Environmental Accounting in Development Decisions: Concepts and Application to Agricultural Soil Loss

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Economic growth poses a dilemma. Growth in the manufacture of goods such as food, housing, health care, and transportation contribute importantly to human well-being. But the manufacture of these goods also produces pollution. As pollution increases, chronic and acute health problems increase, labor productivity declines, and economic well-being falters.

Standard indicators of economic growth reflect only a portion of a nation's productivity. The national accounting procedures that compute gross domestic product and net domestic product are based on concepts that view only market goods as scarce. They date to the early twentieth century when capital was the primary scarce good. Labor quality and environmental resources were considered the fixed gifts of nature.

Scarcity conditions and policy concerns have changed. Environmental goods are now scarce and in danger of neglect. Local environmental decay threatens human health and well-being in areas throughout the world. Global environmental change threatens uncertain dislocations for human society. Better indicators of economic performance are needed; indicators that account for the scarcity of environmental resources and reflect real tradeoffs involved in economic growth and development decisions.

Environmental accounts are one approach to understanding the link between economic and environmental change. Like the treatment of capital in standard accounts, environmental accounts treat environmental resources as one form of national wealth. The accounts identify available resources, measure investment and depreciation, and place an economic value on the services produced by such resources. The accounts place environmental resources on a level comparable to other forms of wealth.

Environmental accounts serve at least three purposes. First, the accounting process imposes organization on existing environmental information. Information is drawn together in an integrated framework. Second, the accounts identify the available quantity and quality of specific resources. Depreciation and investment can be tracked over time. Policy performance can be assessed. Third, a well developed accounting system identifies policy trade-offs across resources and across environmental and economic sectors. It place the environmental resources on a level comparable to other forms of economic wealth.

This paper examines environmental accounting procedures as a pragmatic method for analyzing and prioritizing environmental problems. Previous and ongoing experiments in environmental accounting are reviewed briefly in the first section. The analysis then focuses on developing an accounting method for one set of resources--the soil resources of Uruguay.

The soil account grew out of a project jointly sponsored by the Uruguayan government and the Organization of American States. The project's purpose was to set policy priorities and identify appropriate analytical methods. Environmental accounts were one of the methods selected for further analysis. The purpose of the soil account was to examine the feasibility of environmental accounting and its usefulness in analyzing national policy alternatives.

Previous Research on National Environmental Accounts

Guidelines published by the United Nations Statistical Office (1979) give a standard framework for national income accounting. The United Nations accounts are encompass only environmental resources that are privately owned or are used in commercial production. These resources include tree plantations, soils, and mineral resources. Non-private resources such as air quality or stocks of wild species do not enter in the United Nations accounts.

Various countries and organizations have tried to improve on the United Nations guidelines. Norway has developed accounts to track energy resources, renewable resources such as forests and fisheries, and non-private resources such as water and air quality (Alfsen et al, 1987). The Norwegian accounts are expressed entirely in physical units (e.g., tons, liters, population numbers). France has extended the Norwegian accounts to cover additional features of the physical environment and living organisms (Weber, 1983). The French accounts convert physical units to dollar valuations when resources are sold into a market system.

Environmental accounts expressed entirely in money terms are usually limited in scope by the difficulty of valuing goods that are not explicitly priced in commercial exchange (e.g., non-market goods). Accordingly, Peskin (1990) limits his Tanzanian resource accounts to forest resources but manages to include both the market and non-market services of forests. In Peskin's forest accounts, the non-market service sector includes subsistence agriculture, hunting, fishing, and fuelwood.

A study by Repetto et al (1989) produced accounts expressed in money units for timber, petroleum, and soil resources in Indonesia. The Repetto et al study follows conventional accounting procedures but uses market price and yield reduction estimates to produce estimates of resource depletion. The Repetto et al study shows that proper accounting has a significant impact on estimated economic growth rates: estimated annual national income growth for Indonesia is 7 percent per year when standard accounting procedures are used but is only 4 percent when resource depletion is correctly accounted for. Given the miscalculations inherent in standard procedures, damaging economic policies are easily mistaken as beneficial. Truly beneficial policies may be overlooked.

Though they differ widely in specifics, environmental accounts share four prominent features in their design and construction. First, their primary objective is to provide information that is relevant to economic and environmental policy. This policy orientation implies that a system of accounts will address the environmental resources that are of greatest concern to the particular nation or agency that is responsible for developing the accounts. It also implies the detail and accuracy that are built into an accounting system are selected with policy analysis in mind. When the goal of policy analysis is forgotten, resources are easily misspent on unnecessary detail or in producing irrelevant information.

Second, a particularly appealing feature of national accounts is that income is expressed in sustainable terms: income is the maximum amount that a nation can consume without reducing the productivity of its capital and environmental resources (Peskin, 1990; Repetto et al, 1989). Investment occurs through savings, maintenance, and rehabilitation. Investment enhances capital, resource productivity, and future income. Depreciation occurs due to use, decay, and neglect. Depreciation reduces future productivity and income. National income is therefore expressed as consumption plus investment less depreciation.

Third, existing environmental accounts focus on the depreciation of private or semi-private resources. These resources include forest, energy resources, and soil. With these resources, consumption and investment are typically included in standard income accounts. The primary environmental accounting problem for these resources is to estimate a suitable measure of depreciation. This restriction to private and semi-private resources is largely due to the practical difficulties of measuring and valuing public resources such as air quality, water quality, or wild species. However, with appropriate research, these difficulties can be overcome and the accounts extended to purely public resources.

Finally, the development of an environmental accounting system is best viewed as an evolutionary process. At the initial stages of the development process, policy concerns are identified and a small number of relevant accounts are proposed. Information sources are identified, the practicality of the proposed accounts is reviewed, and the needed research is begun. Initial accounts may be expressed in physical terms. Conversion to money valuation takes place at later stages of development.

Soil Resources in Uruguay

Soil resources are fundamental to agriculture, forestry, and natural ecosystems in Uruguay. Through agriculture[1] and livestock, soil resources generate 12 percent of the gross national product. Over 80 percent of Uruguay's export earnings are obtained from agricultural and livestock products (BCU, 1989).

Soil erosion has potentially important environmental and economic impacts. Erosion reduces soil fertility and, in turn, agricultural productivity. Declining soil fertility jeopardizes future income possibilities. Important off-site impacts of soil erosion in Uruguay include reduced hydroelectric and irrigation potential of dams, increased treatment costs for drinking water, and ecosystem damages due to dredging for navigation.

Uruguay has a well developed set of basic soils data. The most comprehensive soil inventory is the *Carta de Reconocimiento de Suelos del Uruguay* (Direccion de Suelos y Fertilizantes, 1979). The *Carta de Reconocimiento de Suelos del Uruguay* (*Carta*) describes the physical and chemical properties of over 100 soil groups found in Uruguay. It also summarizes their spatial distribution in a national soils map.

Table 1 summarizes land use information contained in the *Carta*. The *Carta* indicates that over 90 percent of Uruguayan lands are used in agriculture, livestock operations, or natural and plantation forests. Livestock is by far the most extensive use and occupies over 80 percent of all Uruguayan lands. Crops account for approximately 6 percent of land use. Forests account for about one percent. Horticulture, vineyards, and orchards are relatively minor uses and together cover less than one percent all lands.[2]

Table 2 shows average physical and chemical characteristics of Uruguayan lands by land use. The averages shown in Table 2 were calculated by taking a weighted average across the physical and chemical data in the appendices to the *Carta*. The weighting factors were the amount of Uruguayan land area covered by each soil type. Since samples tend to be taken from the soils least disturbed by human use, these data represent as closely as possible the natural endowments of soils in Uruguay rather than the general condition of soils in use.

Table 2 indicates that Uruguay is endowed with a rich set of soils. Horizon A averages about a third of a meter in depth. Organic material is very adequate and averages a little over 5 percent. Total nitrogen averages 0.35 percent.

The potential for damaging soil loss is characterized, in part, by the slope, K, and T values shown in Table 2. The average slope of the land is only 3.6 percent. This rather slight slope tends to diminish the potential for soil loss. The average

Table 1. Uruguayan Lands and Uses

Land and Uses	Percent of Total Land Area	Area in Square Kilometers
All Land	100.0	175215
Total Agricultural, Livestock, and Forest	91.5	160247
Livestock	81.3	142446
Crops	5.8	10224
Forests	1.0	1812
Horticulture	0.32	560
Vineyards	0.04	67
Orchards	0.18	319

Note: The source for total land area and land in agriculture, livestock, and forests is the Direccion de Investigaciones Economicas Agropecuarias, 1983. The source for all other data is the Direccion de Suelos y Fertilizantes, 1979.

Table 2. Characteristics of Uruguayan Soils by Use

Use	Depth of Horizon A (cm.)	Organic Material (%)	Nitrogen (%)	Slope (%)	K	T
All Agricultural, Livestock, and Forest Land	32	5.16	0.35	3.6	0.34	5
Livestock	32	5.18	0.35	3.6	0.34	5
Crops	31	4.92	0.29	3.0	0.30	7
Horticulture	33	4.73	0.26	3.2	0.27	8
Vineyards	29	4.55	0.23	2.7	0.30	7
Orchards	24	5.28	0.28	2.2	0.25	5

Source: Direccion de Suelos y Fertilizantes, 1979.

K value (see Puentes, 1983; and Puentes and Szogi, 1983) in Table 2 is 0.34. The average T value is 5 tons per hectare per year. These K and T values imply that Uruguayan soils are moderately susceptible to erosion.

Table 2 shows only minor variations in the properties of Uruguayan soils across different uses. Soils are average or deeper than average in livestock and horticultural areas. Soils in crop, vineyard, or orchard areas are shallower than average. Organic material and nitrogen are lower than average in crop, horticulture, and vineyard areas. This slight variation in soil characteristics is probably due to the difficulty of finding an undisturbed sample in these areas rather than to a difference in the natural endowment of physical or chemical characteristics.

Despite the physical similarities across soils, Cayssials et al (1978) note that existing erosion levels vary substantially across different regions of the country. Erosion is most severe in the southern part of the country in the Departments of Canelones and Montevideo. In these Departments, traditional monoculture methods are used extensively and there is little investment in the continued fertility of soils. Until recently, sugar beets were grown in Canelones using highly erosive cultivation techniques.

Table 3 gives estimates of existing soil losses due to historical land uses. Estimates are listed for all lands and for lands in different uses. For the country in general, existing soil losses are rather small. For all land, cumulative historical soil losses average about 4 centimeters or 12.7 percent of soil horizon A and about 6.5 percent of horizons A and B. Livestock operations have had less than average impacts on soil depth. The average loss on livestock lands is only 3 centimeters. This translates into 10.9 percent of horizon A and about 5.6 percent of horizons A and B.

Soil losses on agricultural lands are greater than average. Agricultural soil loss averages 10 centimeters. This is 30.9 percent of horizon A and 14.3 percent of horizons A and B.

The most severe soil losses have occurred in horticultural, vineyard, and orchard crop areas. With vineyards, soil losses average 16 centimeters or about 56 percent of horizon A and 21 percent of horizons A and B. Horticultural soil loss average 62 percent of horizon A and 29 percent of horizons A and B. Soil loss is greatest in orchard areas, averaging 100 percent of horizon A and 44 percent of horizons A and B.

Three implications can be drawn from Table 3. First, agricultural soil loss does not appear to be a general problem for soil fertility across the country as a whole. Over 80 percent of Uruguayan lands are in low intensity livestock

Table 3. Estimated Soil Losses due to Historical Land Uses

Use	Estimated Total Soil Lost (cm)	Depth of Horizon A (cm)	Estimated Loss of Horizon A (%)	Depth of Horizons A and B (cm)	Estimated Loss of Horizons A and B (%)
All Agricultural, Livestock, and Forest Land	4	32	12.7	62	6.5
Livestock	3	32	10.9	61	5.6
Agriculture	10	31	30.9	67	14.3
Horticulture	21	33	61.7	72	28.8
Vineyards	16	29	56.0	76	21.3
Orchards	26	24	100	59	43.9

Sources: Cayssials and Alvarez, 1983; Direccion de Suelos, 1985; and Direccion de Suelos y Fertilizantes, 1979.

production. The predominance of lands in livestock reduces the impact of human activity on soil resources.

Second, soil erosion is severe in areas where land use has been intense. The most severe impacts have occurred in horticultural, vineyard, and orchard areas. As recognized in previous studies (Direccion de Suelos, 1985; Rabuffetti, 1986), these areas of intense soil use require research and extension efforts to improve soil management practices and reduce future soil losses.

Third, the significance of soil erosion in crop production--agriculture--requires further research. Erosion on agricultural lands has been substantial, amounting to about a third of horizon A. These lands cover approximately 6 percent of all Uruguayan territory. Recent changes in soil management practices and technology may have reduced the ongoing impact of crop production on soil loss in some areas. However, recent economic policy has encouraged more intensive production on agricultural lands. The net impact of these shifts in technology and economic policy on soil loss are not yet clear. They require further research.

Soil Loss Accounting Procedures

The importance and history of soil use in Uruguay underscores the need to develop accounting methods for changes in the quantity and value of soil resources. Although agricultural land is subject to intense use, there is no quantitative information on current soil conditions or soil loss rates on agriculture lands. To provide an example of how a soil account may be developed, the present study analyzes soil loss due to Uruguayan crop production.

The objective in constructing the account is to obtain a physical measure of the physical soil depreciation on agricultural lands. This is similar to studies of other private and semi-private resources (Repetto et al, 1989; United Nations Statistical Office, 1979) where consumption and investment are assumed to be captured by standard national accounting procedures.

The account encompasses 8 different crops: barley, flax, maize, rice, sorghum, soybeans, sunflower, and wheat. These crops account for approximately 70 percent of the crop area planted in Uruguay. Oats, sugarcane, and sugarbeets are three crops that were not included in the analysis due to insufficient price information.

The soil account has three components. The first component summarizes the physical relationship between climate, soil characteristics, production technology, and soil erosion rates. The primary difficulty in constructing this component is to identify soil characteristics and technology groupings that are representative of the agricultural and pastoral areas in each of the 19 Uruguayan departments. Output from this component gives annual erosion rates for agricultural crops, forages, and livestock.

The second component estimates total soil losses by department and for the nation as a whole. This is a matter of multiplying the erosion rates obtained in the first component by crop areas in each department to obtain annual soil loss. Annual national soil loss is the sum of the losses by department.

The third component analyzes how technology and economic policy affect annual soil loss. Changes in technology are represented by shifts in the distribution of soil management practices. These shifts feed back into the first component to affect cropland erosion rates.

Economic policy affects crop production by either subsidizing or taxing product prices. As the effective producer prices rise or fall, so too does the profitability of producing a crop. Profitability, in turn, influences the number of hectares under cultivation. The third component uses statistical methods to link changes in economic policy--effective product prices--to changes in area planted. These estimates are then fed into the second component to estimate soil loss. With technology constant, soil loss is proportional to area planted.

The following subsections detail each of the three components of the soil loss accounts. The computer program that calculates soil erosion under different technological and economic scenarios is available upon request to the author.

Component A: Soil Erosion Rates

There are two objectives in estimating erosion rates. The first is to estimate the amount of erosion that impairs or depreciates the fertility of Uruguayan soils. The second is to estimate the amount of soil that enters surface waters to impair non-agricultural investments and ecosystems. Both measures of erosion are influenced by climatic, geophysical, and technological factors.

The two measures of soil erosion are produced in three steps. First, annual gross soil erosion is estimated. Gross soil erosion is the total amount of soil disturbed by climatic factors and cultivation.

Second, net soil erosion is computed. Net soil erosion is gross soil erosion less the appropriate T value--the amount of soil erosion that a given soil type can tolerate without losing fertility. Net soil erosion measures the physical depreciation of inherent soil fertility.

Third, soil loss to surface water bodies is estimated. Soil loss to water bodies is proportional to gross soil erosion where the factor of proportionality depends on soil composition and stream density per square kilometer. Soil loss to water bodies estimates the amount of soil that enters streams, rivers, and lakes to impair non-agricultural resources such as dams, water treatment plants, and natural ecosystems.

Each soil erosion measure is estimated using the Universal Soil Loss Equation (USLE) (Novotny and Chesters, 1981; Salas, 1988). The USLE has its origins in the United States. It has been extensively researched and adapted for use in Uruguay (Puentes, 1983; Puentes and Szogi, 1983). Though commonly used in research and policy analysis (Novotny and Chesters, 1981; Salas, 1988), it should be recognized at the outset that the USLE is an approximation.

The USLE gives annual gross soil erosion in metric tons per hectare. Gross soil erosion in metric tons per year (GSL_h) is calculated as (Salas, 1988)

$$(1) \quad GSL_h = (R)(K)(LS)(CxP)$$

where

GSL_h = gross soil erosion in metric tons per hectare per year,

R = a factor based on rainfall energy,

K = a factor summarizing the erodability of different soils obtained through laboratory or field experiments,

LS = a factor that accounts for topography, and

CxP = a factor that accounts for crop cover and soil management practices.[3]

Puentes (1983) suggests that R varies from 500 to 700 in Uruguay. However, recent experience suggests that an R of 500 is likely to best represent the country as a whole (Sganga, 1990). To provide an initial lower bound on erosion, this study uses R equal to 500 for the entire country.

Other factors in the USLE depend on soil characteristics and technology. These are discussed after two other erosion measures are introduced.

Soils can tolerate a certain amount of soil loss without a loss in fertility. The T values measure this tolerance in metric tons per hectare. Net erosion is by subtracting T from GSL_h. Net soil erosion per hectare per year is

$$(2) \quad NSL_h = GSL_h - T.$$

The final erosion measure is the amount of soil that is carried off into streams and rivers. This is the amount of erosion that is available to impair aquatic ecosystems, fill dams, impair water treatment, and increase the need for dredging. These soil losses to water bodies are calculated by multiplying GSL_h by a factor S_d. S_d depends on soil composition and the stream drainage density within a river basin (Salas, 1988). Net soil erosion to water bodies per hectare (NWB_h) is

$$(3) \quad NWB_h = (GSL_h)(S_d).$$

For Uruguay, drainage density varies from 1 to 5 kilometers per square kilometer. Since most agricultural soils are loamy clays, this translates into a S_d factor of 0.5 to 0.7 (Salas, 1988). For this study, an average S_d value of 0.6 is used.

Table 4 lists the values of the USLE for different Uruguayan regions and departments. Each of these values was selected to be representative of the agricultural soils within a given department.

The K values listed in Table 4 show that the erosiveness of Uruguayan soils varies substantially by geographic area. The least erosive soils--soils with the smallest K values--are found in departments of the littoral and northwestern part of the country. The most erosive soils are found in the northeast where K values are as much as two times larger than those in the littoral-northwest. Soils in the south-southeast have properties that make them moderately erosive.

T values show little variation across the agricultural soils of different departments. Uruguayan agricultural soils appear to be about equal in their ability to withstand erosion without suffering a fertility loss.

The LS factor accounts for the topography of agricultural soils. LS is a function of slope and length of slope (Novotny and Chesters, 1981). LS values tend to be somewhat smaller and less conducive to erosion in the littoral-northwest. They tend to be higher in the south-southeast and the northeast.

Table 4. Components of the Universal Soil Loss Equation by Region and Department

Department	K	T	LS	Technology		Estimated Soil Loss (tons/ha)	
				Class[a]	CxP	Gross	Net
LITTORAL-NORTHWEST							
Artigas	0.21	7	0.5	I	0.375	20	13
Colonia	0.27	7	0.6	C	0.239	19	12
Paysandu	0.24	7	0.7	C	0.239	20	13
Rio Negro	0.19	7	0.6	C	0.239	14	7
Salto	0.27	7	0.5	I	0.375	25	18
Soriano	0.34	7	0.7	C	0.239	28	21
SOUTH-SOUTHEAST							
Canelones	0.27	7	0.6	D	0.433	35	28
Flores	0.23	7	0.6	C	0.239	16	9
Florida	0.27	7	0.6	I	0.375	30	23
Lavalleja	0.56	5	0.6	D	0.433	72	67
Maldonaldo	0.39	7	1.0	I	0.375	73	66
Montevideo	0.39	7	0.3	I	0.375	22	15
San Jose	0.27	7	0.6	D	0.433	35	25
NORTHEAST							
Cerro Largo	0.48	7	0.7	I	0.375	63	56
Duranzo	0.34	7	0.6	I	0.375	38	31
Rivera	0.22	9	0.8	I	0.375	33	24
Rocha	0.43	7	0.7	I	0.375	56	49
Tacuarembo	0.38	9	0.8	I	0.375	57	48
Treinta y Tres	0.43	7	0.7	I	0.375	56	49

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[a] A D denotes a department with a traditional technology mix, an I denotes a department with an intermediate technology mix, and a C denotes a department with a conservation oriented technology mix.

Source: Salas, 1988, and J. C. Sganga, Direccion de Suelos, July, 1990.

CxP values indicate how crop cover and soil management technology influence erosion. CxP values were obtained using the 6 technology-crop combinations identified by Puentes (1983). These technology crop combinations are listed in Table 5. Traditional agricultural technology has the most erosive CxP value of 0.52. CxP values diminish as more soil conserving strategies are used. The lowest CxP value is for pasture with 80 percent cover.

The CxP value for each department depends on the mix of technologies A though E that are used in that department to produce annual crops. To account for the different technological mixes found in different departments, three different technology classes were developed.

Table 6 lists the 3 baseline technology classes under the heading "Baseline Technology". Each baseline technology class is intended to describe the actual technological conditions found in different departments. For instance, the traditional technology mix is characteristic of Canelones. With this traditional technology mix, 70 percent of agricultural land is cultivated using the technology A of Table 5 and 30 percent is cultivated with technology B of Table 5. In the intermediate technology class that is characteristic of Florida, 50 percent of agricultural land is managed with technology A and 50 percent with technology B. In a conservation oriented department such as Paysandu, one finds a conservation technology mix where 10 percent of agricultural land is subject to technology A and 60 percent is subject to technology B. In the conservation technology class, the remaining fractions are produced using technologies C, D, and E.

The CxP mix for each technology class in Table 6 is a weighted average of the CxP values given in Table 5. The weights are the percentages of agricultural land that is subject to each of technologies A through E. As the right hand column of Table 6 shows, CxP value of 0.433 for the traditional technology mix is almost twice as large--twice as erosive--as the CxP value for the conservation technology mix.

The technology classes and respective CxP values were assigned to each department in consultation with the Direccion de Suelos. These assignments are listed in Table 4. The littoral-northeast includes both intermediate and conservation technology mixes. Traditional and intermediate technology mixes are found in the south-southwest. The northeast is composed entirely of intermediate technology mixes.

The last two columns of Table 4 list the estimated gross and net erosion rates. The estimates show that agricultural erosion varies substantially across geographic areas. The lowest estimated gross erosion rate is found in Rio Negro. The largest gross erosion rates are in Lavalleja and Maldonaldo. Gross erosion in the littoral-northwest ranges from 14 to 28 tons per hectare per year. Gross

Table 5. Technology Groups and C x P Parameter

Technology	Description	C x P
A	Traditional Agriculture - Continuous cultivation - Little added fertilizer - Fields left clean after harvest - Conventional plowing	0.52
B	Continuous Cultivation with Conservation Management - Continuous cultivation - Fields left clean after harvest - Contour plowing with grass strips	0.23
C	Conservation Management/Reduced Tillage - Continuous cultivation - Chisel plowing - Harvest residuals left in field - Contour plowing	0.19
D	Rotation System - 2 years cultivation, 4 years in legumes - Conventional tillage	0.15
E	Rotation System/Conservation Management - Rotation system - Tillage in contour	0.07
F	Natural Pastures - 80% coverage	0.013

Source: Puentes, 1983.

Table 6. Baseline and Alternative Technology Scenarios.

Technological Scenario (Characteristic Department)	Distribution of Tillage Systems (% in each class) A	B	C	D	E	C x P Value for Tech. Group
BASELINE TECHNOLOGY						
Traditional (Canelones)	70	30	0	0	0	0.433
Intermediate (Florida)	50	50	0	0	0	0.375
Conservation (Paysandu)	10	60	20	5	5	0.239
TRADITIONAL TECHNOLOGY IN ALL DEPARTMENTS						
Traditional (Canelones)	70	30	0	0	0	0.433
Intermediate (Florida)	70	30	0	0	0	0.433
Conservation (Paysandu)	70	30	0	0	0	0.433
CURRENT CONSERVATION TECHNOLOGY IN ALL DEPARTMENTS						
Traditional (Canelones)	10	60	20	5	5	0.239
Intermediate (Florida)	10	60	20	5	5	0.239
Conservation (Paysandu)	10	60	20	5	5	0.239

Source: J. C. Sganga, Direction de Suelos, M.G.A.P.

erosion in the Northeast is as much as 4 and a half times larger than in the littoral-northwest and ranges from 33 to 63 tons per hectare per year. The most extreme variation in erosion is in the south-southeast where rates range from 16 to 73 tons per hectare per year. Net soil erosion varies across geographic areas in a manner similar to gross erosion.

Following equation (3) net soil loss to water bodies, NWB_h, is gross erosion per hectare times the S_d value of 0.6 identified above. Hence, net soil loss to water bodies also varies geographically in a manner similar to gross erosion.

Component B. Soil Loss by Department and for the Nation

Total annual soil loss is the annual soil erosion per hectare times the number of hectares planted in agricultural crops. Since Uruguayan departments vary significantly in their erosion rates, the calculation of total soil loss begins at the departmental level. This would be a straightforward task if the area planted in crops were available by department on an annual basis. Unfortunately, such data were not available during the course of this study.

Areas planted by department were calculated in three steps. First, data on hectares planted in the 8 crops for the nation as a whole were obtained from the Direccion de Programacion y Politica Agropecuaria (1990). Data on hectares planted for 1986 were used as a representative baseline scenario.[4]

Second, hectares planted in the 8 crops for the nation as a whole were apportioned to the respective departments based on each department's share of national area planted in 1980. Shares were calculated from 1980 census information (Direccion de Investigaciones Economicas Agropecuarias, 1983).

Third, estimated erosion rates for each department were multiplied by the estimated hectares planted in each department to obtain total annual soil loss by department. Departmental soil losses were summed over all departments to obtain total agricultural soil loss for 8 major crops across the nation as a whole. Since the 8 crops represent 70 percent of the land in agriculture, the total soil loss estimate is approximately 70 percent of total annual agricultural soil loss in the nation as a whole.

Loss of organic matter, nitrogen, and phosphorus are also of interest since these are linked to soil fertility.[5] According to the Direccion de Suelos, losses of these materials are proportional to total soil loss. Loss of organic matter is calculated as 5.18 percent of total soil loss for the 8 crops. Nitrogen loss is estimated to be 0.17 percent. Phosphorous loss is estimated to be 7 parts per million parts of soil loss.

Component C. Technology and Economic Policy

Technology and economic policy have significant impacts on soil erosion. As shown in Table 5, traditional soil management technology is more than 7 times more erosive than the most conservation oriented crop production technology. Economic policy can have a substantial impact on input and product prices. These effects, in turn, affect profitability, choice of production technology, and area planted. Component C introduces a portion of these considerations into the soil account and permits the analysis of alternative technological and economic scenarios.

In this account, technology affects erosion rates through component A. Economic policy takes technology as fixed and focuses on the relationship between prices and hectares planted. Changes in prices change the number of hectares planted and soil loss since soil loss is, by component B, proportional to area planted. Given their distinct effects, technology and economic policy are discussed separately.

Technology

Technology enters the estimation of agricultural soil erosion by shifting the CxP values in component A. For the baseline scenario, the baseline technology was used as described in Table 6. The impact of alternative technological policies is examined by changing the mix of technologies used in different departments.

The first alternative technology scenario examines soil loss assuming a traditional technology mix is used in *all* departments. This first scenario is described in Table 6 in the subsection labeled "Traditional Technology in All Departments". With this scenario, 70 percent of the areas planted are managed using technology A and 30 percent with technology B.

The second alternative technological scenario assumes that the "Current Conservation Technology" is used in all departments. With this scenario, the mix of technologies used in traditional and intermediate departments is identical to that of the conservation oriented departments such as Paysandu.

For each alternative, CxP values are calculated as weighted averages in a manner identical to those for the baseline scenario. These CxP values are then used as data in component A to estimate erosion rates. These erosion rates are multiplied by the area planted in component B to obtain total soil loss under each of the alternative technological scenarios.

Economic Policy

The economic analysis is based on a simple profit maximization model. Farmers are assumed to select area planted and yield in order to maximize profit. This simple model results in an algebraic relationship between product price and hectares planted. Given an econometric estimate of this relationship, changes in hectares planted can be calculated given changes in price subsidies or taxes. Since soil loss is proportional to hectares planted (see component B), economic policy can be linked to and analyzed for its impact on soil loss.

Profit is revenue minus production costs. Revenue is product price, p, multiplied by yield per hectare, r, and the number of hectares planted, h. Yield is, in part, a function of rainfall and technological possibilities; that is, yield is a function $r = r(a,t)$ where a is rainfall and t represents technological possibilities.

Production cost is a function of an input price index, w, hectares planted, and yield. Algebraically, production cost is

$$\text{cost} = c[w,h,r(a,t)]. \tag{4}$$

Profit, π, is therefore

$$\pi = phr - c[w,h,r(a,t)]. \tag{5}$$

Using equation (5), the marginal conditions for profit maximization can be derived and the reduced form equation for hectares planted determined. This reduced form equation for hectares planted is, in log-linear form,

$$\ln(h) = \alpha_0 + \alpha_p \ln(p) + \alpha_w \ln(w) + \alpha_a \ln(a) + \alpha_t \ln(t) \tag{6}$$

where $\ln(\bullet)$ denotes the natural logarithm of the variable in parentheses.

Equation (6) states that acreage planted is a function of product price, the index of input prices, rainfall expectations, and existing technological possibilities. Since (6) is a reduced form, coefficients such as α_p are mixtures of structural parameters. It is therefore not possible to formulate any strong hypotheses regarding the anticipated signs of the coefficients.

Economic policies of subsidies and taxes may be summarized in terms of their effects on input and product prices. Through input and product prices, equation (6) links economic policy to area planted. It also links economic policy to soil erosion since soil erosion is proportional to area planted. To examine the impact of economic policy on soil erosion, one requires an estimate of equation (6).

Equation (6) was econometrically estimated using annual data on the production of the eight crops from 1965 to 1988. Producer price and area planted data were obtained from the Direccion de Programacion y Politica Agropecuaria (1990).[6] Annual rainfall data were obtained from the Direccion de Meteorologia (1990). Technological possibilities were modeled as a time trend variable beginning at 1 in 1965 and ending with 24 in 1988.

Seemingly unrelated least squares (Judge et al, 1980) was used to estimate equation (6) for each of the eight crops under study. Results are displayed in Table 7. Price and rainfall variables were entered in the equations after lagging each by one time period. These lagged variables were intended to account for the difference between expectations at the time of planting and the realized values of rainfall and price during the year of harvest.[7] The estimated coefficients are elasticities since all variables entered the statistical analysis in their logarithmic form.

The coefficients of greatest interest to this analysis are the estimated price elasticities in Table 7. The largest price elasticity is for Flax. It indicates the an 10 percent increase in product price increases hectares planted by 11.3 percent. The smallest price elasticity is for barley. It is negative and suggests the barley acreage falls by 1.56 percent with a 10 percent increase in product price. The negative relationship for barley may imply that farmers have a tendency to substitute higher yields for increased hectares as price increases.

The statistical significance of the price coefficient was tested for the 8 equation system. The null hypothesis was that the price coefficients were each equal to zero. An F test with 140 and 8 degrees of freedom rejected the null hypothesis at the 95 percent level of significance. Hence, product price is a statistically significant variable in explaining the number of hectares planted.

The impact of a change in product price policy (e.g., a subsidy or tax) is estimated using equation (6) and the price coefficients in Table 7. Let the product price for a baseline scenario be represented by p^0 and the number of hectares planted be h^0. Let the product price under an alternative price policy be p^a. Using equation (6), the estimate of the number of hectares planted under the alternative price is, in logarithmic form,

Table 7. Estimated Reduced Form Equations for Uruguayan Crops

Dependent Variable	Intercept α_0	Price α_p	Rainfall $\alpha_{\bullet}$	Time α_t
Wheat,	7.00**	0.361**	-0.538	-0.324**
$R^2 = 0.52$	(3.80)	(2.22)	(-1.69)	(-4.13)
Flax,	-4.36	1.13**	0.731	-0.807**
$R^2 = 0.68$	(-1.19)	(4.45)	(1.10)	(-4.90)
Barley,	1.87	-0.156**	0.384	0.362**
$R^2 = 0.62$	(1.44)	(-2.53)	(1.39)	(5.12)
Maize,	3.40**	0.436**	-0.0151	-0.318**
$R^2 = 0.76$	(2.58)	(3.45)	(-0.07)	(-4.96)
Sunflower,	3.10*	0.308**	0.0890	-0.324**
$R^2 = 0.60$	(1.84)	(2.31)	(0.30)	(-4.33)
Rice,	0.68	0.172	0.248	0.477**
$R^2 = 0.80$	(0.52)	(1.42)	(1.21)	(9.44)
Sorghum,	-1.99	0.894**	0.159	0.267**
$R^2 = 0.41$	(-0.85)	(3.64)	(0.42)	(2.77)
Soybeans,	-16.6	1.07	1.67*	2.89*
$R^2 = 0.33$	(-1.67)	(1.04)	(1.81)	(1.84)

Note: T-statistics for each coefficient are given in parentheses. A "*" indicates that a coefficient is statistically different from zero at the 90 percent level of confidence. A "**" indicates that a coefficient is statistically different from zero at the 95 percent level of confidence.

(7) $$\ln(h^a) = \ln(h^0) + \alpha_p \ln(p^a) - \alpha_p \ln(p^0)$$

or, taking the anti-logarithm of (7),

(8) $$h^a = h^0(p^a/p^0)^{\alpha_p}.$$

Equation (8) gives the hectares planted for any alternative price policy that can be represented by p^a. For instance, an alternative policy that increases product prices relative to p^0 is represented by a p^a that is greater than p^0. An alternative policy the reduces subsidies or increases taxes is represented by a p^a that is less than p^0.

To calculate soil loss under alternative price policies, h^a is first estimated using equation 8. The estimate is used as an input into component B. For a given technology, soil loss is proportional to hectares planted.

Economic and Technology Policy Analysis

Economic and technology policy are routinely analyzed for their impact on priced resources such as capital and labor. However, the effects of policy on nonmarket resources is often overlooked. The purpose of this section is to demonstrate the effects of economic and technology policy on soil loss.

Economic policy is considered in terms of its impact on internal product prices. An economic policy may increase product prices through price supports or subsidies. As product prices increase, resources are used more intensively in the subsidized sector. In the subsidized sector, depreciation is likely to increase for both market and nonmarket resources. A reduction in subsidies or an increase in product price taxes is likely to have the opposite effect.

In actual practice, the implementation of technology policy is less precisely defined than economic policy. The primary tools that affect technology and its use are research and education. Research on soil conserving technologies may be conducted directly by a government agency. Additionally, tax and subsidies may be used to influence the amount of research conducted by private firms. Education takes place in schools and through extension. Extension efforts may include demonstration farms, meetings, and one-to-one consultation.

In this section, two economic policy alternatives and two technological alternatives are considered. Economic policy is described by its impact on product prices. Technology policy is described by the mix of soil management practices used across different departments. The baseline or initial scenario is described by

1986 quantities and prices. The baseline area planted is the number of hectares planted in the 8 crops in 1986. The baseline technology scenario and the effects of alternative technology policies are described in Table 6.

The baseline and alternative price policies are shown in Table 8. The first column in Table 8 lists each of the 8 crops analyzed. The second, third, and fourth columns list the baseline and alternative prices for each crop. These internal product prices are stated relative to the international f.o.b. price at Montevideo. For instance, the baseline wheat price of 1.8 means that in the baseline scenario, effective wheat prices to producers are 1.8 times the f.o.b. price in Montevideo. The 0.9 for flax means that internal flax prices are 0.9 times the f.o.b. price.

Baseline prices shown in Table 8 were selected to be representative of the recent structure of Uruguayan subsidies and taxes. The prices shown were calculated from a study of comparative advantage by von Oven and Paysse (1988) and are simply the implicit rates of effective protection that are commonly used in the analysis of international trade.

The third column of prices in Table 8 is intended to represent an economic policy without subsidies to agriculture. Effective producer prices are 10 percent less than unity to reflect the likely presence of at least some taxes and transportation costs to Montevideo.

The fourth column represents a general increase in the level of subsidies. Twice the border price was selected since this was the highest level of price support in 1986.

Table 9 describes gross soil loss, net soil loss, and soil loss to water bodies for the baseline set of prices, quantities, and technology. With prices fixed at the baseline level, 591 thousand hectares are planted in the 8 crops. Gross soil loss is 18.115 million tons. This is equivalent to approximately 31 tons per hectare. On average this implies a loss in soil depth of 2.5 millimeters per year. Losses of organic material, nitrogen, and phosphorus are proportional to gross soil loss.

These baseline calculations suggest that soil erosion is rather high in Uruguayan agriculture. In the United States, gross soil loss averages approximately 12 tons per hectare (Conservation Foundation, 1984; Crosson and Brubaker, 1982). There are a relatively few areas in the United States where rainfall, topography, and technology combine to produce soil losses that meet or exceed 30 tons per hectare.[8]

Net soil loss estimates are given in the third column of Table 9. Net soil loss is the loss of soil in excess of the amount that soils can tolerate without losing inherent soil fertility. Net soil loss is 13.969 million tons or about 77 percent of

Table 8. Alternative Product Price Policies

Crop	Alternative Product Price Scenarios[a]		
	Baseline (1986 prices[b])	No Subsidy: Border Price Less 10%	High Subsidy: Twice the Border Price
Wheat	1.8	0.9	2.0
Flax	0.9	0.9	2.0
Barley	1.0	0.9	2.0
Maize	2.0	0.9	2.0
Sunflower	0.8	0.9	2.0
Rice	0.7	0.9	2.0
Sorghum	1.7	0.9	2.0
Soybeans	1.2	0.9	2.0

a. Internal product prices are stated relative to international f.o.b. prices in Montevideo.

b. These are calculated from the rates of implicit protection estimated by von Oven and Paysse (1988).

gross soil loss. This translates to a loss of 24 tons per hectare or, on average, a little less than 2 millimeters of soil depth per year.

Finally, soil loss to water bodies is shown in the right hand column of Table 9. Soil loss to water bodies is 60 percent of gross soil erosion. This fraction stems directly from equation (3). The table indicates that 10.869 million tons of soil enter Uruguayan rivers and streams to fill dams and irrigation channels, increase the cost of water treatment, and impair natural ecosystems.

Table 10 shows how the two alternative price policies affect net soil loss relative to the baseline scenario. In the baseline scenario 591 thousand hectares are planted and 13.969 million tons of soil are lost from agricultural lands. Under the no subsidy scenario, the number of hectares planted and net soil loss declines by approximately 13 percent to 506 thousand hectares planted in the 8 crops and an annual net soil loss of 12.203 million tons.

Under the high subsidy scenario, prices increase to twice their border price, hectares planted increase to 671 thousand hectares, and net soil erosion increases to 16.007 million tons. The increase in hectares planted and soil loss is approximately 15 percent more than the baseline level.

An analysis of gross soil loss and soil loss to water bodies showed that they respond to prices in a manner similar to net soil loss. Thus, under the no subsidy price policy, gross soil loss and soil loss to water bodies decline by approximately 13 percent. Under the high subsidy scenario, each increases by about 15 percent.

Table 11 gives net soil losses under the baseline scenario and the two alternative technology scenarios. The second column in Table 11 lists net soil loss under the baseline scenario. The third column lists net soil loss under the assumption that traditional soil management technology is used in all Uruguayan departments. Under this scenario, net soil loss increases by 54 percent relative to the baseline scenario. Net losses are 21.439 million tons per year or 36 tons per hectare. This translates to a loss of 2.9 millimeters of surface soil. Losses of organic matter, nitrogen, and phosphorus also increase by 54 percent under the traditional technology scenario. These results indicate that the diffusion of improved soil management technology to at least a portion of Uruguayan departments has achieved very significant reductions in damaging soil loss.

The fourth column in Table 11 lists net soil losses for the scenario that extends the technology currently used in conservation oriented departments to all Uruguayan departments (see Table 6). That is, under this conservation scenario, the technology mix of departments like Paysandu is assumed to be used across the country as a whole. This conservation scenario reduces annual net soil loss to 9.976 million tons or by 29 percent relative to the baseline scenario. Net soil loss

Table 9. Baseline Estimates of Gross Soil Loss, Net Soil Loss, and Soil Loss to Water Bodies (8 crops)

Category	Baseline Estimates		
	Gross Soil Loss	Net Soil Loss	Soil Loss to Water Bodies
Area Planted, 1000 hectares	591	591	591
Soil Loss			
Total, millions of tons	18.115	13.969	10.869
Tons per hectare	31	24	18
Loss of Soil Depth, mm	2.5	1.9	1.5
Organic Material, 1000 tons	938	724	563
Nitrogen, 1000 tons	31	24	18
Phosphorus, tons	127	98	76

Table 10. Hectares Planted, Net Soil Losses above Tolerance, and Nutrient Losses with Different Price Scenarios and Existing Technology (8 crops)

Category	Baseline Scenario (at 1986 prices)	No Subsidy: Border Price Less 10%	High Subsidy: Twice the Border Price
Area Planted, 1000 hectares	591	506	671
Net Soil Loss above Tolerance			
Total, millions of tons	13.969	12.203	16.007
Change from Existing Loss (%)	0	-13	+15
Tons per hectare	24	24	24
Loss of Soil Depth, mm	1.9	1.9	1.9
Organic Material, 1000 tons	724	632	829
Nitrogen, 1000 tons	24	21	27
Phosphorus, tons	98	85	112

Table 11. Hectares Planted, Net Soil Losses, and Nutrient Losses with Baseline Prices and Alternative Technologies (8 crops)

Category	Baseline Scenario (at 1986	Traditional Technology, All Depts. prices)	Current Conservation Technology, All Depts.	Current Conservat. Technology, All Depts.; No Subsidy
Area Planted, 1000 hectares	591	591	591	506
Gross Soil Loss (GSL)				
Total in 1000 tons	13.969	21.439	9.976	8.681
Change from Existing Loss (%)	0	+54	-29	-38
Tons per hectare	24	36	17	17
Loss of Soil Depth, mm	1.9	2.9	1.3	1.4
Organic Material, 1000 tons	724	1,111	517	450
Nitrogen, 1000 tons	24	36	17	15
Phosphorus, tons	98	150	70	61

per hectare is 17 tons and the annual loss in terms of soil depth is 1.3 millimeters. Losses of organic matter, nitrogen, and phosphorus also decline by 29 percent. The scenario suggests that the extension of existing conservation technology to all departments would result in significant soil savings.

The last column in Table 11 combines the current conservation technology in all departments scenario with the no subsidy scenario. With this combined technology and economic policy scenario, net soil loss falls to 8.681 million tons per year from the baseline loss of 13.969 million tons per year. This is a reduction of 38 percent in net soil loss. Identical reduction rates are obtained for net soil loss per hectare, organic matter, nitrogen, and phosphorus.

Conclusions

The soil account developed in this study illustrates the potential contribution that environmental accounts can make to environmental policy. Uruguayan agencies maintain excellent basic data on soil types and uses. The basic problem for policy analysis is that the data are not easily accessible. The soil account organizes existing information in a policy relevant manner, keeps track of resource use and depreciation, and assists in analyzing policy alternatives.

The soil account suggests that economic and technology policy have a significant impact on soil loss in Uruguay. Net soil loss declines by 13 percent when the current mix of crop subsidies and taxes are shifted to a policy based on market prices. Soil loss declines by 29 percent when existing conservation technology are extended to all agricultural areas in Uruguay. A combined policy of market prices and the extension of existing conservation technologies to all departments reduces net soil loss by almost 40 percent.[9]

The results of the soil account analysis are preliminary. The account is based on data and assumptions that would be modified in a longer term research program. The account is primarily intended to outline the design of an environmental account and set a foundation for further research. Further research would attempt to price the impact of soil loss and to extend the accounts to soil erosion off-site effect on water quality, water impoundments, and navigational dredging.

Endnotes

1. The term agriculture is generally used to refer to non-livestock agricultural operations in Uruguay.

2. The data on land use obtained from the *Carta* does not correspond exactly to the data in the 1980 agricultural census (Direccion de Investigaciones Economicas Agropecuarias, 1983). This lack of correspondence is apparently due to different data collection procedures and somewhat different time periods.

3. A description of the physical units measured by each factor is given in Salas (1988).

4. The computer program may be adapted to evaluate erosion levels for other crop years.

5. The value of organic matter, nitrogen, and phosphorus may be more easily measured than the value of soil itself. For instance, the value of available nitrogen and phosphorus may be approximated by the market price of the appropriate commercial fertilizers. The price of organic matter may be viewed as the cost of an appropriate management strategy (e.g., crop rotation) to replace lost organic matter.

6. Product prices were assumed to be fixed by the international market in any given year. Effective producer price should therefore be exogenous and reflect the international price plus any government subsidy and less any tax.

7. The seasons of the southern hemisphere imply that crops are planted in the last few months of one calendar year and harvested in the first half of the next calendar year. Rainfall and prices lagged one time period from the harvest year are likely to give a good indication of the rainfall and price expectations prevailing at the time of planting.

8. The United States situation is used as a point of comparison only because estimates of soil erosion are easily accessible for this country.

9. Extension of conservation oriented technologies to traditional and intermediate departments would require research to adapt these technologies to different geophysical and socioeconomic conditions. The Instituto Nacional de Investigaciones Agropecuarias is currently developing a proposal to carry out such farming systems research in Canelones.

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