IMPLICATIONS OF SOIL LOSS CONTROL POLICIES UPON THE LONG-RUN SUSTAINABILITY OF AGRICULTURAL PRODUCTION WITHIN THE STATE OF IOWA

by

James A. Langley
Earl O. Heady
Burton C. English*

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*Research Associate, Distinguished Professor and Director, and Staff Economist, respectively, The Center for Agricultural and Rural Development, Iowa State University, Ames, Iowa 50011.

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There is a growing tendency in the United States for decentralized public policymaking concerning agricultural production and resource use. Regional differences in climate, soil characteristics, water resource development, and input factor costs present each region with a unique situation. Individual regions have an incentive to develop a framework for analyzing both the impacts of national farm policies upon their own area, and in formulating region-specific policy programs which take explicit account of important local problems.

The Food and Agriculture Program of the International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, has initiated a series of case studies directed at examining the important relationships between agricultural production technologies, resource use, and the environment which will affect the stability and sustainability of the global food and agricultural system in the long run. These case studies, organized on a regional basis in each of eight countries, incorporate the site-specific nature of resource inputs and environmental impacts of agricultural production in a general methodological framework.

The objective of this paper is to present an overview of the modeling framework developed by the authors for the U.S. case study, which focuses upon the State of Iowa with necessary attention given to Iowa's relationship within the agricultural economy of the United States. Iowa is one of the most important agricultural areas in the United States.

Primary crops produced include corn, oats, soybeans, grain sorghum, wheat, and hay. Iowa's production of corn, soybeans, and oats accounted for 22, 18, and 14 percent, respectively, of total U.S. production in 1980. The state is also prominent in commercial meat production, particularly beef and pork.

Concern over the long-run sustainability of agricultural production in Iowa is most evident by increased public attention over soil loss and land use. Soil loss is recognized as one of the most widespread and destructive agents involved in bringing about the rapid depletion of the fertility and productivity of the U.S.'s cultivated lands. Soil erosion in Iowa has been severe in three out of the past eight years. Gross soil loss of 40 to 50 tons per acre was common in some parts of the state, and it reached as high as 200 tons/acre in some areas. Soil of 100 to 150 tons per acre means that approximately an inch of topsoil across an acre of land has been lost or relocated by water erosion. To alleviate the problem of soil loss, the Iowa Legislature has passed laws which impose limits and practices on land use. The results to be presented address the implications of the Iowa laws upon agricultural production both within Iowa and the United States.

The methodology used to analyze the impacts of alternative soil loss limits is the Iowa Regional-National Recursive Hybrid model (Iowa-RN). Iowa-RN consists of four main components: a regional linear programming model for the State of Iowa sub-divided into 12 producing areas, a national econometric simulation model for the United States excluding Iowa, a physical component which determines crop yields based on accumulated soil loss and technological change, and a linkage procedure which transfers information between the programming and econometric models.

The linear programming component maximizes net returns from the production of crops subject to a set of resource constraints, and includes 12 spatially delineated producing areas consistent with Iowa soil conservancy districts [English, et al, 1980]. Crop production activities simulate rotations producing corn grain, corn silage, legume and nonlegume hay, oats, sorghum grain, soybeans, and wheat, in crop management systems incorporating rotations of one to four crops. Each rotation is defined for three conservation methods (straight-row, strip cropping, and contour plowing), with each conservation method being associated with three tillage practices (conventional tillage, residue removed, and reduced tillage). Thus, each rotation, combined with a specific conservation-tillage practice, defines a unique crop management system. Coefficients defined for each activity include the cost of production, land use (one acre), the quantity of nitrogen required, the yield adjusted for conservation-tillage practice, and the average number of tons of soil leaving the field during a one-year period.

The econometric simulation component estimates resource use and commodity output originating in the United States excluding Iowa. Major categories of agricultural production are included in the simulation component by five crop submodels--beef, pork, land and mutton, chicken, and turkey; and, a submodel which aggregates components from each of the other ten and sums those results with the exogenously determined variables for the rest of the United States [Schatzer, et al, 1981; Roberts and Heady, 1979, 1980]. Each crop submodel is divided into three stages corresponding to the preinput (planning), input (planting), and output (havesting and marketing) decisions in a sequential production cycle for one year at a time. The econometric sector consists of 210 equations (151 for crops and 59 for livestock) formulated primarily in a sequential framework. Annual time series data are used to estimate the structural parameters of the model using appropriate statistical estimation techniques. Most equations are estimated from 1949-76 data with portions of the livestock submodels using 1953-76 data.

Protection from the degredation of crop yields due to excessive erosion is perhaps the most important aspect of sustaining long-run agricultural productivity. The physical component of Iowa-RN is designed to address this issue. It has been repeatedly documented through field observations that as topsoil depth declines due to erosion, crop yields also decline, ceteris paribus [Wetter, 1977; Kaiser, 1967; Pawson, et al, 1961]. Larson [1982] indicates that where sufficient surface and sub-horizons exist, crop yields do not differ greatly on soils with different degrees of erosion especially if good management practices and fertilizers are used. However, as the topsoil continues to erode, yields begin to be adversely affected and tend to drop sharply once coarse subsoil material is exposed. Most empirical yield functions related to soil erosion rely on changes in topsoil depth estimated by the Universal Soil Loss

Equation as the primary independent variable, because of the lack of relevant agronomic information which can be readily incorporated into simulation models [Dumsday, 1971].

The hypothesized relationship between topsoil depth and the yield of, for example, corn is presented in Figure 1. Topsoil depths of 1.5, 5.0, and 9.5 inches correspond to average soil depths of erosion phases 3 (severely eroded), 2 (moderately eroded), and 1 (slightly eroded), respectively. This study assumes that changes in topsoil depth above 9.5 inches or below 1.5 inches do not affect crop yields. Available empirical evidence tends to support this assumption. Benchmark corn yield-soil depth functions similar to Figure 1 are estimated for each of 5 land classes for each of 12 producing areas based on the principal soil association areas in each PA, the dominant soil classification by land class for each Land Resource Area, and information on 18 Iowa farms from Pope, Bhide, and Heady [1982].

Initial yields in the LP model are based on the 1970-75 average for the 8 crops in the 12 PA's, adjusted for land class differentials. These initial yields are then adjusted for each crop between time periods due to two factors. First, average yields per acre per land class per producing area increase over time because of technological improvements in crop varieties, etc. This improvement essentially amounts to a gradual horizontal upward shift of curve DCBA in Figure 1. Hence, technological improvement is expected to allow more bushels per acre of the respective crop to be produced from a given topsoil depth.

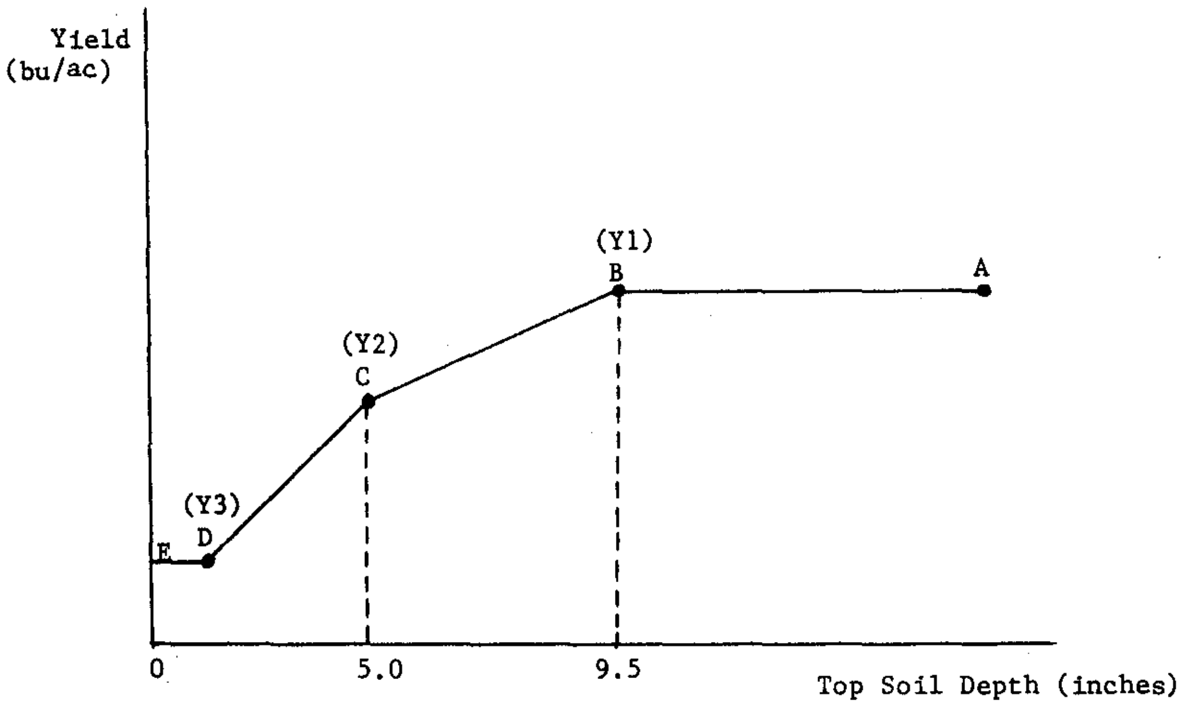

Figure 1. The hypothesized relationship between topsoil depth and corn yields.

A second adjustment procedure allows decreases in crop yields over time due to loss of topsoil. The procedure used to make these adjustments is as follows. Tons of soil loss associated with each activity are estimated by the Universal Soil Loss Equation. Tons of soil loss are converted to inches of soil loss according to average bulk density of the soil. Inches of topsoil lost is subtracted from depth of topsoil last year to obtain the new topsoil depth. Let Y1, Y2, and Y3, in Figure 1 be the corn yields corresponding to soil depths of 9.5, 5.0, and 1.5 inches, respectively. The slope over line segment AB = M(1) = 0; the slope over BC = M(2) = ((Y1 - Y2)/Y1)/4.5; the slope over CD = m(3) = ((Y2 - Y3)/Y1)/3.5; and, the slope over DE = m(4) = 0. Based on the benchmark plots as in Figure 1, the yield adjustment factor ($YADJ_t$) due to loss of topsoil are computed as:

If $SOILD_t \geq 9.5$ then $YADJ_t = 1.0$;

If 5.0 $SOILD_t \leq 9.5$ then $YADJ_t = m(2) * (SOILD_t - 5.0) + (Y2/Y1)$;

If 1.5 $SOILD_t \leq 5.0$ then $YADJ_t = m(3) * (SOILD_t - 1.5) + (Y3/Y1)$;

If $SOILD_t < 1.5$ then $YADJ_t = 1.0$

Using the appropriate yield adjustment factor determined above on the basis of topsoil depth ($SOILD_t$), crop yields are determined for each crop in each land class in each producing area as:

$CYLD = IYLD * (1- YADJ)$;

$YIELD_t = IYLD' - (CLYD * WGT)$,

where CYLD is the estimated change in crop yield; IYLD is the initial yield based on the 1970-75 average crop yeilds in Iowa; IYLD' is the initial yield adjusted for conservation tillage practice; and WGT is the weight of the crop in the particular rotation. To summarize, the primary purpose of the physical component of the Iowa regional national recursive model is to determine the net adjustment in crop yields between time periods. The net adjustment is the difference between the technological improvement and the soil loss detriment.

The purpose of the linkage component of Iowa-RN is to retrieve and transfer information between the programming, econometric, and physical components; and, to revise selected variables between time periods to simulate the recursive sequence of agricultural production and its interaction with the environment. The basic solution procedure for the Iowa model is shown in Figure 2. The regional programming component is first solved for the profit maximizing level of crop production and resource use for the State of Iowa. These values are summed with estimates of production and input use occuring in the United States excluding Iowa (estimated from the national econometric simulation component) to obtain national totals. Commodity prices and other important economic variables are estimated in the econometric component. Crop yield adjustment factors are determined in the physical component bases on inches of topsoil lost and on technological improvements in crop yields, and are used to revise the crop yields in the LP sector. The newly estimated commodity prices are used to revise the crop sell

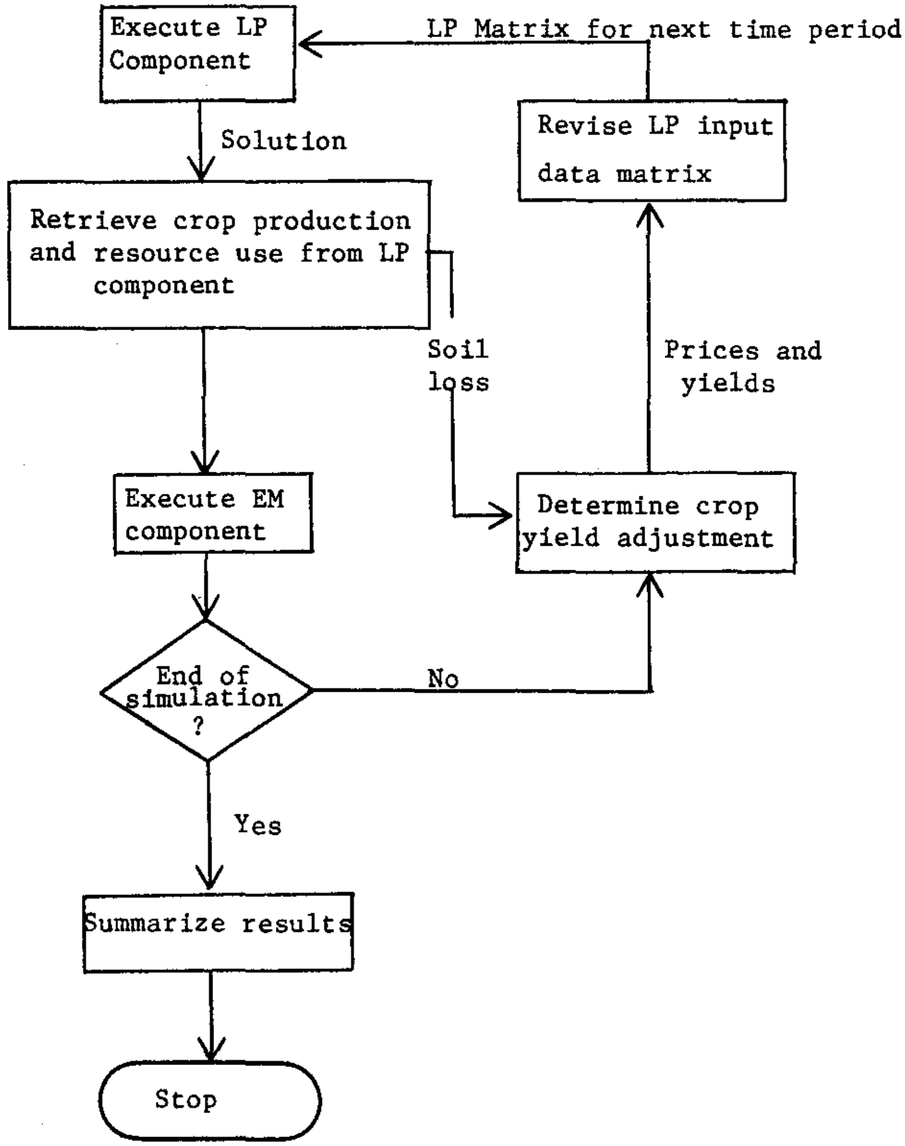

Figure 2. Basic solution procedure of the Iowa model

coefficeints in the LP objective function. After the LP input data matrix has been revised, the programming component is solved for the next time period, thus repeating the entire process again until the predetermined number of simulations are completed.

Benefits are gained from the integration of information on the spatial pattern of regional supply, resource use, technical means of production, and the environmental implications (generated by a regional programming model) with the detailed information on market structure and prices of commodities and inputs (generated by a national econometric simulation model). A more detailed description of each model component appears in Heady and Langley [1981].

The Iowa Regional National Recursive Hybrid model is currently operational and has been used for some preliminary analysis to investigate crop production activity under alternative soil loss limits. Such limits have been imposed by the State Legislature of Iowa to alleviate the impact of soil erosion on Iowa's agricultural lands. Under Iowa law "acceptable" limits have been established for every major soil type and on every acre of land. If losses exceed these limits and cause damage to adjacent property, the property owner can file a complaint and seek to have the person permitting the excessive erosion take corrective action to end such losses.

Results of early model tests indicate that limiting the use of crop management practices which cause soil loss in excess of a 5 tons/acre tolerance limit leads to highly erosive land being idled and an increased use of small grains (oats and wheat) in the selected crop management schemes. Average soil loss is reduced from a state average of 7 tons/acre with no restrictions to 4 tons/acre with tolerance limits, with the most noticeable benefits occuring in the highly erosive lands of western Iowa. In terms of the yield adjustments mentioned in regards to the physical sector, it can be concluded that programs or policies which are successful in reducing soil loss would be highly advantageous. As soil erosion is reduced, the detrimental impacts of the loss of topsoil upon crop yields will likely be offset by the beneficial aspects of technological improvement in crop yields. Hence, agricultural productivity is likely to be sustained longer into the future. A more complete analysis of selected results is forthcoming.

Other potential scenarios which may be investigated with this type of model include analysis of the implications of controlling soil erosion via tax or subsidy schemes; restricting the availability of selected inputs into the production process (e.g., nitrogen fertilizer, energy supplies, etc.); and, shifts in production patterns in Iowa due to changes in relative input and output prices. Also, the model can be expanded to a multiregional model of the entire United States (or other country) as resources become available and such a model is needed [e.g., Huang, et al, 1980; Langley, Huang, and Heady, 1981].

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