PN ABG 889

is needed to confirm long term impacts of soil loss on forest productivity in this region.

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Soil erosion studies in Peru

Julio C. Alegre, Carmen Felipe-Morales, and Braulio La Torre

ABSTRACT: Because of its pronounced topography, much of Peru is sensitive to the erosive action of wind and water. The Coast is subject to wind erosion, and water erosion is dominant in the Sierra. Erosion also occurs in the High Selva when vegetation is cleared and in the Low Selva where high-intensity rains fall on land farmed under slash-and-burn practices. A review of erosion problems in Peru and results from erosion studies in the Sierra and Selva regions shows that the use of cover crops and mulching conserve soil and water efficiently. Contoured rows present both advantages and disadvantages for water erosion control, depending on climatic conditions and slope.

THE pronounced topography of Peru results in considerable sensitivity to the erosive action of wind and water in a large part of the country. Two other climatic factors that contribute to the country's soil erosion problems are the seasonal dichotomy of a wet summer and a dry winter in many regions and erratic rainfall patterns in others.

The Coast

The Coastal region has an arid climate and three physiographic units: the desert plains, large alluvial fans, and the western most foothills of the Andes Mountains. In the flat desert, wind is the primary erosive factor, producing dunes, even in cropped areas, that spread over existing infrastructures, such as bridges and irrigation canals.

The alluvial coastal valleys have the best soils for cultivation. Because of their aridity, however, all agriculture in the valleys is irrigated. Moreover, poor water management has resulted in superficial runoff, salinity problems, and loss of nutrients.

The foothills of the Western Andean Range are bare and support only a thin grass cover during the sporadic rainfall periods. That cover is depleted rapidly by grazing sheep. Sporadic rains cause gullies and landslides, often resulting in property damage and human death. For example, landslides along the central road linking Lima with the central Sierra frequently cut off the road and, thus, part of the food supply to Lima.

The Sierra

Rainfall in the Sierra, 500 to 1,000 mm/year (20-40 inches), is greater than in the Coast region. About 90% of the Sierra is steepland, with some slopes greater than 100%. Population density is high, which has led to intensive cultivation. Common farming practices include slash-and-burn techniques, plowing and planting parallel to the maximum slope, monoculture, and intensive overgrazing by goats and sheep. Poorly designed roads, reservoirs, and irrigation canals constructed over unstable geological material also contribute to erosion problems. Sheet erosion, deep gullies, and landslides are common in the Sierra, creating soil erosion of maximum intensity. All of this greatly affects food production.

The Selva

The Selva region is characterized by a humid, tropical climate with an annual rainfall of 1,000 to 3,500 mm/year (40-138 inches). Erosion occurs where vegetation is cleared. In the High Selva, the erosion process often is intensive, with high hydric erosion—slumping and landslides—due to the steep slopes. In the Low Selva, the rivers rising in the Sierra flood the low terraces, resulting in high-quality alluvial soils. Good river transportation causes the population to remain close to the rivers. The gently sloping upland soils are subject to erosion after the forest is cut and before a crop, weed, or forest fallow canopy develops.

Study sites and methods

Erosion research has or is being conducted at one Sierra site and two High Selva sites. Table 1 shows initial soil chemical and physical properties at the sites.

Santa Ana site. The Santa Ana site, in the province of Huancayo, is situated in an inter-Andean valley of the central Sierra at an altitude of 3,200 m (10,500 feet). Slope averages 25%. Initially, the field was covered by a shrub and herbaceous vegetation, mainly *Spartium junceum* and several wild grass

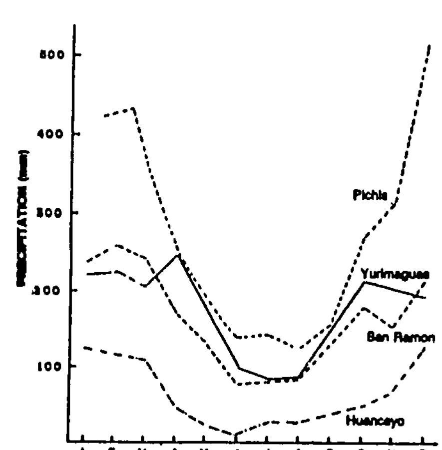

Figure 1. Distribution of annual precipitation at Peruvian research sites.

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species. The vegetation formation is classified as transitional between low, dry mountainous woodland and humid mountainous woodland. Average annual precipitation, based on a 52-year record, is 768 mm (30 inches). Rainfall distribution is seasonal; the rainy season is from October to April (Figure 1). Maximum mean temperature is 19°C (66°F); minimum mean temperature is 5°C (41°F); mean annual temperature is 11°C (52°F).

San Ramón site. Two sites are located in the Chanchamayo River valley in the central High Selva near the city of San Ramon. Elevation is 800 m (2,625 feet). The soils are Entisols on alluvial-colluvial parent material with many rocky fragments. Effective soil depth is about 40 cm (15.7 inches). One site was located on a hillside with 30% slope at the Tupac Amaru Cooperative. The experimental field initially was covered with natural herbaceous and shrubby vegetation in which yaragua grass *(Hyperrhenia rufa)* predominated. The second site, located at the Jose Santos Atahualpa Cooperative was on a hillside with a 20% slope. Initially, the soil was covered with herbaceous vegetation, predominantly *Panicum pilosum* and *Andropogon rutummess.*

Average annual precipitation, based on an 18-year period at both sites, is 2,000 mm (79 inches), but may be as low as 1,500 mm (59 inches) in some years. Monthly rainfall distribution is irregular, with a noticeable wet season from October to May (Figure 1). Mean maximum temperature is 30° (86°F); mean minimum temperature is 18°C (64°F); annual mean temperature is 24°C (75°F).

Experimental procedures. Tables 2, 3, and 4 list the management systems at the three sites. Details about the management of each crop are given by Alegre (*1*), La Toree (*6*), and Felipe-Morales (2). The experimental plots were 10 m long x 4 m wide (32.7 x 13 feet), with two replications for each treatment—a total of 10 plots for each experimental field. Water runoff and soil sediment carried in the runoff waters were measured for individual runoff plots. Borders on their upper and lateral sides were installed to prohibit water from entering the plots from surrounding areas. These edges were made of "Eternit," an asbestos roofing material. On the downhill side, a collector system of small channels and cylinders collected water and sediment. The first cylinder of each plot had a multislot divisor with three slots. Water and suspended sediment passed from the central grove to a second cylinder, that is, the second cylinder accumulated one-third of the runoff water that exceeded the volume of the first cylinder. A more detailed explanation of this procedure is given by Fournier (*4*). Rainfall was read daily using a rain gauge, and water runoff was read daily from the collection cylinder. Sediment samples were taken from the bottom channel and from the final suspension on the sediment collector. Stable aggregates in the runoff water were determined by the Henin method (*5*).

Table 1. Initial soil chemical and physical properties at three Peruvian research sites.

Soil Depth (cm)	pH	Al	Ca	Mg	K	Available P (ppm)	Organic Matter	Total N	Al Saturation	Sand	Clay	Silt
		meq/100cc					%					
Santa Ana (fallow)												
0-25	6.9	0	14.0	1.40	0.32	18	2.5	0.13	0	56	24	20
25-45	7.3	0	19.2	2.00	0.32	11	1 2	0.06	0	38	42	20
45+	7.3	0	20.0	1.90	0.32	11	0.1	0.06	0	42	42	16
Tupac Amaru (grass fallow)												
0-25	6.7	0	13.8	1.26	0.30	11	3.89	0.185	0	46	32	22
25-45	7.2	0	10.3	1.07	0.34	11	1.79	0.084	0	46	30	24
Jose Santos Atahualpa (grass fallow)												
0-20	5.2	0.20	7.0	1.44	0.24	28	2.5	0.120	2	58	20	22
20-35	5.4	0.25	8.9	0.64	0.12	12	4.0	0.200	3	58	24	18
35-55	5.3	0.24	2.2	0.17	0.10	15	1.4	0.07	9	72	14	14
55+	5.5	0.26	3.4	0.17	0.06	19	0.9	0.04	7	75	12	22

Table 2. Management systems investigated at Santa Ana during the 1975-1979 cropping season.

Treatment Number	Crop Rotation*	Row Alignment	Organic Input and Tillage
I	Continuous fallow	—	—
II	Potato-corn-potato-oat	Following maximum slope	None
III	Potato-corn-potato-oat	Contour	None
IV	Potato-corn-potato-oat	Following maximum slope	Green manure, *Linus mutabillis*, incorporation before each crop
V	Wheat-corn-potato-oat	Following maximum slope	Mulch (no incorporation & maximum tillage)

*Potato (*Solanum tuberosum*); corn (*Zea mays* L.); oat (*Hordeum vulgare*); wheat (*Triticum vulgare*).

Table 3. Management systems at the Tupac Amaru site during the 1976-1977 cropping season.

Treatment Number	Crop Rotation*	Row Alignment	Organic Input and Tillage
I	Bare soil	—	—
II	Fallow+burning-corn-cowpea-potato	Following maximum slope	None
III	Pasture	None	None
IV	Potato-corn-potato-oat	Following maximum slope	Mulch
V	Fallow-pineapple	Following maximum slope	None

*Corn (*Zea mays* L.); cowpea (*Vignia unguiculata*); potato (*Solanum tuberosum*); pasture (*Centrosema pubescens*); pineapple (*Ananis sativa*).

Table 4. Management systems investigated at the José Santos Atahualpa site during the 1978-1980 cropping season.

Treatment Number	Crop Rotation*	Row Alignment	Organic Input and Tillage
I	Bare soil fallow	—	—
II	Corn-cowpea-potato-peanut-cassava	Following maximum slope	No fertilizers
III	Corn-cowpea-potato-peanut	Following maximum slope	With fertilizers
IV	Corn-cowpea-potato-peanut-cassava	Following maximum slope	Mulch+minimum tillage, with fertilizers

*Corn (*Zea mays* L.); cowpea (*Vignia unguiculata*); potato (*Solanum tuberosum*); peanut (*Arachis hypogaea*); cassava (*Manihct esculenta* Krantz).

Results and discussion

Santa Ana. Table 5 shows water runoff and soil sediment collected during 4 years of study. Runoff and sediment were greater where cultivation followed the slope (treatment II and IV), showing the negative effect of this common practice in the Andean region. Planting on the contour (treatment III) reduced sediment loss 50%. Mulching plus minimum tillage (treatment V) provided good soil protection. Inclusion of a dense crop, such as wheat in treatment V, favored high water infiltration and decreased soil erosion. Incorporation of green manure (treatment IV) loosened the soil and led to high soil loss.

Tupac Amaru. Table 6 shows crop yields, water runoff, and sediment loss for the 1976-1977 cropping season, during

2

which precipitation was 2,154 mm (85 inches). The highest runoff occurred on the bare soil (treatment I) and pineapple (treatment IV) plots. The soil was bare during the early growth stages of pineapple. Soil loss was lower for treatments with a good soil cover. Smallest soil loss occurred on pasture (treatment III) because the soil surface was protected from the direct impact of rain. On the bare soil, surface sealing reduced infiltration, leading to a higher erosion rate. Treatment II is the typical land management system used by farmers and exceeded the tolerable limits of soil erosion. According to recommendations of the U.S. Department of Agriculture's Soil Conservation Service, these soils should be used only for forest or permanent pasture. Such guidelines are difficult to apply in Peru because of the limited amount of flat land and a strong steepland farming tradition. It is thus necessary to develop a practical management system to reduce erosion. Treatment IV is a system that could be adopted by farmers. The residue is not burned but is left on the soil surface as a mulch. Soil erosion was considerably lower under this system (Table 6).

Table 7 shows selected nutrient losses in the runoff water and sediment. The greatest loss of nutrients in runoff water occurred in the traditional system of pineapple plantation (treatment V). Nutrient losses associated with the sediment were similar for the bare soil (treatment I) and the traditional system (treatment II). These losses were about three times higher than those in the improved system (treatment IV).

José Santos Atahualpa. Table 8 shows runoff and sediment removal and crop yields during the 1978-1980 cropping season, during which rainfall was 3,120 mm (123 inches). The corn-cowpea-potato-peanut-cassava rotation with mulch and fertilizer (treatment V) had the least nutrient loss; losses were highest for bare soil (treatment I). Mulch was efficient in controlling runoff and soil loss because it increased infiltration and protected the soil surface against direct raindrop impact. Crop yields were higher when both mulch and fertilizers (treatment IV) were used, although potato production was low due to fungal disease.

Table 9 shows nutrient losses during the 1978-1979 cropping season, during which rainfall was 1,636 mm (65 inches). The greatest losses were on bare soil (treatment I); the lowest nutrient losses were on the treatment with mulch and fertilizer. The amount of nutrients lost in the sediment was proportional to the amount of soil eroded.

Conclusions

Based on data from the three sites, we drew the following conclusions:

► Soil erosion in the High Selva of Peru is high under traditional agriculture.

► Cover crops and mulches conserve soil and water efficiently.

► Contoured rows present both advantages and disadvantages for water erosion control, according to the climatic conditions of the zone and degree of slope.

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Table 5. Crop yield, water runoff, and sediment removal at the Santa Ana site during the 1975-1979 cropping season.

Treatment Number	Crop Yield					Water Runoff (mm)	Soil Sediment Loss (t/ha)	Mean Sediment Removal (t/ha/yr)
	First Potato	Corn*	Second Potato	Oat†	Wheat			
	(t/ha)							
I	—	—	—	—	—	186	16.3	4.1
II	2.9	4	29	14	—	307	47.2	11.8
III	27	10	32	14	—	184	22.7	5.7
IV	26	5	38	14	—	295	42.8	10.7
V	—	15	36	16	5.6	125	12.9	3.2

*Fresh corn.
†Grain and straw.

Table 6. Crop yield and sediment loss at the Tupac Amaru site during the 1976-1977 cropping season.

Treatment Number	Crop Yield					Water Runoff (mm)	Soil Sediment Removal (t/ha)
	Corn	Cowpea	Potato	Pasture	Pineapple		
	(t/ha)						
I	—	—	—	—	—	222	148
II	8.3	1.1	13	—	—	198	119
III	—	—	—	28	—	73	1.3
IV	9.2	1.2	13	—	—	138	46
V	—	—	—	—	16	228	72

Table 7. Nutrient losses in runoff water and sediment at the Tupac Amaru site during the 1976-1977 cropping season.

Treatment Number	Water					Sediment				
	NO_3-N	P	K	Ca	Mg	Total N	P	K	Ca	Mg
	(kg/ha)									
I	23	3	5	13	4	115	4	19	310	7
II	21	8	8	20	11	108	4	14	316	8
III	7	2	3	7	2	0.8	0	0.2	3	0.1
IV	11	2	7	14	3	38	1	6	122	3
V	24	4	7	25	6	71	3	9	208	4

Table 8. Average yield of crops, water runoff, and soil erosion at the José Santos Atahualpa site during the 1978-1980 season.

Number Treatment	Crop Yield					Water Runoff (mm)	Soil Sediment Removed (t/ha)
	Corn	Cowpea	Potato	Peanut*	Cassava		
	t/ha						
I	—	—	—	—	—	371	98.7
II	3.2	1.30	0.3	4.2	14.7	271	87.8
III	5.7	1.20	2.2	3.7	15.3	305	104.1
IV	6.2	1.60	2.9	4.0	20.8	91	15.9

*With hulls.

Table 9. Nutrient losses in runoff water and sediment at the José Santos Atahualpa site during the 1978-1979 cropping season.

Treatment Number	Water Runoff					Soil Erosion				
	NO_3-N	P	K	Ca	Mg	Total N	P	K	Ca	Mg
	(kg/ha)									
I	4.8	0.6	2.8	8.9	2.5	52	2.4	2.6	44	3.2
II	2.8	0.4	1.9	6.4	1.2	29	1.7	1.2	34	2.2
III	2.6	0.5	4.2	9.0	1.0	35	2.2	1.4	39	3.3
IV	1.1	0.1	2.5	2.2	0.2	6	0.3	0.3	5	0.3

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Constraints to conservation farming in Java's uplands

Paul C. Huszar and Harold C. Cochrane

ABSTRACT: The Citanduy II Project's model farm program on steep slopes in West Java was started in 1981 with the dual goals of reducing erosion and increasing farmer incomes. Both goals appear to have been reached. However, input requirements and output restrictions of the program reduced the farmers ability to respond to changing market conditions and, consequently, reduced the success of the project in increasing net incomes.

INDONESIA has the fifth largest population in the world, with a 1984 population of nearly 160 million (*6*). While Indonesia consists of 13,677 islands, about two-thirds or 107 million of the people live on the island of Java. Java, however, is only roughly the size of the state of New York, with a land area of 136,000 km² (*2*). As a result, Java is one of the most densely populated islands in the world, with about 787 people per km² (2,038 people/square mile) (*3*).

A central range of volcanoes covers about two-thirds of Java, limiting level land for cultivation. As Java's population continues to grow, pressure to produce more food is forcing farmers to clear and cultivate increasingly steep slopes. Slopes in excess of 50% are being cultivated on a continuous basis. Moreover, much of the uplands are cultivated by subsistence farmers who may have neither the means nor the motivation to invest in soil-conserving measures. As a consequence, soil erosion may be accelerating.

Java's background

Thirteen watersheds on Java are considered to have critical erosion problems. Critical land outside of forests on Java encompass about 568,506 ha (1.4 million acres). While no systematic monitoring of erosion rates has been conducted, it is estimated that soil erosion rates average from 10 to 40 Mg/ha/yr (4.4 to 18 tons/acre/year). Moreover, these rates seem to be increasing (*5*).

Soil erosion may pose a serious threat to the continued productivity of steep-sloped upland regions as topsoil and nutrients are washed away. Moreover, upland erosion may cause off-site damages to downstream irrigation systems, exacerbate the potential for flooding, contribute to the sedimentation of reservoirs and estuaries, and clog navigation channels in rivers and ports. It is argued by some that the ability of Java's land to support its population is being threatened by the present form of upland farming (*2*).

In response to these potential problems, the Indonesian government, with support from the U.S. Agency for International Development (USAID), formally began an uplands conservation program in 1976. This paper reports an ex post facto evaluation of one component of this conservation program, the model farm program of the Citanduy II Project.

Model farm program

While the major goal of the Citanduy II Project was to reduce soil erosion, the project's planners realized that to induce farmers to participate in the model farm program more direct benefits to the farmers were necessary. Therefore, the project started in 1981 with the dual goals of reducing erosion and increasing farmer incomes. The program established 48 model farm units and impact areas over a 5-year period. The model farms are located in the Citanduy watershed in the southeastern area of West Java.

The model farm program consisted of introducing a package of upland agricultural inputs and conservation practices, including construction of bench terraces and using new cropping patterns, seed varieties, and inputs of chemical fertilizers and insecticides on land with slopes up to 50%. Land with slopes of more than 50% received an agroforestry package. Subsidies were provided for the construction of bench terraces and the purchase of inputs.

Under the model farm program, the first step was to establish a model farm. Because an upland farmer's land is typically fragmented into a number of relatively small parcels of less than 1 ha (2.47 acres) each and because an area of about 10 ha (25 acres) is needed to make bench terracing physically feasible, selection of the model farm site depended upon the cooperation of a number of farmers on 10 ha of contiguous land. Moreover, implementers of the project supposedly sought sites with the worst erosion conditions to provide the most dramatic demonstration of the benefits of the program and to produce the greatest soil conservation benefits.

After the model farm was established, extension agents tried to persuade groups of nearby farmers, in what are called the expansion areas, to adopt the model farm package. Extension agents induced farmers to adopt the model farm package by providing them with information regarding the expected returns from adopting the model farm technology and by providing terracing and input subsidies for one year.

Model farmers received terracing and input subsidies for 3 years, while expansion area farmers received subsidies for only 1 year. Terracing subsidies actually received averaged Rupiah (Rp) 32,130/ha for model farmers and Rp 9,300/ha for expansion area farmers. Input subsidies received averaged Rp 112,190/ha for the first year, Rp 91,490/ha for the second year, and Rp 3,500/ha for the third year for model farmers, and Rp 117,650/ha for one year for the expansion area farmers. For purposes of comparison, the exchange rate is approximately Rp 1,650=U.S. $1.

The model farm program appears to have achieved its first goal of reducing soil erosion. Soil erosion on terraced fields is about 40% less than on unterraced fields. This reduction in erosion, however, was observed on both project and nonproject sites with terracing. Moreover, significant soil erosion

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