A Method for Evaluating Erosion Control in Farm Planning

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Many good studies dealing with economics of conservation have been reported, but some essential questions remain unanswered. What effect does planning the farm to achieve conservation goals have on farm income? How much income could a farmer earn if he ignored conservation? How would income differ between farms planned to keep erosion losses below an acceptable physical level and the same farms planned to get the most profit? This article shows how linear programming can be used to answer questions of this type. The opinions expressed are those of the authors and do not necessarily represent the views of the Farm Economics Division, Economic Research Service, or the U.S. Department of Agriculture.

LINEAR PROGRAMMING has been used extensively to determine that combinations of resources and enterprises that would give maximum profit or minimum costs for a farm. The technique itself is not new. An application of the technique to answer questions like those posed above is, however, a new use for an accepted tool. It gives us a more precise method for determining whether given conservation practices are in fact economic.

The study reported here was developed on the premises that farmers in general do not hold erosion control as a paramount goal; that the goal of most farmers is profit maximization using resources available to them during a relevant planning horizon; and that acceptable farm plans embodying erosion control practices need to be formulated with reference to the particular resource structure, unique tenure expectancy, managerial skill and risk preference of each farm operator. Consequently, the analysis was to determine, for a single farm with a given set of resources and planning horizon of the operator, the economic consequences of formulating the farm plan around specified erosion control goals under different assumptions regarding the availability of operating capital. Economic consequences could be stated in terms of (1) the relationship between net revenue and progressively greater soil loss rates at two levels of capital availability; (2) the soil loss rate which would allow the maximum net revenue farm plan at each assumed capital level; and (3) the effect of progressively higher levels of capital use on net revenue if soil loss were restricted to 5 tons per acre per year.[1]

Characteristics and Resources of the Study Farm

The analysis was applied to a 173-acre farm in southwest Iowa, consisting of 10 acres of bottom land and 163 acres of upland, 129 acres of which are of the Monona soil series with slopes ranging from 7 to 15 percent. The remaining 34 acres of upland soils are of the Marshall series with an average slope of approximately 3 percent.[2] The bottom land soil is Judson silt loam, a colluvial soil formed from eroded material from adjacent upland slopes. The combination and amounts of the soils found on this farm would appear to be fairly representative of farms in the extensive Marshall-Monona transition zone of western Iowa.

Existing building facilities on this farm impose a maximum limit on livestock enterprises of 40 litters of hogs, 100 hens, and 6 dairy cows. Facilities are adequate for extensive cattle-feeding operations. In addition to owning sufficient equipment to care for all enterprises considered as programming alternatives, $8,100 of farm operating capital is available. The only labor available is that of the owner-operator who has a planning horizon of 9 years.

[1] A soil loss rate of five tons per acre per year is usually cited as the maximum permissible rate (or physical planning norm) consistent with productivity maintenance on upland soils of the study farm.

[2] Marshall soils have a slightly higher productivity potential than Monona soils, but both are fertile, well drained, deep loess soils.

Programming Activities and Coefficients

The soils of the study farm were grouped into six land restrictions differentiated by type, slope, and antecedent erosion.[3] Alternative crop activities for upland soils consisted of five rotations (continuous corn; corn, corn, oats and meadow; corn, oats and 2 years of meadow; corn, oats and 4 years of meadow; and continuous meadow). With the exception of continuous meadow, three alternative levels of erosion control (terraced and contoured, contoured only, and neither terraced nor contoured) were permitted for each rotation. Thus, for each of the upland soil types, 13 rotation activities were considered. For the bottom land, only the four rotation activities including some corn, neither terraced nor contoured, were regarded as feasible alternatives. Combinations of rotations and erosion control practices on the various soil types resulted in a total of 69 crop activities for programming.

Livestock activities consisted of one- and two-litter hog systems; dairy cows for butterfat production; cattle feeding enterprises of deferred-fed calves, drylot calves and medium yearlings; a beef cow herd; and laying hens. The alternatives of either buying or selling corn were also included.

Programming restrictions reflected the acres of each soil type on the study farm, the existing facilities to accommodate livestock enterprises, the labor of the owner-operator seasonally distributed among five time periods and the availability of operating capital.

Projected 1965 product prices were used. Production costs reflected the same general price level and "average" production efficiency.

Additional Costs Associated With Erosion

Sheet erosion results in decreased productivity or additional land treatment costs. Land treatment costs associated with an erosion-producing management system change throughout the 9-year planning horizon. In this analysis, two such costs have been treated. They are (1) costs of additional fertilizer necessary to maintain productivity as surface soil is lost, and (2) costs of additional terrace maintenance due to siltation of the terrace channel.[4]

Additional fertilizer costs were estimated from recent agronomic field experiments in the Marshall-Monona transition area of western Iowa.[5] These experiments show that for each inch of surface soil lost, approximately 11 pounds of applied nitrogen per acre are needed to maintain a constant level of corn production. For rotations including small grains or meadow, application of phosphorous to maintain rotation productivity is necessary as surface soil is lost. Annual sheet erosion rates (in fractional inches) were computed for alternative rotations on each upland soil in the study farm.[6] Thus, it was possible for each year during the planning horizon to estimate the additional fertilizer costs due to erosion for each rotation on all of the upland soil types by relating the fertilizer-surface soil substitution rates to the rate of soil loss. These costs ranged from zero to a maximum of $2.88 per acre.

The other element of increased costs due to sheet erosion was computed as the average annual cost of silt removal from the terrace channel accomplished by maintenance plowings with a two

[3] References to "soil type" in this paper imply a soil area that is unique with regard to series, slope, and antecedent erosion.

[4] Future income flows and costs were not converted to a common point in time. Doing so would not have affected greatly the methodology demonstrated or the results obtained since additional costs necessary to maintain productivity as erosion progressed were a small portion of the total production costs. Moreover, such a precise consideration of time would have required a dynamic programming model accounting for family living expenses, fixed costs, and capital accumulation.

[5] Engelstad, Orvis P. Effect of Surface Soil Thickness on Corn Yield on Marshall and Monona Soils in Iowa. Unpublished Ph. D. Thesis, Iowa State University Library, Ames, Iowa, 1960.

[6] Erosion rates associated with the various alternative rotations were computed through the use of "Browning's Erosion Factors." This method of estimating soil loss considers type of soil, crop management, vegetative cover, supplemental practices, degree of slope, length of slope and antecedent erosion in yielding an average annual soil loss expressed in tons per acre. For details see: R. K. Frevert, G. O. Schwab, T. W. Edminster and K. K. Barnes. *Soil and Water Conservation Engineering.* John Wiley and Sons. New York. 1955. pp. 122–125.

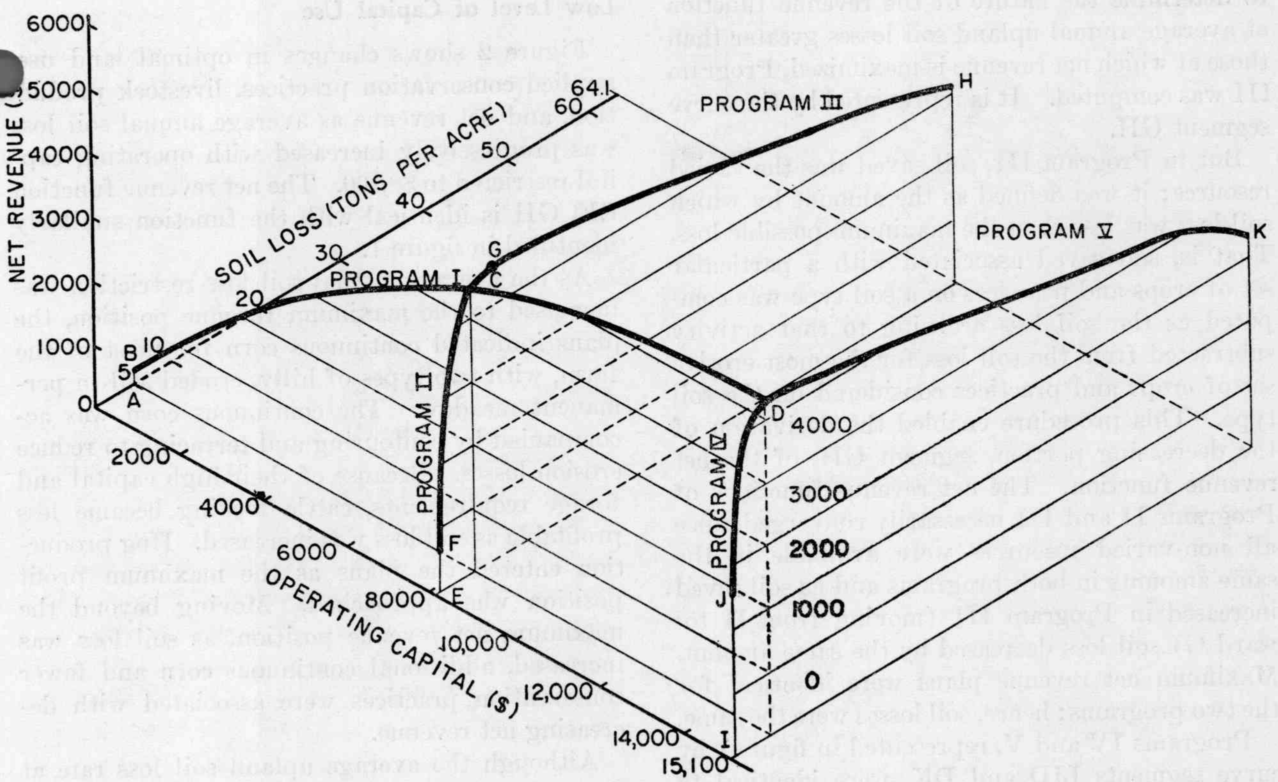

Figure 1.—The relationship of net revenue to capital use and average annual upland soil loss for the study farm.

way plow.[7] For all rotations considered on each terraceable soil type, the average annual silt accumulation was estimated through use of the "Browning Erosion Factors."

Since part of the accumulated silt would be removed incidental to normal plowing operations, only additional plowings necessary to restore the terrace to full capacity and the prorated fixed costs of owning a two-way plow were charged as terrace maintenance costs. These costs ranged from $0.21 (the prorated per acre annual costs of owning a two-way plow) on soil types where extra maintenance plowings were unnecessary, to $1.38 per acre.

The Framework of Analysis

To determine the interdependence among erosion rates, capital availability, and net revenue on the study farm, five variable resource linear programs were solved. The relationships among these programs are shown in figure 1.

Curve ABCD in figure 1 represents the relationship between net revenue and the varied resource, capital, with soil loss restricted to 5 tons per acre on each soil type. For this program (Program I), crop activities on any soil type were limited to those crop sequences and mechanical practices resulting in less than 5 tons per acre annual soil loss.

The other two revenue functions shown in figure 1 were generated by variable resource linear programming with soil loss the varied resource. Curve EFCGH represents a capital availability of $8,100 and curve IJDK a higher ($15,100) capital level. The portion EFCG of curve EFCGH was derived from Program II. The maximum point of this curve is at G where no other combination of crops, livestock and conservation practices, using the limited resources of this farm, could produce additional net revenue. In order

[7] Procedure adapted from George A. Pavelis. Economic Planning Within Small Agricultural Watersheds. Unpublished Ph. D. Thesis, Iowa State University Library, Ames, Iowa, 1958, pp. 61–62.

to determine the nature of the revenue function at average annual upland soil losses greater than those at which net revenue is maximized, Program III was computed. It is represented by the curve segment GH.

But in Program III, soil saved was the varied resource; it was defined as the amount by which soil loss was less than the maximum possible loss. That is, soil saved associated with a particular set of crops and practices on a soil type was computed as the soil loss accruing to that activity subtracted from the soil loss for the most erosive set of crops and practices considered on the soil type. This procedure enabled the derivation of the decreasing portion, segment GH, of the net revenue function. The net revenue functions of Programs II and III necessarily converged since all non-varied resources were available in the same amounts in both programs and as soil saved increased in Program III (moving from H toward G) soil loss decreased by the same amount. Maximum net revenue plans were identical for the two programs; hence, soil losses were the same.

Programs IV and V, represented in figure 1 by curve segments IJD and DK, were identical to Programs II and III except for the additional amount of operating capital available. The effect of capital availability on the most profitable level of conservation was evaluated by relaxing the capital restriction in Programs IV and V to that amount which drove returns to capital to 3 percent in Program I. The profit maximum in Programs IV and V occurred at an average annual upland soil loss of 4.94 tons per acre. This rate of loss and the 5-ton restriction were plotted as point D.

Relationships Between Soil Loss and Net Revenue

Substantial changes in net revenue resulted from varying the rate of soil loss in programming the study farm. Increases in revenue were very rapid, progressing from the lowest rates of erosion possible to the rate associated with the profit-maximizing plan. Revenue decreased slowly as the soil loss rate was further increased. The level of capital availability affected the net revenue functions, farm plans, and associated rates of erosion.

Low Level of Capital Use

Figure 2 shows changes in optimal land use applied conservation practices, livestock production, and net revenue as average annual soil loss was progressively increased with operating capital restricted to $8,100. The net revenue function EFCGH is identical with the function similarly identified in figure 1.

As the average annual soil loss restriction was increased to the maximum revenue position, the plans indicated continuous corn for most of the farm, with two types of hilly, eroded soil in permanent meadow. The continuous corn was accompanied by contouring and terracing to reduce erosion losses. Because of their high capital and forage requirements, cattle feeding became less profitable as soil loss was increased. Hog production entered the plans as the maximum profit position was approached. Moving beyond the maximum net revenue position, as soil loss was increased, additional continuous corn and fewer conservation practices were associated with decreasing net revenue.

Although the average upland soil loss rate at the maximum profit position was approximately six tons, which is near the often-used five-ton planning restriction, the rates varied for individual soil types. Soil loss rates exceed five tons per acre per year on three of the five upland soil types.

Because the net revenue function increases very rapidly up to the profit-maximizing plan and then decreases very slowly as erosion rates are increased, plans which restrict soil loss too far would have serious income consequences for the owner-operator of the study farm. Land uses and treatment measures much like those found in figure 2 corresponding to a rate of about 1.5 tons of soil loss are frequently recommended. Moving from the optimum plan associated with 6.05 tons of soil loss to the plan with an average of 1.54 tons of soil loss would result in a decrease in net revenue from $4,573 to $2,316—a large income loss due to over-planning.

The highest profit obtainable from the frequently used continuous corn-no-conservation management systems represented on the right-hand portion of figure 2 is also low, reflecting the consequences of inadequate conservation planning.

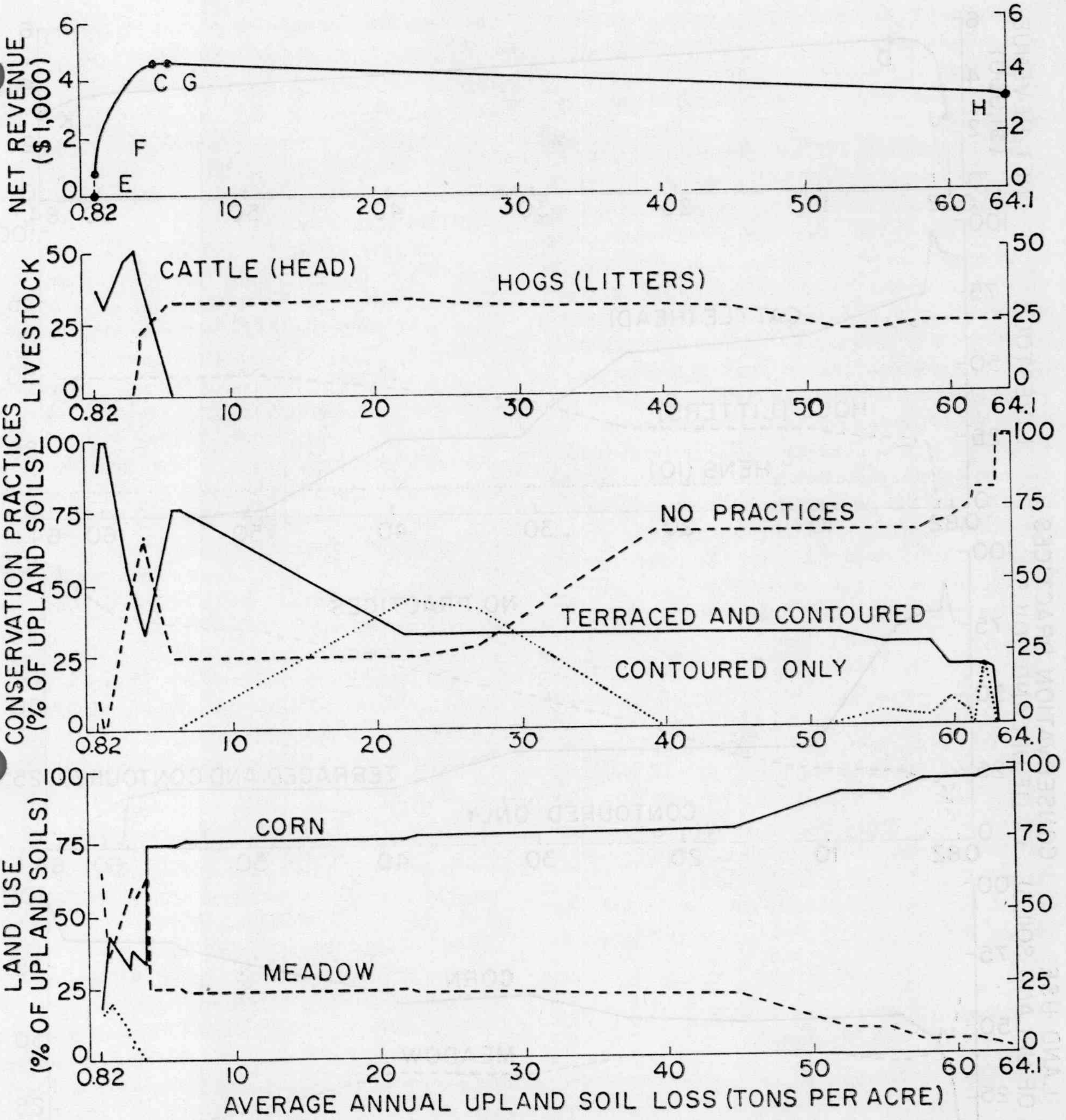

Figure 2.—Land use, conservation practices, livestock systems, and net revenue related to average annual upland soil loss, low level of capital use.

Prolonged excessive erosion rates would likely decrease land values at the end of the planning horizon. Land depreciation costs chargeable to highly erosive management systems were not included in this analysis; these costs would be negligible for profit-maximizing farm plans, and there was no available estimate of their magnitudes at higher soil loss rates.

High Level of Capital Use

An increase in available operating capital to $15,100 yielded programming solutions which in-

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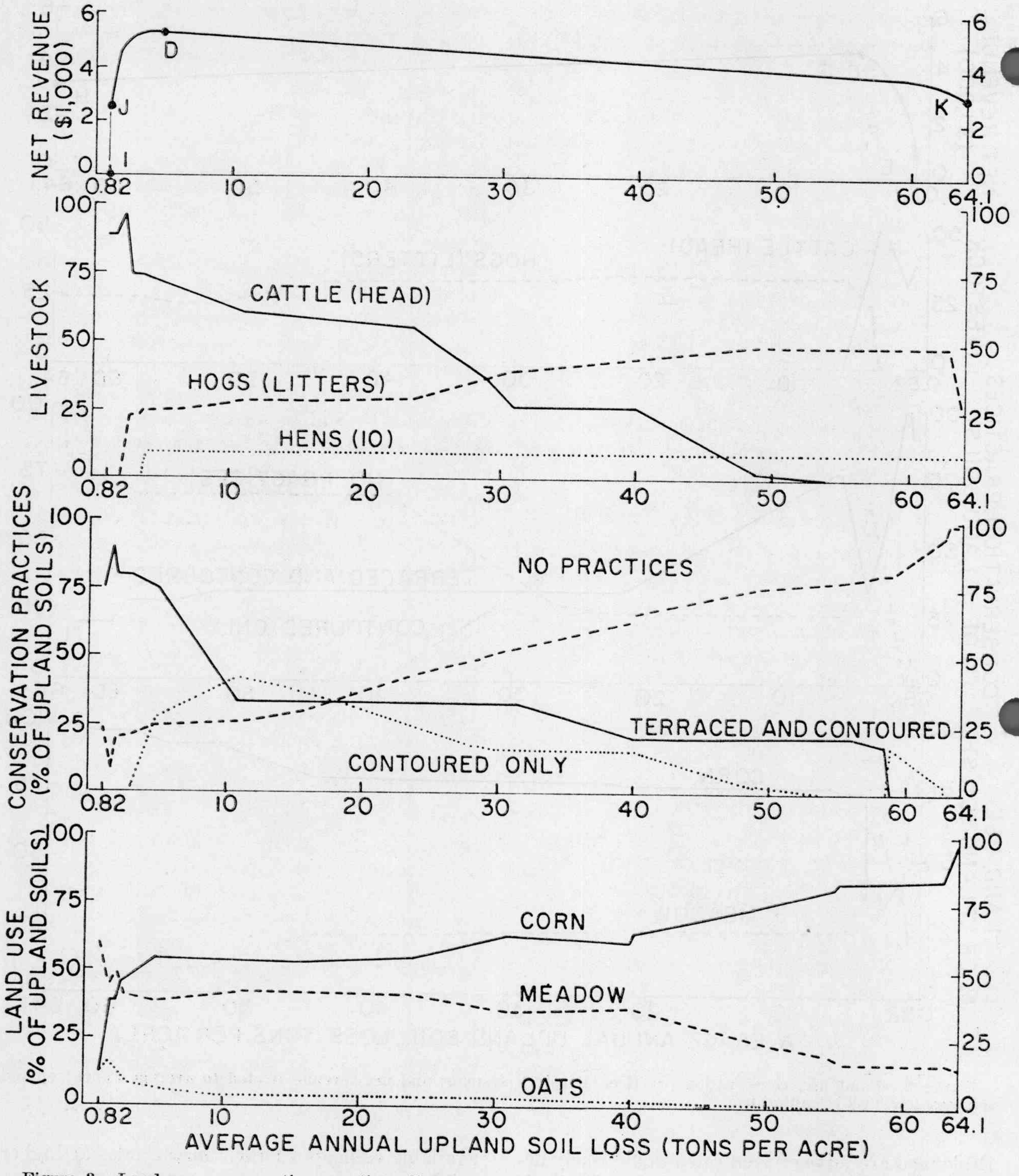

Figure 3.—Land use, conservation practices, livestock systems, and net revenue related to average annual upland soil loss, high level of capital use.

creased net revenue and indicated a slightly lower level of soil loss (4.94 tons per acre per year) associated with the farm plan yielding the highest profits. The shape of the net revenue function derived from Programs IV and V was similar to the one derived for the low level of capital availability. The new revenue function representing the higher level of capital availability is shown as curve IJDK in figures 1 and 3.

The higher level of capital availability allowed more cattle feeding and a shift to forage production on Monona soils, resulting in an increase from \$4,573 to \$5,250 in maximum net revenue plans. Increased forage production in the highest profit plan resulted in the lower rate of soil loss. For both the low and the high levels of capital availability, all rotations which included row crops were designated as being contoured and terraced in the highest profit-producing plan.

Effects of Restricted Soil Loss on Farm Plans

By imposing an annual 5-ton-per-acre limit on soil loss for each soil type, the consistency of this limit with the individual goal of profit maximization was tested. In this program, available capital was varied to show the effect of capital limitations on farm plans with soil loss limited. In general, increasing the level of capital allowed net revenue to increase at a decreasing rate. Program I (summarized in figure 4 and represented by curve ABCD in figure 1) indicated that at extremely low levels of capital availability, crop enterprises alone were in the farm plans. Livestock enterprises became more intensive as capital availability was increased.

The placing of a soil loss restriction on the operator's crop enterprises decreased the net revenue attainable to \$4,386 at the lower (\$8,100) level of capital availability. The imposition of the soil loss restriction, therefore, cost the owner-operator of the study farm \$187 (\$4,573 minus \$4,386) per year. This difference in net revenue was attributable to the soil loss restriction eliminating continuous corn on Monona soils with 11 percent slopes and moderate antecedent erosion as an alternative in Program I. This revenue loss was partly compensated since some of the operating capital committed in Programs II and III to continuous corn was made available for the feeding of cattle.

In the formulation of a farm plan to achieve a given income goal, additional operating capital could compensate for the imposition of a five-ton soil loss restriction. In the limited capital (\$8,100) situation with an imposed soil loss restriction of five tons, marginal returns to additional operating capital were rather high—about 27 percent. Hence, \$8,800 of operating capital in the restricted soil loss program would have achieved the same net revenue as that attainable when operating capital was limited to \$8,100 but soil loss was not restricted.

As available operating capital was increased from the low level to the high level, the farm plans resulting from the soil loss restricting and nonrestricting programs became more similar. When operating capital was set at a level of \$15,100 and soil loss was not restricted to an absolute limit (Programs IV and V), maximum net revenue attainable was \$5,250. At this same level of capital availability when the soil loss restriction was imposed, maximum net revenue reached \$5,219, a difference of only \$31 attributable to the five-ton soil loss limit. This compares with a difference of \$187 in the more limited capital situation.

Limitations of Analysis

Planning Horizons

The length of planning horizon established for the operator of the farm analyzed in this study was 9 years and was reflected in the net revenue coefficients associated with alternative crop activities. A shorter planning horizon presumably would have encouraged more erosive crop rotations, since average annual additional fertilizer costs necessary to replace eroded surface soil would have been decreased for high frequency row-crop rotations relative to less erosive rotations. Conversely, a longer planning horizon probably would have tended to encourage less erosive crop rotations.

Characteristics of Soils

Marshall and Monona soils are characterized by extraordinarily deep loess subsoils which can be made productive by the application of fertilizer. On other soils that are immediately underlain with a rock mantle or nontillable subsoil, substitution of fertilizer for surface soil has limited applicability.

Tenure Arrangements

The study farm was operated by the owner. In the case of tenant-operated farms, if the planning

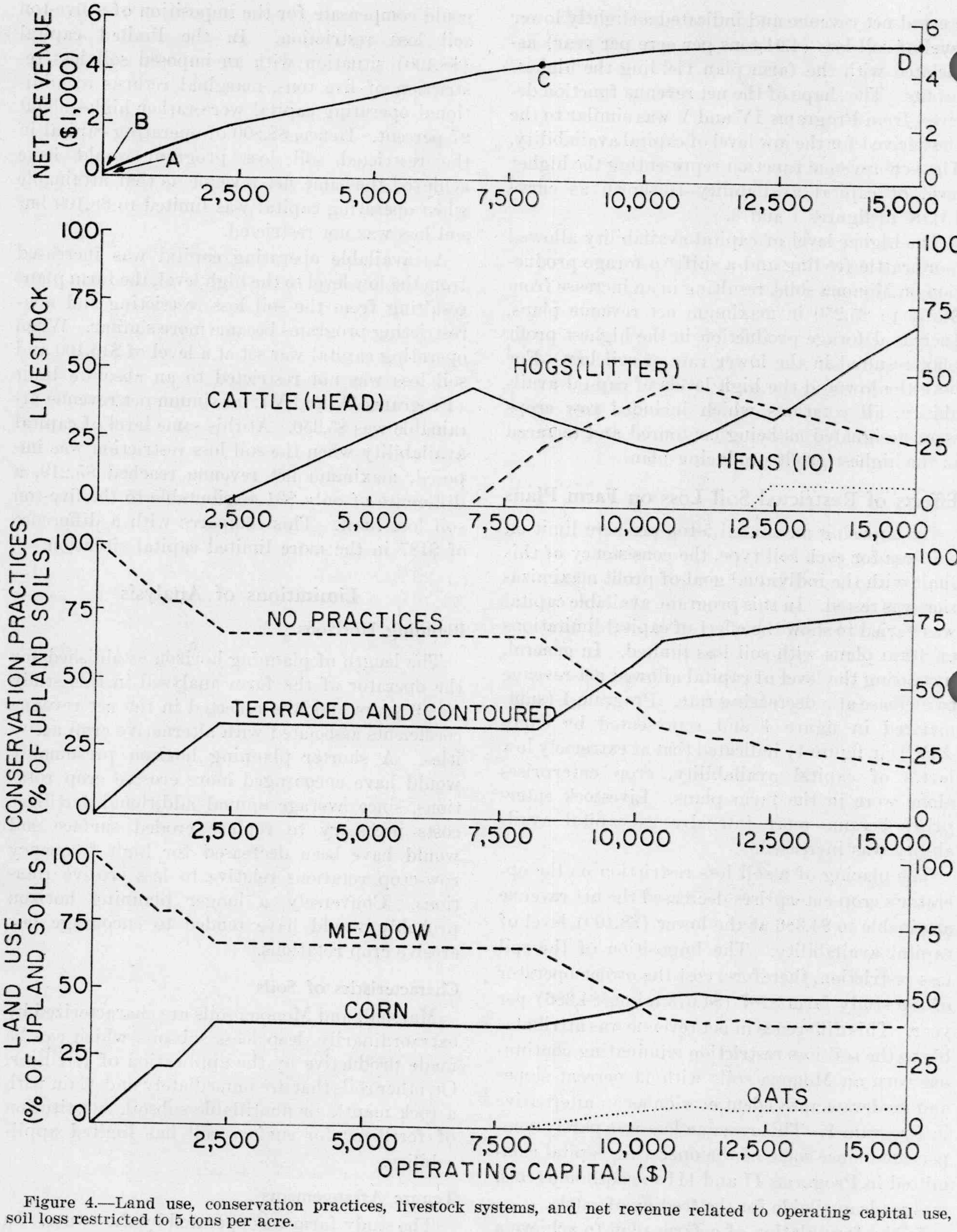

Figure 4.—Land use, conservation practices, livestock systems, and net revenue related to operating capital use, soil loss restricted to 5 tons per acre.

horizons of the tenant and owner were different, conflicts would arise with respect to the profit-maximizing plans and associated rates of erosion. As customary leasing arrangements usually do not result in identical planning horizons, normally it would not be possible to establish a rate of soil loss which would maximize net revenue to both tenants and landlords within the framework of such leasing arrangements. However, it should be possible to devise a compensation structure which would, in effect, make the tenant's and landlord's planning horizons coincide.

Concluding Comments

Our findings indicate that, for the study farm, the rates of erosion that result from highest profit plans do not differ greatly from the frequently used five-ton per acre annual limit. An average annual upland soil loss rate of from five to six tons per acre per year was found to be associated with highest profit plans, though annual soil losses for some soil types were somewhat higher.

Restricting farm plans by an erosion control goal of less than five or six tons per acre per year would sharply decrease profit. On the other hand, net revenue would be decreased only gradually for farm plans yielding more than five or six tons of soil loss per acre per year. From the point of view of the individual farm operator, income consequences of formulating the farm plan around too low an erosion control goal would be far more serious than erring in the direction of inadequate conservation planning.

Formulating farm plans around an absolute erosion control goal of not more than five tons per acre per year for all soil types resulted in slightly decreased net revenue relative to farm plans where soil loss was not considered as a restrictive factor.

Lower erosion rates resulted from increased capital availability as additional livestock entered the plans, forcing a shift from continuous corn to forage-producing rotations. In the highest profit plans, intensive cropping systems, accompanied by contouring and terracing to control erosion, were prevalent on the better soils. Poorer soils were generally devoted to permanent meadow.

In situations other than that represented by the study farm, economic analysis could show more or less conflict between an imposed soil loss limit and a goal of profit maximization. In any event, the determination of the rate of erosion and control methods associated with the net revenue maximizing plan requires economic analysis of the entire complex of soil types, capital and other resources unique to each farm. Planning with reference to physical factors alone may lead to suboptimal plans.