the deeper is the soil. It is very likely that a point will be reached where additional soil and more intensive farming practices have no effect on current output (Crosson and Stout, 1983), but to sharpen the results of the model I assume that F is increasing, twice differentiable and strictly concave. It also seems reasonable to assume $F(0,S_t) = 0$ and $F(R_t,0) = 0$. The assumption that agricultural output is zero when R is zero is just another way of saying that to grow crops, some land must be tilled.

Let the instantaneous social utility function be given by $U(C_t)$, where C_t is per capita consumption. Assume $U_C > 0$, $U_{CC} < 0$, and $\lim_{C \to 0} U_C(C_t) = \infty$.

In the low-income countries, agriculture accounts for a large share of aggregate output and for virtually all output in rural areas. We might as well assume then that the economy is purely an agricultural one. Letting p denote the fixed price of the output, $C_t = pF(R_t,S_t)$. When discussing society's optimal program, p can be taken to be the world price of the traded crop at the equilibrium exchange rate. [To the farmer, p is the price paid by the parastatal agency or the border price (less transportion costs) converted at the *official* exchange rate.] Note that even though all output is consumed, investment and disinvestment in the capital stock (S) still take place. *Whenever $R_t > M$, there is disinvestment; whenever $R_t < M$ there* is investment.

Society's problem is to

$$\left.\begin{aligned} &\max_{\{R_t\}} \int_0^\infty U[pF(R_t,S_t)]e^{-\delta t}dt, \qquad \delta > 0 \\ &\text{s.t.} \quad \mathring{S}_t = M - R_t,\ S_0 > 0 \text{ given.} \end{aligned}\right\} \tag{2}$$

This is a standard problem of optimal control. In the steady state, soil depth is determined by (see Appendix)

$$F_R(M,S^*) = F_S(M,S^*)/\delta. \tag{3}$$

Is S^* unique? Liviatan and Samuelson (1969) have shown that for problems of this type uniqueness is not guaranteed. Denote the rate of return on soil by $r(R,S) = F_S(R,S)/F_R(R,S)$. In the steady state, $R = M$, and the rate of return on soil depth becomes $r(M,S)$. Uniqueness is guaranteed if $r(M,S)$ is monotonic. Differentiating we obtain

$$r_S = (F_{SS} - rF_{RS})/F_R.$$

Strict concavity of F implies $F_{RR}F_{SS} > F_{RS}^2$, but it does not restrict the sign of F_{RS}. However, if $F_{RS} \geq 0$, then uniquess is assured. This seems to be a highly plausible assumption. More generally, uniquess of S^* will be guaranteed if we assume

$$\lim_{S\to 0} F_S(M,S)/F_R(M,S) > \delta, \quad \lim_{S\to\infty} F_S(M,S)/F_R(M,S) < \delta.$$

Eq. (3) might be called the Golden Rule of Soil Conservation, and it can be given an intuitive interpretation. At time $t = 0$, S_0 is given as datum. R_t, however, is free to be chosen. Consider the policy proposal: set $R_t = M$ for all t. In judging this proposal, we ask: what effect will a small deviation from this policy have on social welfare? Increase R_t by one unit on the interval $[0,\epsilon)$, $\epsilon > 0$, and then set $R_t = M$ for all $t \geq \epsilon$. As $\epsilon \to 0$, this deviation will increase output in the short-run by $F_R(M,S_0)$. However, it will also decrease output over the long-run, the present value loss being $\int_0^\infty F_S(M,S_0)e^{-\delta t}dt$. If the marginal gain of erosion exceeds this loss, then set $R_t > M$. If the marginal benefit of erosion falls short of this loss, then set $R_t < M$. The economy is in equilibrium if and only if $F_R(M,S) = \int_0^\infty F_S(M,S)e^{-\delta t}dt = F_S(M,S)/\delta$.

Assuming $S_0 \neq S^*$, how should the optimum be reached? All our assumptions are not sufficient to characterize the optimal conservation policy. To push the analysis further we will have to specify a functional form for F. An obvious candidate is the Cobb-Douglas function:

$$F(R,S) = AR^{\alpha}S^{\beta} \text{ where } \alpha, \beta > 0, \text{ and } \alpha + \beta < 1. \quad (4)$$

If F obeys (4), then the phase diagram for this problem will appear as in Figure 1.[3] It is easy to verify that the Routh-Hurwitz (necessary and sufficient) conditions for neighborhood stability are satisfied, and that the equilibrium $[\beta M/(\alpha\delta),M]$ is a saddle point.

The analysis up to this point can be summarized by the following proposition.

Proposition 1. *Under our assumptions, there exists a unique steady state solution to problem (2) given by eq. (3). If* F *satisfies (4), then the steady state soil depth is given by* $S^* = \beta M/(\alpha\delta)$. *In this case (provided* η, *the elasticity of the marginal social utility of consumption, is a positive constant) there is a unique optimal approach path tending to the steady state, and along this path both* S_t *and* R_t *are monotonic:* $\mathring{S}_t, \mathring{R}_t < 0 \; \forall \, t \geq 0$ *if* $S_0 > S^*$*; and* $\mathring{S}_t, \mathring{R}_t > 0 \; \forall \, t \geq 0$ *if* $S_0 < S^*$.

We also have

Corollary 1. *For problem (2), an unanticipated permanent increase in the output price will have no effect on optimal soil conservation.*

This last result holds for any functional form for F, and is verified by noting that the Golden Rule of Soil Conservation [eq. (3)] is independent of the output price. To draw out the implications of the model, consider a permanent, unanticipated rise in the output price at date T, and assume that, prior to T, farmers had chosen a cultivation practice which balanced the marginal benefits of soil conservation with the associated marginal costs [that is, eq. (3) is obeyed]. At date T, farmers reevaluate this decision. They still seek to balance marginal benefits and costs. The only question is whether the price rise tilts the balance in the favor of more or less soil conservation. With the output price higher, the benefit of slightly deviating from the equilibrium policy by increasing erosion [the LHS of eq. (3)] increases by the percentage rise in price. The benefit of adopting additional soil conservation measures--the present value sum of future profits made possible by the additions to soil depth [the RHS of eq. (3)]--also increases by the percentage rise in price. But if the percentage change is identical in both instances, then the merits of deviating from the original policy in either direction are exactly the same. Hence the farmer has no incentive to conserve additional soil--or less. If the price rise is to influence the farmer's soil conservation decision, then it can do so only by influencing the farmer's decision to employ nonsoil inputs.

2. Mitigating Erosion-Induced Productivity Losses

Farmers can do more than control erosion; they can also seek to mitigate erosion-induced productivity losses by substituting non-soil inputs. This is usually accomplished by increasing soil fertility--that is, by adding fertilizer. Let N_t be the (variable) non-soil input, which can be thought of as nitrogen fertilizer.[4] Write the agricultural production function as $Q(R_t,S_t,N_t)$, and assume $Q_N \geq 0$, $Q_{NN} \leq 0$, and $Q(R,S,0) \geq 0$ for R, S > 0.[5] Finally, assume the price of the input is fixed at p_N. (Again, to society p_N will be the world price converted at the equilibrium exchange rate. To farmers, p_N may include a subsidy.) Society's problem then becomes

$$\left.\begin{aligned} &\max_{\{R_t,N_t\}} \int_0^{\infty} U[pQ(R_t,S_t,N_t) - p_N N_t]e^{-\delta t}dt, \quad \delta > 0 \\ &\quad \text{s.t.} \quad \dot{S}_t = M - R_t,\ S_0 > 0 \text{ given.} \\ &\qquad\quad N_t \geq 0. \end{aligned}\right\} \tag{5}$$

Assuming that it is optimal to employ some positive amount of the non-soil input, the equilibrium will be given by the solution to

$$Q_R(M,S^*,N^*) = Q_S(M,S^*,N^*)/\delta \tag{6}$$

and

$$p_N = pQ_N(M,S^*,N^*). \tag{7}$$

Note that the interpretation of (6) is entirely unaffected by the addition of the non-soil input. The Golden Rule of Soil Conservation remains: in equilibrium, the marginal benefit of soil conservation must equal the marginal cost. The only change is that the equilibrium now consists of another unknown and another equation. The latter is a familiar equilibrium condition for the employment of variable inputs, and says that the value of the marginal product of the non-soil input must equal the price of the input.[6]

Note, too, that the optimal approach path to the equilibrium need no longer be monotonic, even in the Cobb-Douglas case.

In general, soil depth and the quantity of added nitrogen will be determined jointly in equilibrium. However, depending on the functional specification of Q, eq. (6) may remain a function of soil depth alone. This will certainly be true if Q is Cobb-Douglas. However, it will also be true if Q is a two-level production function with an unrestricted constant elasticity of substitution (CES) between N and F(R,S), where the latter is still held to be Cobb-Douglas:

$$Q(R,S,N) = B\{\pi[F(R,S)]^{(\sigma-1)/\sigma} + (1-\pi)N^{(\sigma-1)/\sigma}\}^{\sigma/(\sigma-1)}, \tag{8}$$

where $\sigma \geq 0$ is the CES and $1 > \pi > 0$. The two-level form has a certain intuitive appeal. For F may be thought of as "utilized soil services," or the amount of soil made available to production, given soil depth, by choice of a cultivation practice (effectively, by choice of R).[7] Output is then seen to depend on how these soil services are combined with nitrogen.[8] In either of these cases, the steady state soil depth toward which the system should tend remains $S^* = \beta M/(\alpha\delta)$.

Proposition 2. *If the technical rate of substitution between the rate of erosion and soil depth is independent of the use of non-soil inputs, as it will be if the production function is Cobb-Douglas or takes the form of eq. (8), then the optimal soil conservation decision will be unaffected by changes in either the output or the non-soil input price. Output may change under these circumstances, but the change will be brought about by adjustments in the use of non-soil inputs and not directly by adjustments in soil conservation.*

This is a powerful result. For notice that the socially optimal conservation rule will be the private farmer's rule if we only substitute the social rate of pure time preference with the farmer's rate of discount.[9] Proposition 2 says, then, that a policy of lifting price controls on agricultural outputs and inputs may have very little effect on aggregate output if the reason for agriculture's poor performance is inadequate soil conservation.

Suppose soil depth is at its optimal stationary state at current prices but that there follows an unanticipated, permanent increase in the output price. The rise in output price will induce farmers to increase their use of nonsoil inputs, and as a consequence output will rise. But unless the addition of nitrogen raises the marginal benefit of conservation by more (or less) than the marginal cost, the effect of adding nitrogen will not upset the balance that existed before the price change; additional (less) soil conservation will not be forthcoming.

To be more concrete, consider a very slight deviation from the original equilibrium. Suppose R is increased for a very short period of time and then once again set equal to M, the consequence being that soil depth is reduced permanently by one centimeter but that present value profits are left unchanged compared with the original equilibrium. Now add an extra unit of fertilizer both to the farm in the original position and the farm that deviated slightly from this position. If as a consequence of adding the fertilizer the profits earned in both instances rise by precisely the same amount, then the price rise plainly would not affect the soil conservation decision. If instead present value profits fall upon deviating from the original position, then the price rise will induce additional soil conservation; and if present value profits rise, then additional erosion will be encouraged. *The mechanism through which changes in the output price influence soil conservation is not enhanced farmland value, as Gray (1913) and Repetto (1987) argue, but the technical nature of the production process. Furthermore, what matters is not the output price alone but the ratio of the output price to the input price.* If the policy reform involves raising both of these prices by the same percentage, then the effect of the reform on both soil conservation and output will be nil. This last finding is important, for low agricultural prices are often accompanied by input subsidies. The relevance of Proposition 2 to policy hangs on the true functional form of the agricultural production function, and this is an empirical question.

Although the indirect effect of price changes on soil conservation could go either way, some evidence suggests that an increase in the output price will encourage soil conservation. Crosson and Stout (1983, p. 56) report: "The yield response to fertilizer on some heavily eroded soils is smaller than on less eroded soils, suggesting that on these soils the response of farmers to erosion may be to put on *less* fertilizer, not more." In the context of our discussion this implies that farmers may well respond to the application of more fertilizer (made economic by an increase in the output price, all else being equal) by conserving more soil.

All erosion control measures with the exception of conservation tillage reduce the quantity of land in row crops, and hence the short-term profitability of the farming enterprise (Crosson and Stout, 1983, pp. 67-68). Interspersing row crops with less-valued or zero-valued grasses (strip-cropping), for example, protects the soil but reduces profits in the near-term. Conservation tillage, a practice whereby crop residue is left on the soil surface, need not reduce the fraction of land in row crops but it will reduce current yields unless additional herbicides are added to suppress the weed growth normally eliminated by tilling. If herbicides are not available (as assumed in Section 1), then an increase in the output price will not alter the farmer's decision to adopt conservation tillage. But if herbicides are available, an increase in the output price may (indirectly) effect additional conservation. The price increase would lead farmers to add more herbicides. But the increment in herbicide use is likely to raise output by more on plots adopting conservation tillage. Hence, conservation tillage will probably appear more attractive after the price rise. Conservation tillage is practiced widely in the United States. Though not as popular in poor countries, use of conservation tillage does hold a promise for higher yields in Africa (Brown and Wolf, 1985, pp. 42-43).

There is one important exception to the above analysis. Where terracing is practiced, current output is sacrificed because some land will have to be taken out of crop production (Brown and Wolf, 1985). But a substantial portion of the total cost of terracing consists of terrace construction and maintenance costs. Here, Gray's (1913) analysis is more applicable. An increase in the output price (all else being equal) will increase the returns to terrace construction and maintenance, but is unlikely to increase the associated costs (the most important being for labor) by very much.[10]

3. Pricing Policy, Crop Choice, and Soil Conservation

The conclusions reached thus far assume that the choice of which crop (or crop rotation) to plant is fixed. But if the relative prices of different crops change, then farmers may want to adjust their crop mix. The empirical evidence indicates that substantial switching does indeed occur as a result of such price changes (see Bond, 1983). And the World Bank (1986, p. 79) has argued that pricing policies can worsen soil ersosion by encouraging farmers to plant less environmentally benign crops:

> "...different crops have different effects on soil conservation, and pricing policies may exacerbate soil erosion by inducing farmers to choose the wrong crops."

Lipton (1987, p. 209) has retorted by saying that "...pricing policies can just as well induce environmentally 'right' crops." And he is correct, of course, in pointing out that price deregulation will not necessarily benefit soil conservation (see also Repetto, 1987). But implicit in both views is the belief that crops entailing more erosion are in some sense "wrong," or that farmers will blindly switch crops without considering the implications of such a change for soil conservation. If farmers switch to a crop that is more destructive to the soil, then the Golden Rule of Soil Conservation will have to be adjusted, but it will not be forgotten. True, if associated with this alternative crop is a larger α and a smaller β then it will be optimal to conserve less soil in the steady state. But this will cause no loss in efficiency provided the prices of both crops reflect their true opportunity costs. Our concern should not lie with soil *per se* but with the land's ability to yield a stream of net social benefits.

How will the dynamics of such a change operate? Consider a very simple example. Suppose there are no non-soil inputs and that at current prices it is optimal for the farmer to produce crop A. Suppose also that soil depth is initially at its optimal stationary level for crop A. At time $t = 0$ the price of crop B (p_B) rises relative to the price of crop A (p_A). The farmer has two options: continue to produce crop A or switch to producing crop B. Denote the optimal stationary soil depth for crop A by S^* and that for crop B by S^{**}. From Corollary 1 we know that these levels are independent of crop prices. Hence, if the farmer decides to continue to produce crop A after the price change, then he or she will set $R_t = M \; \forall \; t \geq 0$. If crop B is more harmful to the soil then $S^* > S^{**}$. Since $S_0 = S^*$, if it is optimal to switch to producing crop B, R must initially exceed M; i.e., $R_0^{**} > M$. There are three cases to consider.

If $p_BF(R_0^{**},S^*) > p_AF(M,S^*)$ and $p_BF(M,S^{**}) > p_AF(M,S^*)$, then the farmer will switch to producing crop B. Crop B is more profitable initially, and it is more profitable in the steady state. Since R and S must fall monotonically to their equilibrium values (Proposition 1), crop B must be more profitable at every time $t \geq 0$. Hence the farmer will unhesitantly switch to crop B, even though it is optimal to conserve less soil when producing this crop. Similarly, if $p_AF(M,S^*) > p_BF(R_0^{**},S^*)$ and $p_AF(M,S^*) > p_BF(M,S^{**})$, then the farmer will unambiguously stick to producing crop A.

If $p_BF(R_0^{**},S^*) > p_AF(M,S^*) > p_BF(M,S^{**})$, then crop B yields greater profits initially but less in the steady state. In this case, the farmer will want to switch crops *if and only if* the present value of the stream of profits associated with the optimal program for crop B exceeds $p_AF(M,S^*)/\delta$, the present value of the stream of profits associated with the optimal production of crop A. It can be optimal to switch to producing crops that are more destructive to the soil, even if they yield a smaller rate of profit in the steady state.

4. Conservation of Soil Fertility in Traditional Agriculture

In most poor countries, food is still produced by traditional agriculture, and soil fertility is maintained not by applying artificial fertilizer but by returning cropland to fallow. Fallow periods are especially important in the tropics, where most nutrients are stored in the standing vegetation and not in the soil itself. The extent of fallows in the major tropical zones ranges from ten percent in tropical America to over seven percent in tropical Africa and Asia (Lanly, 1982). In some countries, fallows are nearly ubiquitous. For example, in Sierra Leone, fallows make up 58 percent of the land. In neighboring Liberia and the Ivory Coast, fallows comprise just under 50 percent of the land.

While the land lies fallow, fallen leaves naturally fertilize the topsoil, and the deeper tree and bush roots carry nutrients back up from the subsoil. The quantity of nitrogen returned to the soil during fallow periods is substantial and may amount to 75 kg/ha in a secondary rain forest, 45 kg/ha in a highland forest, and 15 kg/ha in a savanna forest (Ruthenberg, 1980, p. 47).

The time needed to restore soil productivity to original levels varies according to the climate and soil characteristics. In tropical rain forests, restoration takes eight to 12 years; in drier areas, restoration may take 15 years or longer (Ruthenberg, 1980). Crop yields tend to fall rapidly once the standing vegetation has been cleared, and the period during which the land is under cultivation ranges from about two to four years [see, e.g., Ruthenberg (1980) and Unger (1984)]. The rate of decline in crop yield is greatest in damp, warm climates where the soils are poor. On unstable soils in the rain forests, the third crop will typically produce no more than one-half that of the first (Ruthenberg, 1980, p. 46).

The practice of returning cropland to fallow, or shifting cultivation, is ecologically stable provided the productivity of the soil can be maintained. But under the pressure of rising human populations, fallow periods have grown shorter, and fertilizers have not been used to an extent necessary to prevent productivity declines. As a consequence, soil fertility has decreased. This is seen to be a major environmental problem in many low-income countries.

In this section I want to determine how shifting cultivation should be managed to maximize the present value flow of social benefits. This problem is similar to that of determining the optimal forest rotation. The main difference is that here the benefits of felling the trees (clearing the standing vegetation) are not felt instantaneously. The shifting cultivator, like the forester, must determine the optimal fallow (tree growth) period. But unlike the forester, the shifting cultivator must also determine the optimal cultivation period.[11] Our problem then is to determine the optimal fallow-cultivation *cycle*.

Suppose that a social farmer inherits at date $t = 0$ a plot of land which if put immediately into production would earn the farmer an instantaneous net profit equal to V_0. The farmer has two options. He or she can put the land into production or commit the land to fallow.[12] Assume that if the land is put into production, its productivity--that is, the farmer's (instantaneous) net income--declines at a constant rate γ. Then if the land is put into production for an interval of τ years the farmer will earn

$$\int_0^{\tau} V_0 e^{-(\gamma+\delta)t} dt$$

in present value profits. Assume now that if the land is allowed to lie fallow its productivity will obey the function $V(T;V_0)$ where T is the length of fallow. It is assumed that $V(T;V_0)$ is differentiable and monotonically increasing in T.[13] The function $V(T;V_0)$ can be expected to look like the curve drawn in Figure 2.

One possible functional form for $V(T;V_0)$ is the logistic equation. In this case, productivity would approach a maximum V^{max}, with the approach path depending on the initial productivity level:

$$V(T;V_0) = V^{max}/\{1 + [(V^{max} - V_0)/V_0]e^{-rT}\},$$

where r is the instrinsic rate of growth of soil productivity.

While the land lies fallow, the farmer receives no income. However, the ability of the land to generate an income at some future date is enhanced. Suppose the farmer can cultivate the plot of land for as long as he or she likes, but that only *one* fallow-cultivation cycle is permitted. The farmer's problem then is to

$$\left.\begin{array}{l} \max\limits_{T,\tau} \displaystyle\int_0^{\tau} V(T;V_0)e^{-\gamma t}e^{-\delta(t+T)}dt, \quad \delta > 0 \\ \\ \text{s.t.} \quad V_0 \text{ given and } T \geq 0. \end{array}\right\} \qquad (9)$$

This is a simple calculus problem. Assuming an interior solution, the optimal length of fallow T^* should be chosen such that $V_T(T;V_0)/V(T;V_0) = \delta$: keep the land out of production only so long as its value grows at a rate in excess of the social rate of discount. Since there is no opportunity cost associated with cultivation in this problem, and since the land cannot be returned to fallow after the land has been tilled, it is optimal to keep the land in production forever, even though the income derived from it declines very quickly. The solution is illustrated in Figure 3. The problem as I have constructed it is nearly identical to the once-and-for-all forest problem, with the decision of "when to cut" replaced by the decision of "when to clear the fallow and plant the first crop."

But as in the forest rotation problem, the land *does* have an opportunity value, for the farmer can always return the land to fallow and thus increase his or her future income. And the farmer can do this an infinite number of times. Problem (9) can therefore be rewritten as:

$$\left.\begin{aligned}
\max_{T_0,\tau_0,T_1,\tau_1,\ldots} \quad & \int_0^{\tau_0} V(T_0;V_0)e^{-\gamma t}\exp[-\delta(T_0+t)]dt \\
+ \quad & \int_0^{\tau_1} V(T_1;V_1)e^{-\gamma t}\exp[-\delta(T_0+\tau_0+T_1+t)]dt \\
+ \quad & \int_0^{\tau_2} V(T_2;V_2)e^{-\gamma t}\exp[-\delta(T_0+\tau_0+T_1+\tau_1+T_2+t)]dt \\
+ \quad & \ldots \\
\text{s.t.} \quad & V_0 \text{ given and } T_0 \geq 0, \\
\text{where } & V_1 = V(T_0;V_0)\exp(-\gamma\tau_0),\ V_2 = V(T_1;V_1)\exp(-\gamma\tau_1),\ldots.
\end{aligned}\right\} \quad (10)$$

Problem (10) is more complex than (9) and the usual forest rotation problem because the fallow-cultivation cycles are interdependent. The optimal choice for T_n and τ_n depends on V_n, the productivity level inherited from the previous cycle; and the choice for T_n and τ_n in turn determines V_{n+1} and hence the optimal choice for T_{n+1} and τ_{n+1}; and so on.

Because of this interdependence, the first order conditions for a maximum are messy. However, the problem can be simplified once we recognize that the *decision rules* governing the optimal choice for each cycle are identical. In other words, the optimal choice for T_n and τ_n can differ from the optimal choice for T_{n+1} and τ_{n+1} only if V_n differs from V_{n+1}. Consider then the initial cycle. V_0 will be given. Suppose V_0 is "small." Then it will be optimal to build up soil fertility; that is, it will be optimal to choose $T_0 > 0$. Soil fertility at the end of the initial fallow period will be $V(T_0;V_0)$. Since the optimal decision rules for T_0, T_1, ... are the same, soil fertility at the end of each fallow period must be identical (if there is an interior solution). Hence we have $V(T_0;V_0) = V(T_1;V_1) = ...$ Now if the fertility levels at the start of each cultivation period are identical, then clearly the length of each cultivation period must also be identical since the rules governing the choice for τ_0, τ_1, ... are the same. Hence we have $\tau_0 = \tau_1 = ...$ But if this is true then it follows that $T_1 = T_2 = ...$

If V_0 is sufficiently large, then it will be optimal to choose $T_0 = 0$. Choice of τ_0, given V_0, will then determine V_1. Applying the same logic as above suggests that soil fertility at the end of each cycle must be identical. Hence we must have $V_1 = V_2 = ...$ We know from above that if the inherited fertility levels are identical then the length of each fallow period must also be identical. Thus we have $T_1 = T_2 = ...$ But then the fertility levels at the end of each fallow period will be identical and hence the length of each cultivation period must be identical as well; that is, $\tau_1 = \tau_2 = ...$

The above reasoning suggests that the initial cycle will be transitional, moving the system from its initial state to the optimal periodic solution (T^*,τ^*). If V_0 is "small," as it will be if soil fertility has been heavily depleted, then the length of the initial fallow will exceed that of each succeeding fallow, while the length of each cultivation period--including the initial one--will be identical. If V_0 is "large," as it will be if the land has been left uncultivated for many years, then it will prove optimal to skip an initial fallow period altogether and begin cultivating immediately. The duration of the initial cultivation period will then exceed that of each succeeding cultivation period, and each cycle following the initial one will be identical.

If V_0 is "small," the necessary conditions can therefore be written concisely as

$$\partial V(T_0);V_0)/\partial T_0 + \sum_{n=1}^{\infty} [\partial V(T;V)/\partial V](\partial V/\partial T_0)e^{-\delta n(T+\tau)}$$

$$= \delta V(T_0;V_0) + \delta \sum_{n=1}^{\infty} V(T;V)e^{-\delta n(T+\tau)} \qquad (11)$$

$$V(T;V)e^{-\gamma\tau} = \delta \sum_{n=0}^{\infty} \int_0^{\tau} V(T;V)e^{-(\gamma+\delta)t}dt e^{-\delta[(n+1)T + n\tau]}$$

$$- \delta \sum_{n=0}^{\infty} \int_0^{\tau} [\partial V(T;V)/\partial V](\partial V/\partial \tau)e^{-(\gamma+\delta)t}dt e^{-\delta[(n+1)T + n\tau]} \qquad (12)$$

$$V = V(T_0;V_0)e^{-\gamma\tau} \tag{13}$$

$$V = V(T;V)e^{-\gamma\tau}. \tag{14}$$

Eqs. (11)-(14) form four equations in four unknowns -- T_0, T, τ and V. The solution is illustrated in Figure 4.[14]

Consider the necessary conditions. There are two types of benefit and two types of cost associated with the decision to increase T_0 very slightly while holding all other variables fixed. If T_0 is increased, the present value profit from the initial cycle and all succeeding cycles will be lower because of the delay. The cost of lengthening the initial fallow period is the opportunity cost of the investment tied up in the initial fallow plus that tied up in each and every succeeding fallow. This cost forms the RHS of eq. (11). One benefit of lengthening T_0 is the resulting immediate increase in the productivity of the land, and hence in the profit of the initial cultivation period. But if τ_0 and all other variables are held fixed, then soil fertility will be higher in all succeeding cycles as well. The present value sum of the increase in future profit levels makes up the second benefit. The sum of these two benefits makes up the LHS of eq. (11).

Consider now the decision to increase τ very slightly. The benefit is that current output is increased. This is the LHS-term in eq. (12). Associated with this decision are two costs. The first is the opportunity cost of the investment tied up in the land--if τ is increased then the farmer will have to wait longer to receive the income on all future cultivation periods. This cost is the first term on the RHS of eq. (12). The second cost recognizes that if τ is increased and all other variables are held fixed then the productivity of the soil will be permanently diminished, and the profit realized on all future cycles thereby reduced. This second cost is the second term on the RHS of (12).

If V_0 is "large," then it will be optimal to choose $T_0 = 0$, and choice for T, V, τ, and τ_0 must obey the following necessary conditions:

$$\partial V(T);V)/\partial T \quad + \quad \sum_{n=1}^{\infty} [\partial V(T;V)/\partial V](\partial V/\partial T)e^{-\delta n(T+\tau)}$$

$$= \quad \delta V(T;V) \quad + \quad \delta \sum_{n=1}^{\infty} V(T;V)e^{-\delta n(T+\tau)} \tag{15}$$

$$V(0;V_0)\exp(-\gamma\tau_0) = \delta \sum_{n=0}^{\infty} \int_0^{\tau} V(T;V)e^{-(\gamma+\delta)t}dt e^{-\delta[(n+1)T + n\tau]}$$

$$- \delta \sum_{n=0}^{\infty} \int_0^{\tau} [\partial V(T;V)/\partial V](\partial V/\partial \tau_0)e^{-(\gamma+\delta)t}dt e^{-\delta[(n+1)T + n\tau]} \qquad (16)$$

$$V = V(0;V_0)\exp(-\gamma\tau_0) \qquad (17)$$

$$V = V(T;V)e^{-\gamma\tau}. \qquad (18)$$

Eqs. (15)-(18) can be interpreted in a similar way as eqs. (11)-(14). The solution is illustrated in Figure 5.

We can state the result formally.

Proposition 3. *The solution to the social shifting cultivator's problem--problem (10)--must satisfy eqs. (11)-(14) if V_0 is "small," and eqs. (15)-(18) if V_0 is "large." After an initial transitional fallow, the optimal fallow-cultivation cycle obeys the equilibrium triple* T^*, τ^*, V^*. *If* V_0 *is "small" then* $T_0 > T^*$ *and* $\tau_0 = \tau^*$. *If* V_0 *is "large" then* $T_0 = 0$ *and* $\tau_0 > \tau^*$.

We also have

Corollary 2. *An unanticipated permanent increase in the output price will have no effect on the optimal fallow-cultivation cycle, and hence no effect on soil fertility and output.*

The reason for this last result is really rather obvious. An increase in the output price increases both the benefits and the costs of a longer fallow period by precisely the same amount. Hence, the shifting cultivator's problem remains unchanged after the price rise. Of course, the value of the land is increased by the percentage rise in price, and so the cultivator is better off after the price rise. But so long as he or she uses only traditional techniques, soil fertility--and output--will be unaffected by the price rise.

Where farmers add fertilizer to lengthen the optimal cultivation period or even to obviate the need for fallow periods altogether, the above model will yield results similar to those of the erosion model. A higher output price will encourage additional employment of fertilizer--fallow periods will shorten, if they exist at all, and soil fertility and agricultural output will increase. What matters again is the ratio of the output and input prices. If both prices rise by the same amount, then output will remain unchanged.

5. Conclusion

The opposing claims by Repetto (1987) and Lipton (1987) can be reconciled by seeing that these authors are looking at different sides of the soil conservation equation. Repetto's claim that higher output prices will encourage conservation is blind to the incentives created for farmers to seek bigger gains now by depleting both the quantity and fertility of soil. Lipton's (1987) claim that higher output prices will lead farmers to deplete soil is similarly blind to the incentives to build up soil depth and fertility so that bigger harvests can be reaped in the future. The economic problem is not, as Gray (1913) claims, "the balancing of present expenditures against future benefits"; it is the balancing (at the margin) of present *costs* against the sum of future benefits, appropriately discounted. Except perhaps where terracing is practiced (admittedly, the example Gray cites), the cost of controlling erosion will largely be felt in reductions in current output, not increases in expenditures. In most cases, the effect of output price increases on soil conservation is likely to be small. There are many good reasons for letting the prices of crops reflect their true opportunity costs, but if the reason for agriculture's poor performance in areas like sub-Saharan Africa is inadequate soil conservation, as some have argued [see, e.g., Brown and Wolf (1985)], then one should not expect pricing policy reforms to have very substantial effects on aggregate output.

APPENDIX

Maximum Principle Formulation of Problem (2). The current value Hamiltonian for this problem is

$$H = U[pF(R_t,S_t)] + \lambda_t(M - R_t),$$

where λ_t the current value shadow price of soil depth. The first order conditions (dropping time subscripts) are

$$U_C pF_R = \lambda \tag{A.1}$$

$$\mathring{\lambda} = \delta\lambda - U_C pF_S. \tag{A.2}$$

Under our assumptions, the Hamiltonian for this problem is concave. Hence, eqs. (1), (A.1) and (A.2) will be sufficient for a maximum provided the transversality conditions

$$\lim_{t\to\infty} e^{-\delta t}\lambda_t S_t = 0 \qquad \lim_{t\to\infty} e^{-\delta t}\lambda_t \geq 0$$

are met.

Using eqs. (1), (A.1) and (A.2), we see that in the steady state, soil depth is determined by eq. (3).

The optimal approach path can be characterized by constructing the phase-plane diagram for problem (2). Differentiating eq. (A.1) with respect to time and substituting yields

$$\mathring{R} = [(R - M)(-\eta F_R F_S + F_{RS}F) + F(\delta F_R - F_S)]/(F_{RR}F - \eta F_R^2), \tag{A.3}$$

where η, the marginal social utility of consumption, is assumed to be a nonnegative constant.

Assuming that F obeys eq. (4), , the $\mathring{R} = 0$ equation becomes

$$R = \frac{(\eta - 1)\alpha\beta M + \alpha\delta S.}{\beta[1 + \alpha(\eta - 1)]} \tag{A.4}$$

Above the $\mathring{R} = 0$ locus, R is rising; below this locus, R is falling. The $\mathring{S} = 0$ locus is simply R = M. Above this locus, S is falling; below this locus, S is rising. The phase diagram for the Cobb–Douglas case is drawn in Figure 1.

NOTES

1. These include overvalued exchange rates, output taxes, excessive margins charged by parastatal marketing agencies, input subsidies, and policies that protect industry at the expense of agriculture. See the rebuttals to the World Bank's (1986) view by Lipton (1987) and Cleaver (1988).

2. Chhibber (1988) provides estimates showing that the short- and long-run aggregate production elasticities are about three times greater in developed countries than in developing countries.

3. See Appendix. The figure assumes that the elasticity of the marginal social utility of consumption, η, exceeds a value of one. Choice of a smaller value of η would imply a smaller initial value for R and a faster approach to the steady state.

4. The main results of this section do not depend on the input being variable.

5. The last assumption can be easily reconciled with the previous model. For suppose nitrogen were necessary for production. Then the two models would be entirely consistent if either (i) a certain amount of nitrogen occured naturally, as indeed it does; or (ii) a certain amount was added, but that this amount was assumed fixed in the previous problem.

6. If a capital input were employed, we would require that it be used up to the point where its marginal productivity equalled the social rate of discount.

7. The problem is similar to that considered by Berndt and Wood (1979) where capital and energy are combined to produce "utilized capital services." The construct "soil services" also plays a similar role to Bhalla's (1988) "effective land."

8. Note that in this case if the elasticity of substitution is less than one and greater than or equal to zero, then "soil services" will remain necessary for production [see Dasgupta and Heal, 1974, p. 14]. Nitrogen is also necessary for production, but, referring back to footnote 5, we may distinguish between the availability of nitrogen and the amount which is added artificially.

9. This is true even if we change the objective to be maximization of the present value flow of profits.

10. Collins and Headley (1983) construct a model in which expenditures are incurred in preventing erosion but no loss in output is suffered.

11. Our problem is similar to that of determining the optimal management of an uneven-aged forest. For here the forester must decide not only when to cut but also how much of the forest biomass to leave standing for future growth. See the model by Chang (1981).

12. In fact, the farmer could abandon the land altogether. However, if we assume that the farmer's opportunity wage is zero, and that the land has no alternative use, then this option can be safely ruled out.

13. The assumption that $V(T;V_0)$ is increasing in T merely reflects our interest in cases where artificial fertilizer is never added. If fertilizer were added, then it is possible that fertility would actually decline during fallow periods as the artificial fertilizer was leached out of the soil.

14. There may not exist a unique solution to the necessary conditions; a global optimization analysis may be required to locate the optimal cycle.

FIGURE 1

Phase Diagram for Problem (2) in the Cobb-Douglas Case

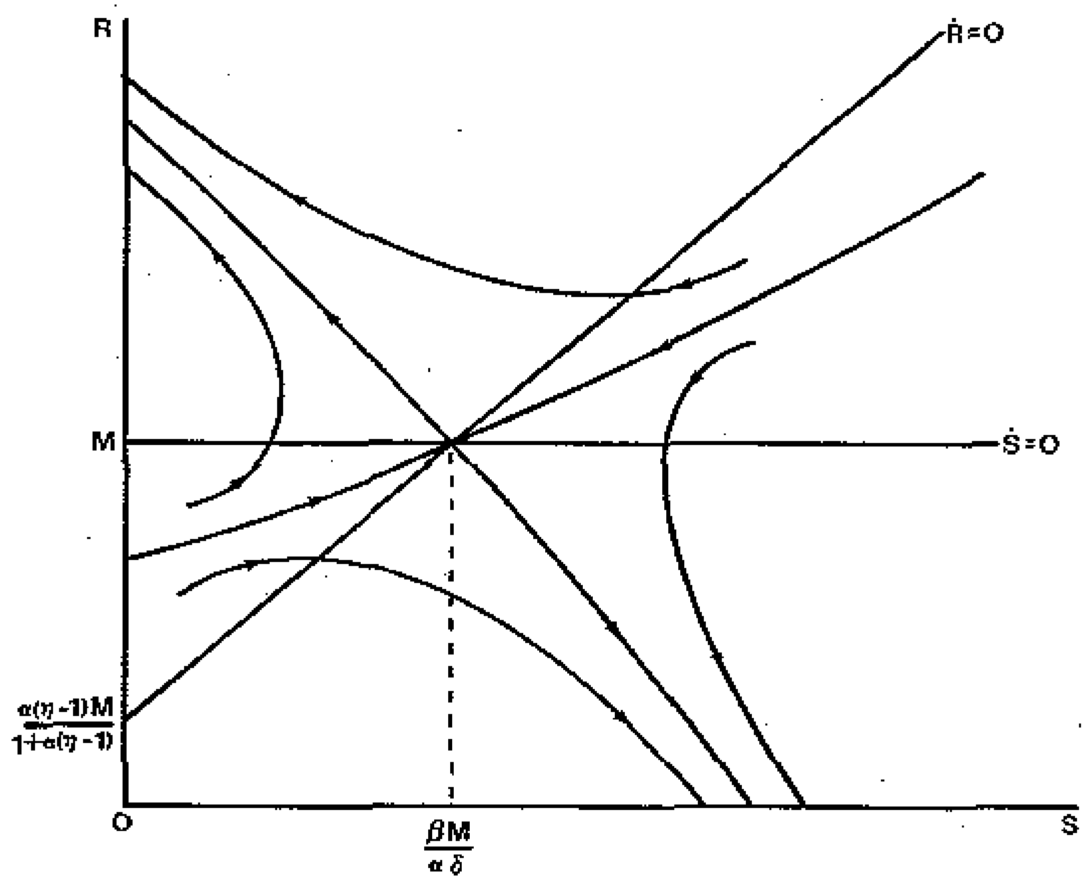


FIGURE 2

Soil Fertility Growth Curve

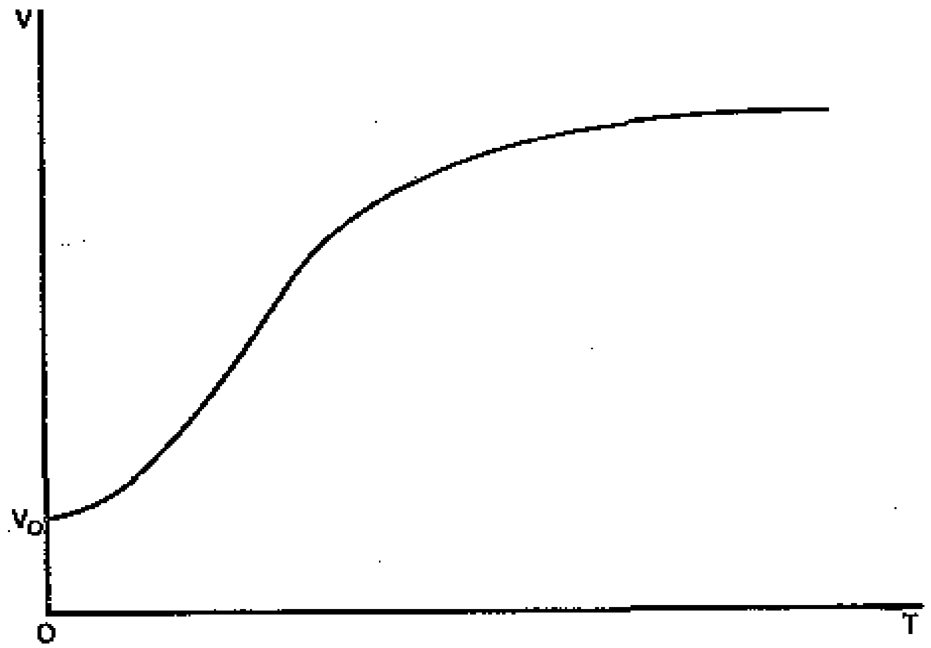


FIGURE 3

Optimal "Once-and-for-all" Fallow

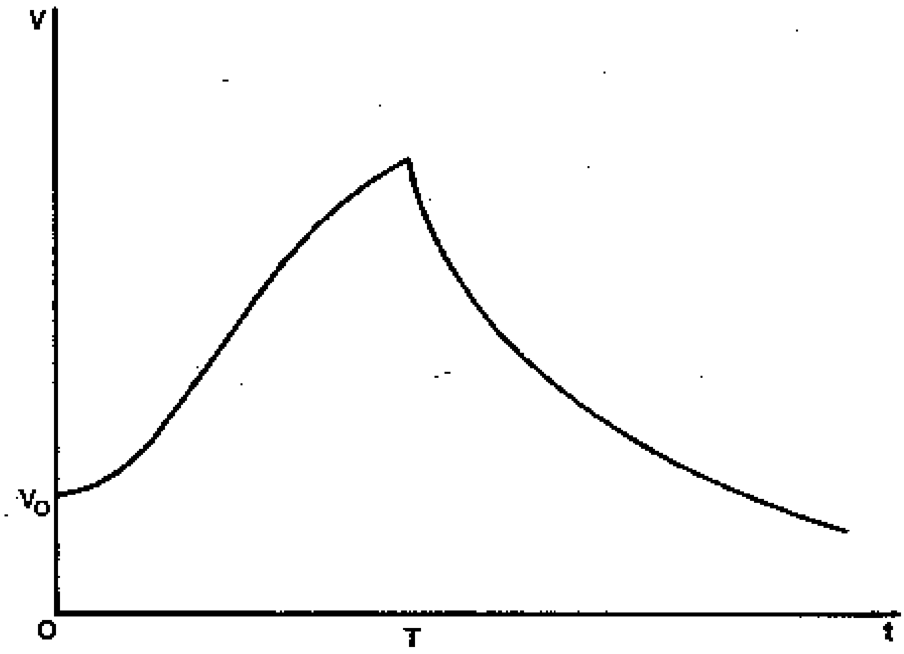


FIGURE 4

Optimal Periodic Solution with V_0 "Small"

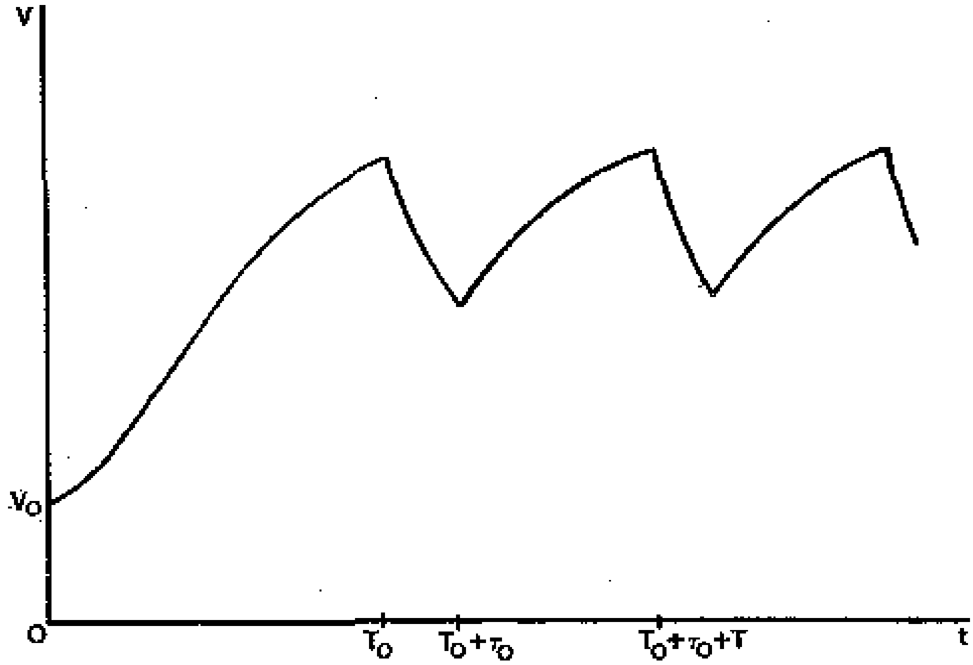
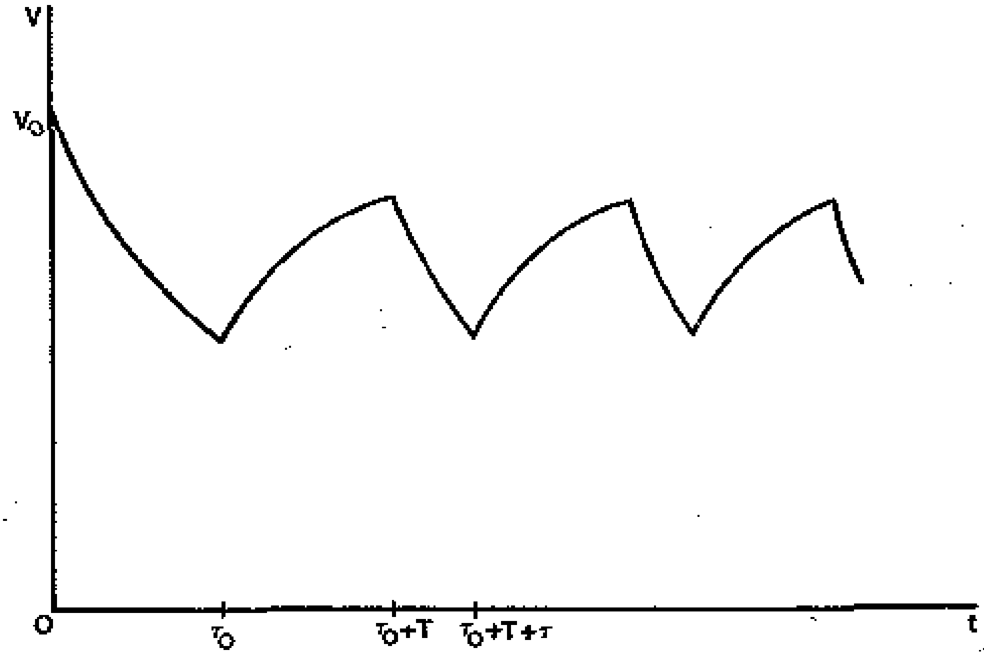


FIGURE 5

Optimal Periodic Solution with V_0 "Large"



REFERENCES

Berndt, E.R. and D.W. Wood, 1979, Engineering and econometric interpretations of energy-capital complementarity, American Economic Review 69, 342-354.

Bhalla, S.S., 1988, Does land quality matter? Theory and measurement, Journal of Development Economics 29, 45-62.

Bond, M.E., 1983, Agricultural responses to prices in sub-Saharan African countries, IMF Staff Papers 30, 703-726.

Brown, L.R. and E.C. Wolf (1985), *Reversing Africa's Decline*, Worldwatch Paper 65, Washington, D.C.: Worldwatch Institute.

Chang, S.J., 1981, Determination of the optimal growing stock and cutting cycle for an uneven-aged stand, Forestry Science 4, 739-744.

Chhibber, A., 1988, Raising agricultural output: Price and nonprice factors, Finance and Development, June, 44-47.

Cleaver, K.M., 1988, The use of price policy to stimulate agricultural growth in sub-Saharan Africa, presented at the World Bank's Eighth Agricultural Sector Symposium on Trade, Aid and Policy Reform in Agriculture, Washington, D.C., January 6-8.

Collins, R.A. and J.C. Headley, 1983, Optimal investment to reduce the decay rate of an income stream: The case of soil conservation, Journal of Environmental Economics and Management 10, 60-71.

Crosson, P.R. and A.T. Stout, 1983, Productivity effects of cropland erosion in the United States (Resources for the Future, Washington, D.C.).

Dasgupta, P. and G. Heal, 1974, The optimal depletion of exhaustible resources, Review of Economic Studies, Symposium, 3-28.

Gray, L.C., 1913, The economic possibilities of conservation, Quarterly Journal of Economics 27, 497-519.

Lanly, J.P., 1982, Tropical Forest Resources, FAO Forestry Paper No. 30 (FAO, Rome).

Lipton, M., 1987, Limits of price policy for agriculture: Which way for the World Bank? Policy Development Review 5, 197-215.

Liviatan, N. and P.A. Samuelson, 1969, Notes on turnpikes: Stable and unstable, Journal of Economic Theory 1, 454-475.

McConnell, K.E., 1983, An economic model of soil conservation, American Journal of Agricultural Economics 65, 83-89.

Myers, N., 1988, Natural resource systems and human exploitation systems: Physiobiotic and ecological linkages, World Bank Environment Department Working Paper No. 12.

Repetto, R., 1987, Economic incentives for sustainable production, The Annals of Regional Science 21, 44-59.

Ruthenberg, H., 1980, Farming systems in the tropics (Clarendon, Oxford).

Streeten, P., 1987, What price food? (Macmillan, London).

Unger, P.W., 1984, Tillage systems for soil and water conservation, FAO Soils Bulletin No. 54 (Food And Agriculture Organization, Rome).

United States Agency for International Development (USAID), 1988, Policy paper: Environment and natural resources, Washington, D.C.

Warford, J.J. and R. Ackermann, 1988, Environment and development: Implementing the World Bank's new policies, Paper prepared by World Bank staff for consideration by the Development Committee at its April 1988 meeting, Washington, D.C.

World Bank, 1986, World development report 1986 (Oxford University Press, Oxford).

THE LONDON ENVIRONMENTAL ECONOMICS CENTRE

PUBLICATIONS

JUNE 1989

LEEC DISCUSSION PAPERS

88-01

David W Pearce, Edward B Barbier and Anil Markandya, Environmental Economics and Decision Making in Sub-Saharan Africa. September 1988. (£2.50)

88-02

Edward B Barbier, Sustainable Agriculture and the Resource Poor: Policy Issues and Options. October 1988. (£2.50)

88-03

David W Pearce, Edward B Barbier and Anil Markandya, Sustainable Development and Cost Benefit Analysis. November 1988. (£2.50)

89-01

Edward B Barbier and Anil Markandya, The Conditions for Achieving Environmentally Sustainable Development. January 1989. (£2.50)

89-02

Nicholas Michael and David W Pearce, Cost Benefit Analysis and Land Reclamation: A Case Study. February 1989. (£2.50)

89-03

Douglas Southgate, Efficient Management of Biologically Diverse Tropical Forests. March 1989. (£2.50)

89-04

Timothy Swanson, A Proposal for the Reform of the African Elephant Ivory Trade, June 1989. (£3.50)

89-05

Edward B Barbier and Joanne Burgess, The Demand For African Elephant Ivory, June 1989. (£2.50)

89-06

Scott Barrett, Deforestation, Biological Conservation, and The Optimal Provision of Wildlife Reserves, July 1989. (£2.50)

89-07

Scott Barrett, On The Overgrazing Problem, July 1989. (£2.50)

89-08

Scott Barrett, Optimal Soil Conservation and the Reform of Agricultural Pricing Policies, July 1989. (£2.50

LEEC GATEKEEPER SERIES

David W Pearce, Sustainable Development: an Economic Perspective (£2.00)

LEEC BOOKS

Edward B Barbier, Economics, Natural-Resource Scarcity and Development: Conventional and Alternative Views. Earthscan Publications Limited, London, 1989. (£29.95)

The history of environmental and resource economics is reviewd, then using insights provided by environmentalism, ecology and thermodynamics, Barbier begins the construction of a new economic approach to the use of natural resources and particularly to the problem of environmental degradation. With examples from the global greenhouse effect, Amozonian deforestation and upland degradation on Java, Barbier develops a major theoretical advance and shows how it can be applied. This book breaks new ground in the search for an economics of sustainable developement.

David W Pearce, Edward B Barbier and Anil Markandya, <u>Sustainable Development: Economics and Environment in the Third World</u>, Edward Elgar Publishing Limited, London 1989 [in press].

The authors attempt to give some structure to the concept of sustainable development and to illustrate ways in which environmental economics can be applied to the developing world. Beginning with an overview of the sustainable development concept, the authors indicate its implications for discounting and economic appraisal. Core studies on natural resource management are drawn from Indonesia, Sudan, Botswana, Nepal and the Amazon.

Copies of the above papers are available from:

Marilyn John
IIED
3 Endsleigh Street
London WC1H ODD
UK.
Tel: 01 388 2117
Teles: 261681 EASCAN G
Fax: 01 388 2826

IIED/UCL LONDON ENVIRONMENTAL ECONOMICS CENTRE

The London Environmental Economics Centre is a joint initiative of IIED and the Department of Economics of University College London. It has been funded by core contributions from the governments of Sweden, Norway and the Netherlands.

The Centre has as its main objectives:

- Research into environmental problems of less developed countries from an economic standpoint;
- Dissemination of research and state of the art environmental economics through publication, public and professional address and specialist conferences;
- Advice and consultancy on specific issues of environmental policy.

IIED

INTERNATIONAL INSTITUTE FOR ENVIRONMENT AND DEVELOPMENT

3 Endsleigh Street, London WC1H 0DD, UK