PN-AAE-639

EROSION CONTROL
A CHALLENGE TO BOLIVIA

by

E. Don Hansen,
SOIL SCIENTIST,
Chemonics International

Jorge Balderrama,
AGRONOMIST,
Instituto Boliviano
Tecnológico Agropecuario

Abstract

Bolivia an inland country of west-central South America, roughly the size of the two large continental states of Texas and Montana together, like many of both developed and Third-World countries is affected seriously with the disturbing process of soil erosion. This distressful problem challenges soil scientist, engineers, agronomists, economists, planners, and local and national leaders to take concerted action to control this growing extensive erosion in each of their countries.

In this report a successful effort is being made in the extreme southern area of Bolivia, bordering northern Argentina. It is in a productive, moderately humid valley of Yacuiba which is designated "the humid Chaco" which comprises sizeable areas of Southeastern Bolivia, Northern Paraguay and Northeastern Argentina. This humid Chaco valley has an average rainfall of nearly 1200 millimeters annually. It is 5 kilometers wide by 40 kilometers in length-roughly 20,000 hectares. The relatively small size does not belie its importance

agriculturally.

Clearing of valley lands from a sub-tropical forested area, began in 1977, with Caterpillar D-7 tractors with dozer blades, on mostly even lands of slightly to moderate slopes of 2-6%. In the years that followed, additional land clearings were made each year. Every year problems of erosion began to appear. With several years of increased rainfall during the past several years including 1984, this problem has assumed most serious proportions.

Great potentiality to produce soya, cotton , wheat corn and other crops prompted the agricultural leaders of the country to lend greater support and more pronounced effort to this erosion control program. A description of the principal technical method used to bring this about-construction of terraces by use of a road grader with the shared cooperation of local farmers, is summarized in this report.

Introduction

A program of erosion control for Bolivia began shortly after the arrival of the senior author in early 1982. Bolivia is an inland country of west-central South America, roughly the size of two large continental states of Texas and Montana, 1,098,580 square kilometers, with a population of 7,400,000. inhabitants (1980). Similar to many of both developed and Third-World contries it has been affected seriously with the wide-spread problem of soil erosion. World-wide and distressful, this situation challenges soil scientists, civil engineers, agronomists, planners and local and national leaders to take concerted action to control this growing potential danger to future food and fibre production in each country.

The erosion control area in which this program is being fully developed and promoted is in the productive, moderately humid area of the valley of Yacuiba which is designated as being a part of the "humid Chaco" which also includes areas around the more remote centers of Caraparí and Villa Montes. The present program has developed around the Yacuiba valley area but is planned for extension to the other two areas. The "humid Chaco" is differentiated from the much larger "dry Chaco" which comprises sizeable areas of southeastern Bolivia, northern Paraguay, and

northeasten Argentina. This "humid Chaco" valley of Yacuiba has an average rain fall of nearly 1200 millimeters annually. It is 5 kilometers wide by 40 kilometers in length - roughly 20,000 hectares. This small size does not belie its importance agriculturally. It is capable of producing soya, wheat, cotton, corn, and other crops. The agricultural leaders of the country recognized its great potentiality and began to lend support to fuller development of this "humid Chaco" area.

Clearing of the valley lands of Yacuiba, from a sub - tropical forested area began in 1977 with Caterpillar D-7 tractors with dozer blades, on mostly even lands of slightly to moderate slopes of 2-6%. In the immediately following years additional land clearings were made each year during the dry season (May - December). Every year problems of erosion began to appear on the newly cleared lands. With several past years of increased rainfall, including 1984, this problem has assumed most serious proportions. The damages on several small water - sheds and drainage areas has been extensive. The seriousness and extent of this growing problem has been noted since the rainy season ended in April of 1984. We had projected a completion of nearly 400 hectares ot terraces for construction during the dry season of 1984 which would double the 200 hectares completed in 1983. However, requests by farmers for construction of terraces on their lands has come in to us in slight excess of 500 hectares. The common cry is - " help us to control the erosion on our farm - we would like to have terraces constructed to save our lands".

Now renewed efforts are being made to find sufficient funds to assist these farmers to obtain the help that they need.

Clearing the Land

As has been previously stated, clearing the land has been done by Caterpillar D-7's with dozer blade. These are operated and leased from CODETAR a provincial quasi - grovernmental agency. When we first began our work we discovered that the operators knew nothing about acceptable and nonacceptable methods of clearing land in order to give the topsoil the greatest protection possible. Most operators were using the bull - dozer blade to produce a soil surface that was called "limpia" - clean. That is; all tree branches, trunks, bushes, brush and other vegetation were removed as well as a layer of the topsoil. The owner of the new-land to be, wanted his land "limpia". This took organization of training of CODETAR operators on our part as well as the potential farmers to know that the better way of clearing land should be "sucio"-or dirty. In this case dirty is "good" - because a "sucio" clearing was made when the bull-dozer blade barely touched the surface lea-

ving all grasses, stems of small shrubs, and bits and pieces of bark, etc. The soil was disturbed as little as possible. Large tree roots were dug out and removed by hand. It was later learned that Argentina used two Caterpillar D-8's with a heavy chain pulled between them to clear land which resulted in a " sucio " type clearing, but the investment in Bolivia had already been made in a bulldozer blading approach and could not be changed by the more rapid and more acceptable D-8 chain method. However our relations with CODETAR tractor operators and administrators gradually improved until we got good compliance in land clearing efforts. Clearing is still limited to nearly even, low grade slopes of 0-6% for agricultural lands. Clearing "limpio" was causing future farmers great loss of topsoil and too much of the important organic matter, which was to help them to protect the soil better from the force of erosion which was to follow, but also to assist them to produce better crops of quantity and quality by conservation of as much organic matter and moisture as possible.

Loss of Topsoil

Lester R. Brown, in "Worldview" which is a summary 3 from his recently published book " State of the World " correctly states how a loss of topsoil may occur anyplace:

" Grave though the loss of topsoil may be, it is a quiet crisis, one that is not widely perceived. Unlike, earthquakes, volcanic eruptions, or other natural disasters, this human made disaster is unfolding gradually. It is not always recognized, because the intensification of cropping patterns and the plowing of marginal lands that leads to excessive erosion over the long run can lead to production gains in the short run, thus creating the false sense of food security.

Although soil erosion is a physical process, it has numberous economic consequences, affecting productability , growth, income distribution, food sufficiency and long term exteral debt. Ultimately it effects people. When soils are depleted and crops are poorly nourished, people are often undernourished as well".

Cause of Soil Erosion

We are confining ourselves here to water erosion because wind erosion is minimal in this part of Bolivia, but in the "humid Chaco", water erosion is of utmost importance to be controlled. The

damage caused by raindrops hitting the bare soil at a high velocity is the first step in the erosion process. We may think of the raindrops as minature bombs hitting the soil surface. In a heavy downpour this will occur with rapidity. The raindrops shatter the soil granules and clods, reducing them to smaller parficles and in return reducing the infiltration capacity of the soil. A raindrop hitting on a wet soil forms a crater, compacting the area immediately under the center of the drop, moving detached particles outward in a circle around this area, finally meeting sufficient resistence to be defected upward. Authorities have estimated that more than 100 tons of soil per acre may be detached by raindrops in a single rain. On sloping land the force of the raindrops on the surface is such that more than half of the splashed soil is moved downslope as it falls back to the surface. The force of millions of raindrops during an intense rain on a cultivated field results in an appreciable movement of soil downslope.

Raindrops hitting a soil surface that is covered by a film of water churn up the soil so that the surface film of water becomes muddy. As this muddy water infiltrates into the soil, the particles are filtered out in the surface layer. The infiltration of the muddy water and the compacting and puddling action of the raindrops falling on the surface combine to form a layer of soil which has a much lower infiltration rate than the soil at the beginning of the rain. This effect is most pronounced for rains of high intensity.

When the rate of rainfall exceeds the rate of infiltration, the depressions on the surface fill and overflow causing runoff. During the rain, the runoff is splashed and resplashed millions of times by the falling raindrops. This breaks the soil particle it is carrying in smaller and smaller sizes and helps to keep them in suspension. Thus a thin sheet of water will carry a much heavier load of silt during a rain than it would if splashing action were not present.

Falling raindrops break down soil aggregates, detach and transport soil particles as the volume of water increases. Runoff water is loaded with finer more valuable particles and cause sealing and compacting of the soil surface. Additional concentration of water follows, which moves sand and larger particles down slope, but many of the small particles have reduced the ability of the soil to absorb water.

Sheet and Rill Erosion

Sheet erosion results from soil movement from raindrop splash and surface runoff. Sheet erosion removes the lighter soil particles, organic matter and the soluble nutrients from the land and is thus a serious detriment to the maintenance of soil fetility and productivity.

The erosiveness of flowing water depends upon its velocity, turbulence, and the amount and type of abrasive material it transports. The amount of material transported depends on the transporting capacity of the runoff and, the transportability of the soil. The larger and heavier - soil particles are more difficult to transport, hence they are not moved great distance. Rill erosion results from the surface runoff when it concentrates in surface depressions in which sufficient soil may be removed to small but well-defined channels. If these channels do not interfere seriously with normal tillage operations they are called rills.

Gully Erosion

While a great deal of erosion takes place by sheet and rill erosion it is gully erosion that prompts us to take concerted action for the actual control of erosion. When surface channels have been eroded to the point that they cannot be smoothed over by normal tillage operations they are called gullies. Gullies may develop at any time as a result of several factors. Soil is removed by surface water flowing through surface channels in sufficient volume to form a gulley. Water from surface channels is often discharged over an abrupt change in grade. This stream of water flowing to a lower elevation has greatly increased erosive power compared to the same stream on a uniform grade. The channel at the foot of a waterfall is deepened and the banks are undermined and cave in. Gullies formed by the combination of these two means can vary from 0.5 meter of less to depths of 3 to 10 meters or more. When the gullies are relatively small, these can be filled and controlled with terraces made with the aid of a roadgrader . But when gullies have grown to a depth of more than 0.5 meter our recommendation is to use the D-7 Caterpillar for filling before terraces are constructed by roadgrader .

Rainfall Records

Associated helpfully with the terrace construction within an area are rainfall record. The longer records have been kept, the better, because it helps us to plan ahead for the fut e in the construction of terraces. We may know the intensity, duration, frequency and seasonal distribution of the rainfall over an average number of years for an area and aids us to know during which part of the year we may be able to have a period dry enough to effect construction of terraces with use of heavy machinery without being hindered by rainfall.

In our area the information is furnished by the local airport authority which has been maintained for nearly, 34 years. Refer to the details presented in Table 1. The record of rainfall data for the past five years has been very important for planning of erosion control for the future. It will be noted in Table 2

that the average monthly rainfall for the six critical months of October thru December and from January thru March has been responsible for the accompanying serious erosion damage to fields, roads, railroad, streets in Yacuiba and other outlying village and watershed areas. This year 1984 hit a new high for the month of March, during which a record rainfall of 725 mm. was registered in only 13 days. It was during this relatively short period that the greatest erosion damages occurred extensively throughout the Yacuiba valley area. More farmers than ever have been prompted to think more seriously about obtaining technical help in battling this serious problem and have been asking for construction of terraces on their properties.

Lindo

TABLE 1 Rainfall Record of Yacuiba 530 M (1768')
at airport by AASANA-33 years
1950 - 1983

Depth	Jan	Feb	Mar	A	M	Jn	Jl	Ag	Sp	Oct	Nov	Dec	Total
mm*	218	190	204	100	34	16	7	10	8.	54	100	162	1113
Inches	7.6	7.5	8.0	3.9	1.3	0.6	0.3	0.4	0.3	2.1	4.3	6.4	43.8

millimeters

TABLE 2 Rainfall Registered, 5 years (1979 - 1984)
AASANA - Yacuiba airport
(S22°01', W64°43')

Year	Jan	Feb	Mar	A	M	Jn	Jl	Ag	Sp	Oct	Nov	Dec	Total
1979	361	239	539	153	26	16	17	48	11	34	163	279	1886.0
	14.2	9.4	21.2	6.0	1.0	0.6	0.7	1.9	0.4	1.3	6.4	10.4	74.0
1980	358	226	309	79	11	16	11	10	0	115	156	134	1425.0
	14.1	8.9	12.2	3.1	0.4	0.6	0.4	0.4	0	4.5	6.1	5.3	55.6
1981	470	373	143	267	67	1	1	16	2	0	95	15.7	1592.0
	18.5	14.7	5.6	10.5	2.7	0.1	0.1	0.6	0.1	0	3.7	6.2	62.8
1982	263	220	478	311	9	27	34	6	10	11	126	130	1675.0
	10.3	8.7	18.8	12.3	0.4	1.1	1.3	0.2	0.4	0.4	5.0	7.0	66.0
1983	497	287	104	175	175	18	34	4	5	37	91	255	1682.0
	19.6	11.3	4.1	6.9	6.9	0.7	1.3	0.2	0.2	1.4	3.6	10.1	66.3
1984	460	330	725	148	8	84	5.8	129	-	-	-	-	(1889.8)
	18.1	13.0	28.5	5.8	0.3	3.3	0.2	5.1					(74.4)
Average	401.5	279.2	283	188.8	49.3	27.0	17.3	35.5	5.6	39.4	126.2	201	
	15.8	11.0	15.0	7.3	1.4	1.0	0.6	1.4	0.2	1.5	4.9	7.9	

* Millimeters ** Inches + Partial

Construction of Terraces

Terrace construction was initiated in July 1983 on the finca of Antonio Mogro in Yacuiba valley, 6 terraces, totaling 2980 meters in length, in a field of 20 hectares, with a varying 4-6 % slope. Before this initial attempt we had made a close study of the terrace construction program of Julio Luna and his technicians of the INTA (Instituto Nacional Tecnologia Agropecuaria) organization in the vicinity of Metan in provice of Salta in Northern Argentina.

Experience during the dry seasons of construction in 1983-1984 helped us to arrive at the following specifications for terraces:

- Width of terrace 8 meters (26')
- Slope of Canal of the terrace 0.3 %
- Altitude difference between ridge and canal in finished terrace at completion of construction of guard terrace 0.8 Meters (31") (highest)
- Altitude difference between ridge and canal in all lower terraces. 0.5 Meters (20")

It should be noted that terrace construction should actually begin near the highest elevation in the field, and should be checked with a level for this point if not readily determined by visual inspection.

The first or highest terrace constructed in the field, 0.8 meters in height is designated a guardian terrace, designed to intercept runoff from the area above, and therefore the ridge is constructed higher than the terraces below by 30 centimeters or more. All terraces below terrace one-or guardian terrace usually have at least 0.5 Meter of elevation which seems to be adequate. However the trained roadgrader operators seem to be able to average nearly 0.8 meter for all terraces.

The second important item is to ascertain there is drainage of the terraces from the field on either side. There may be a natural drainageway established on one or both sides, or it may be necessary to establish a grass waterway on the edge of the field on either side to receive the drainage outflow from the common ends of the terraces when excess water flows from excessive rainfalls. One has been built here on the middle of the farm of Alberto Quiroga by use of a roadgrader. The grass specie of Cynodon dactylon is locally available which could be used to plant vegetatively over this waterway, but will have to be accomplished at the beginning of the rainy season because of non-availability of water during the dry season.

Grass Waterways

It is important to note that grass waterways in themselves do not protect large portions of a given field from ero-

sion. They are designed to work in combination with other soil and water conservation practices, such as terraces, contour farming and diversions which direct water into grass waterways. The waterways conduct this concentrated flow off the field with minimal damage to the soil. Grassed waterways are always planted in those sloping fields where water concentrates naturally or which will concentrate on the edge of fields from terraces, where gullies are most likely to form.

Other grass species which need to be considered and tried in this area for cover for grass waterways are Paspalum notatum, Dactillis glomerata, and Clorys Sp.

Distance between Terraces

The third item to consider in construction of terraces is to calculate the distance berween terraces. Distance is related to the average slope which can be determined by use of the hand level and the following Table 3 can be a guide for terraces in each field. Measurement down the slope can be made from the beginning stake of the first terrace.

Table 3

Distance between Terraces

Average slope	Distance between terraces
%	Meters
0 - 3	100
3 - 5	80
5 - 8	60

Use of Level

The level instrument and leveling rod with use of prepared field stakes can be used to locate the points along each terrace. Two persons may measure off 20 Meters from the beginning point, with the person at the far end of a 20 meter line also holding the rod. After the rod is read by the levelman, the two individuals advance every 20 meters until the end of the terrace is reached on the other side of the field. A stake is driven at the end of each 20 meter measurement to mark the location at every 20 meters of the terrace to be made. Readings of the levelman at each location is the key to maintaining a descending slope in the terrace from the beginning to the end. In order to have sufficient slope to move excess water along the canal of the terrace in case of rainfall runoff, a slight slope of 0.3 % must be built into the terrace. This is accomplished by reading 6 centimeters more on each rod reading for every 20 meters distance along the surveyed terrace line. For example if the begining rod reading is 1.20 meters (1 meter 20 centimeters), the second reading is 1.26, the third reading 1.32, etc. until the end of the terrace. Terraces should not be longer than 500 meters in length because of the volume of water that can accumulate in the canal of a terrace. Longer terraces would not therefore be wise because too much water would be intercepted to flow which might cause an erosion problem not fully anticipated. Longer distances can have terraces overlaped and have the water flow the opposite way from the middle of a field wider than 500 meters. This would assume that there would be a natural drainage to take care of the extra length terraces over 500 Meters. If a natural drainage was not present, a grass water way would need to be established to take care of the extra drainage water from the other side of a large field with widths greater than 500 meters. For example, with a field of a width of 600 meters, a terrace can be surveyed so that the water will flow 300 meters to one drainage way and the water in the other 300 meters would flow from the middle in the opposite direction to the other drainageway.

Roadgrader Construction

Construction of terraces can begin as soon as several terraces are staked ahead rather than wait until a complete field is staked with terrace locations. The roadgrader operator can trace the location between stakes by using the corner of the roadgrader blade, if a person can extract each stake from the field just before the wheel of the road grader gets to it. An operator must be well trained to construct a terrace by making 8 passes (Figure 1) with the road grader along the line of the terrace. The line originally traced in the field locates the middle of the terrace.

Four passes will be made on each side as illustrated in Figure 1, a scheme for construction. The difficult part of the construction for the roadgrader operator are the final passes to keep the wheels of the front 2nd of the roadgrader up on the ridge of the terrace so the blade can push the soil up to the highest extent possible - usually 0.8 Meter above the canal bottom level.

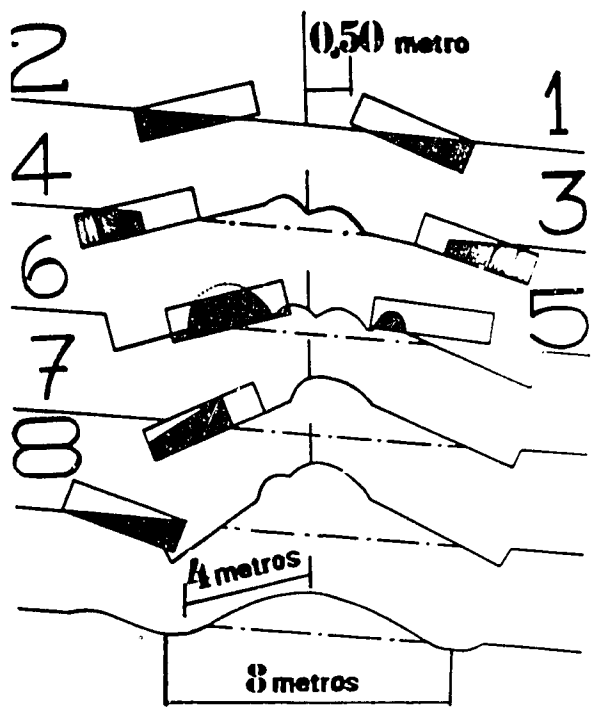

Figure 1 : Scheme for construction of terrace by use of a roadgrader.

Checking Terrace Elevation

Terraces should be checked with a level and rod along the length of the terrace. Readings should be made first in the bottom of the canal and then opposite at the top of the ridge at several intervals for the full length of the terrace. This difference should be 0.8 Meter in a guardian or first terrace, or 0.5 in the terraces below this in the field. Special attention should be made in those areas where a terrace has crossed a gulley, or low area, that the ridges height is maintained 0.5 - 0.8 M. over the canal bottom. In a field where there are gullies to be filled it is better that these be filled before hand with a roadgrader (for shallow ones) and Caterpillar

tractor with dozer blade to fill the deeper ones. The terrace construction should follow after these gullies are filled.

In a field where there are no gullies yet formed, terrace construction can proceed with roadgrader with a Caterpillar tractor following to fill in on the ends of the terraces, where the road grader is too long to reach to the end. When all terraces are complete from end to end and ridge height over canal is up to the minimun elevation for both the guardian canal and all canals below it in the field, terracing is complete. A field of terraces will appear similiar to the aerial photo of terraces in the Yacuiba valley, illustrated in Figure 2.

The sight of the bright orange colored roadgrader becomes a visual symbol of terrace construction in our erosion control program and is often seen as depicted in Figure 3, at some location in the valley.

5" X 7"
Photo

Figure 2 - Aerial View of terraces on a farm in Yacuiba valley.

5" X 7"
Photo

Figure 3 - Roadgrader in Construction of Terraces in Yacuiba.

Cost of Terrace Construction

Terraces in a field are well located so that visual inspection by others is often noted and becomes a good demonstration for other farmers to make note of to see how the terraces actually help to present rill and gulley erosion from becoming serious. This is an important aspect of terrace construction - to give an example for others to follow. However there is the cost to be considered. The cost has been arranged on a shared construction basis, first - to promote the building of terraces for the purpose of demonstration, secondly to assist the farmer during these rather difficult economic times to build terraces to protect his land in the future.

In Table 3 these values are tabulated :

Table 4

Cost - Terrace Construction

Lineal Distance	Time for Construction	Cost per hour
Meters	Hours	$US.
1000 (3281')	3.6	30
TOTAL Cost =	$US.	108.oo

The above costs are basic, for roadgrader but the total cost of construction is somewhat variable because of the high inflation rate in South America countries and the value of the US dollar to the Bolivian peso. Another variable is in use for the D-7 Cost of D-7/hour = $ 50.oo to complete terraces by filling the deeper gullies and filling in the end of the terraces which cannot be reached by the long carriage of the roadgrader. Some fields have no gullies or small gullies which can be filled in by the road grader. Where gulleys are deeper than 50 cm a Caterpillar tractor with dozer blade must be used. Average costs of terrace construction in the Humid Chaco, including both roadgrader and Caterpillar is about $ 22.50 per hectare ($ 9.11/acre).

The financing in southern Bolivia is on a shared basis. In order to assist the cooperating farmer, economically, because of the difficult economic times in Bolivia, and at the same time complete a demonstration in erosion control for others to see who are not yet cognizant of the program, the program pays 1/2 the total cost of construction. This includes the total cost for both the road grader and Caterpillar tractor with dozer blade for construction of all terraces on the farm. The larger the farm the greater the number of terraces necessary and the greater the cost to the farmer. But in every case the cost is on shared-cooperative basis.

Future Program

Financing

Plans have developed to continue the roadgrader with assistance from Caterpillar tractor with dozer blade. Increasing damages from erosion of farm fields, roads, railroad, airport, farm properties, highways, town and village streets and small watersheds, make it imperative to continue a planned and well executed effort in erosion control, each year in the future. The financing needs to be more adequately provided for, to assure farmers that they have the financial backing for terrace construction. All involved need to also be assured that ell maintained heavy machinery is available at all times to do the terracing-for the minimun, one roadgrader, and one Caterpillar tractor with dozer blade. Because of the vast damages which have occurred

this past two years in several of the small watershed areas, financing still needs to be secured to control major gullies which have developed as well to repair all the damages to roads, highways, railroad and other public facilities. Only a well planned and financed program can adequately do the job.

Conservation Tillage

Introduction

Conservation tillage simply defined, is a system of tillage that leaves protective of crop residue mulch on the soil surface through-out the year. It can be classified into three groups, no till, strip till, and chisel.

No Till

With no-till also referred to as zero tillage, seed bed preparation and planting are completed in one operation. The soil is disturbed only in the seed row, an area no wider than 8 centimeters. About 90 % of crop area is left with protective crop residue, depending on the previous crop. A no-till planter is used which is equipped with coulters to cut through the covering vegetation to deposit the seed in a limited area.

Strip Tillage

With strip tillage the seed-bed is prepared and seed is planted in one operation as is in no-till but the row area is wider; it makes up as much as one-third of the field and is cleared or tilled of vegetation. The areas between the seed rows are left untilled with protective cover of crop residue.

Chisel

With the chisel enough residues are left on the surface after planting to effectively reduce erosion. In the chisel system the entire seedbed is loosened and part of the residue is incorpotated in the top few centimeters of soil. Seed preparation and planting can be done in one or separate operations, with a no-till planter.

Extensive research has proved the value of conservation tillage for soil erosion control. Conservation tillage improves water quality in our streams and lakes because it reduces the amount of sediment washed from cropland into the water courses. But some systems of conservation tillage require more pesticides and herbicides than conventional tillage systems. Conservation tillage reduces soil loss from cropland so much that although the concentration of pesticides and herbicides in the sediment may be higher than from conventionally tilled land the total is usually much less. Besides, the saving in energy requirements is much less for plowing and other seed bed practices of normal tillage.

Conservation tillage is being practiced more and more in the United States each year, this type of erosion control

is becoming increasingly noticed in Bolivia's farming neighbors, where in Brazil notill planters are being utilized widely in the high producing soya areas of Rio Grande Do Sur and Paraná.

It is proposed to begin chisel demonstrations here with chisel equipment on loan from IBRA, and to purchase from Brazil as soon as possible a no-till direct seeding planter for demonstration for local use. This type of erosion control needs to be introduced into the area to supplement the present terrace construction method. Coupled with adequate financial support, a growing, continuing program would offer Bolivia a real challenge for the future.

References

1. American Society of Agricultural Engineers St. Joseph Michigan 49085. "Crop Production With Conservation in the 80's". Prodeedings of American Society of Agricultural Engineers Conference on Crop Production with Conservation in the 80's - December 1980.

2. R.P. Beasley, "Erosion and Sedement Pollution Control", The Iowa University Press, Arnes Iowa, 1972.

3. Lester R. Brown, "Legacy of the Soil-World view", pp. 28-30, 49-51 May 1984, American Forests, American Forestry Association, 1319 Eighteenth Street, N.W., Washington, D.C., 20036.

4. Fernando Suarez de Castro, "Conservación de Suelos", Instituto Interamericano de Ciencias Agrícolas, San José, Costa Rica 1980.

5. Deere and Company, "Conservación en La Agricultura", John Deere and Company", Moline Illinois, 1961.

6. Julio E. Luna, Personal Communications Agencia de Extension Piloto, INTA-SENA, METAN, Argentina 1982-83.

7. Glenn O. Schwab, Richard K. Fevert, Talcott W. Edminister, Kenneth W. Barnes, "Soil and Water Conservation Engineering", Third Edition, John Wiley and Sons, New York, 1981.

LIST OF FIGURES

Figure 1 Scheme For Construction Of A Terrace By Use Of A Roadgrader.

Figure 2 Aerial View Of Terraces On A Farm In Yacuiba Valley, Bolivia.

Figure 3 Roadgrader In Construction Of Terraces In Yacuiba Valley, Bolivia.

LIST OF TABLES

1. Rainfall Record Of Yacuiba, 530M (1768')
At Airport By AASANA, 33 Years, 1950 - 1983.

2. Rainfall Registered, 5 Years 1979 - 1984
AASANA - Yacuiba Airport.

3. Distance Between Terraces.

4. Cost - Terrace Construction.

OO oo OO oo OO

EROSION CONTROL

A CHALLENGE TO BOLIVIA

by

E.Don Hansen,
SOIL SCIENTIST,
Chemonics International

Jorge Balderrama,
AGRONOMIST,
Instituto Boliviano de
Tecnologia Agropecuaria

Abstract

Bolivia an inland country of West-central South America, roughly the size of the two large continental states of Texas and Montana together, like many of both developed and Third-World countries is affected seriously with the disturbing process of soil erosion. This distressful problem challenges soil scientist, engineers, agronomists, economists, planners, and local and national leaders to take concerted action to control this growing extensive erosion in each of their countries.

In this report a successful effort is being made in the extreme southern area of Bolivia, bordering northern Argentina. It is in a productive, moderately humid valley of Yacuiba which is designated "the humid Chaco" which comprises sizeable areas of Southeastern Bolivia, Northern Paraguay and Northeastern Argentina. This humid Chaco valley has an average rainfall of nearly 1200 millimeters annually. It is 5 kilometers wide by 40 kilometers in length-roughly 20,000 hectares. The relatively small size does not belie its importance agriculturally.

Clearing of valley lands from a subtropical forested area, began in 1977, with Caterpillar D-7 tractors with dozer blades, on mostly even lands of slightly to moderate slopes of 2-6%. In the years that followed, additional land clearings were made each

ARCHIVAL COPY
Do Not Remove
copies permitted

year. Every year problems of erosion began to appear. With several years of increased rainfall during the past several years including 1984, this problem has assumed most serious proportions.

Great potentiality to produce soya, cotton, wheat, corn and other crops prompted the agricultural leaders of the country to lend greater support and more pronounced effort to this erosion control program. A description of the principal technical method used to bring this about/construction of terraces by use of a road grader with the shared cooperation of local farmers, is summarized in this report.

Introduction

A program of erosion control for Bolivia began shortly after the arrival of the senior author in early 1982. Bolivia is an inland country of West-central South America, roughly the size of two large continental states of Texas and Montana, 1,098,580 square kilometers, with a population of 7,400,000 inhabitants (1980). Similar to many of both developed and Third-World countries it has been affected seriously with the wide-spread problem of soil erosion. Worldwide and distressful, this situation challenges soil scientists, civil engineers, agronomists, planners and local and national leaders to take concerted action to control this growing potential danger to future food and fibre production in each country.

The erosion control area in which this program is being fully developed and promoted is in the productive, moderately humid area of the valley of Yacuiba which is designated as being a part of the "humid Chaco" which also includes areas around the more remote centers of Carapari and Villamontes. The present program has developed around the Yacuiba valley area but is planned for extension to the other two areas. The "humid Chaco" is differentiated from the much larger "dry

Chaco" which comprises sizeable areas of southeastern Bolivia, northern Paraguay, and northeastern Argentina. This "humid Chaco" valley of Yacuiba has an average rainfall of nearly 1200 millimeters annually. It is 5 kilometers wide by 40 kilometers in length - roughly 20,000 hectares. This small size does not belie its importance agriculturally. It is capable of producing soya, wheat, cotton, corn, and other crops. The agricultural leaders of the country recognized its great potentiality and began to lend support to fuller development of this "humid Chaco" area.

Clearing of the valley lands of Yacuiba, from a sub-tropical forested area began in 1977 with Caterpillar D-7 tractors with dozer blades, on mostly even lands of slightly to moderate slopes of 2-6%. In the immediately following years additional land clearings were made each year during the dry season (May-December). Every year problems of erosion began to appear on the newly cleared lands. With several past years of increased rainfall, including 1984, this problem has assumed most serious proportions. The damages on several small water-sheds and drainage areas has been extensive. The seriousness and extent of this growing problem has been noted since the rainy season ended in April of 1984. We had projected a completion of nearly 400 hectares of terraces for construction during the dry season of 1984 which would double the 200 hectares completed in 1983. However, requests by farmers for construction of terraces

on their lands has come in to us in slight excess of 500 hectares. The common cry is - "help us to control the erosion on our farm - we would like to have terraces constructed to save our lands".

Now renewed efforts are being made to find sufficient funds to assist these farmers to obtain the help that they need.

Clearing the Land

As has been previously stated, clearing the land has been done by Caterpillar D-7's with dozer blade. These are operated and leased from CODETAR a provincial quasi-governmental agency. When we first began our work we discovered that the operators knew nothing about acceptable and nonacceptable methods of clearing land in order to give the topsoil the greatest protection possible. Most operators were using the bull-dozer blade to produce a soil surface that was called "limpia" - clean. That is; all tree branches, trunks, bushes, brush and other vegetation were removed as well as a layer of the topsoil. The owner of the new-land to be, wanted his land "limpia". This took organization of training of CODETAR operators on our part as well as the potential farmers to know that the better way of clearing land should be "sucio"- or dirty. In this case dirty is "good" - because a "sucio" clearing was made when the bulldozer blade barely touched the surface leaving all grasses, stems of small shrubs, and bits and pieces of bark, etc. The soil was disturbed as little as possible. Large tree roots were dug out and removed by hand. It was later learned that Argentina used two Caterpillar D-8's with a heavy chain pulled between them to clear land which resulted in a

"sucio" type clearing, but the investment in Bolivia had already been made in a bulldozer blading approach and could not be changed by the more rapid and more acceptable D-8 chain method. However our relations with CODETAR tractor operators and administrators gradually improved until we got good compliance in land clearing efforts. Clearing is still limited to nearly even, low grade slopes of 0-6% for agricultural lands. Clearing "limpio" was causing future farmers great loss of topsoil and too much of the important organic matter, which was to help them to protect the soil better from the force of erosion which was to follow, but also to assist them to produce better crops of quantity and quality by conservation of as much organic matter and moisture as possible.

Loss of Topsoil

Lester R. Brown, in "Worldview" which is a summary 3 from his recently published book "State of the World" correctly states how a loss of topsoil may occur anyplace: "Grave though the loss of topsoil may be, it is a quiet crisis, one that is not widely perceived. Unlike, earthquakes, volcanic eruptions, or other natural disasters, this human made disaster is unfolding gradually. It is not always recognized, because the intensification of cropping patterns and the plowing of marginal lands that leads to excessive erosion over the long run can lead to production gains in the short run, thus creating the false sense of food security.

Although soil erosion is a physical process, it has numerous economic consequences, affecting productability, growth, income distribution, food sufficiency

and long term external debt. Ultimately it affects people. When soils are depleted and crops are poorly nourished, people are often undernourished as well".

Cause of Soil Erosion

We are confining ourselves here to water erosion because wind erosion is minimal in this part of Bolivia, but in the "humid Chaco", water erosion is of utmost importance to be controlled. The damage caused by raindrops hitting the bare soil at a high velocity is the first step in the erosion process. We may think of the raindrops as miniature bombs hitting the soil surface. In a heavy downpour this will occur with rapidity. The raindrops shatter the soil granules and clods, reducing them to smaller particles and in return reducing the infiltration capacity of the soil. A raindrop hitting on a wet soil forms a crater, compacting the area immediately under the center of the drop, moving detached particles outward in a circle around this area, finally meeting sufficient resistence to be defected upward. Authorities have estimated that more than 100 tons of soil per acre may be detached by raindrops in a single rain. On sloping land the force of the raindrops on the surface is such that more than half of the splashed soil is moved downslope as it falls back to the surface. The force of millions of raindrops during an intense rain on a cultivated field results in an appreciable movement of soil downslope.

Raindrops hitting a soil surface that is covered by a film of water churn up the soil so that the surface film of water becomes muddy. As this muddy water infiltrates into the soil,

the particles are filtered out in the surface layer. The infiltration of the muddy water and the compacting and puddling action of the raindrops falling on the surface combine to form a layer of soil which has a much lower infiltration rate than the soil at the beginning of the rain. This effect is most pronounced for rains of high intensity.

When the rate of rainfall exceeds the rate of infiltration, the depressions on the surface fill and overflow causing runoff. During the rain, the runoff is splashed and resplashed millions of times by the falling raindrops. This breaks the soil particle it is carrying in smaller and smaller sizes and helps to keep them in suspension. Thus a thin sheet of water will carry a much heavier load of silt during a rain than it would if splashing action were not present.

Falling raindrops break down soil aggregates, detach and transport soil particles as the volume of water increases. Runoff water is loaded with finer more valuable particles and cause sealing and compacting of the soil surface. Additional concentration of water follows, which moves sand and larger particles down slope, but many of the small particles have reduced the ability of the soil to absorb water.

Sheet and Rill Erosion

Sheet erosion results from soil movement from raindrop splash and surface runoff. Sheet erosion removes the lighter soil particles, organic matter and the soluble nutrients from the land is thus a serious detriment to the maintenance of soil fertility and productivity.

The erosiveness of flowing water depends upon its velocity, turbulence, and the amount and type of abrasive material it transports. The amount of material transported depends on the transporting capacity of the runoff and, the transportability of the soil. The larger and heavier - soil particles are more difficult to transport, hence they are not moved great distance. Rill erosion results from the surface runoff when it concentrates in surface depressions in which sufficient soil may be removed to small but well-defined channels. If these channels do not interfere seriously with normal tillage operations they are called rills.

Gully Erosion

While a great deal of erosion takes place by sheet and rill erosion it is gully erosion that prompts us to take concerted action for the actual control of erosion. When surface channels have been eroded to the point that they cannot be smoothed over by normal tillage operations they are called gullies. Gullies may develop at any time as a result of several factors. Soil is removed by surface water flowing through surface channels in sufficient volume to form a gully. Water from surface channels is often discharged over an abrupt change in grade. This stream of water flowing to a lower elevation has greatly increased erosive power compared to the same stream on a uniform grade. The channel at the foot of a waterfall is deepened and the banks are undermined and cave in. Gullies formed by the combination of these two means can vary from 0.5 meter or less to depths of 3 to 10 meters or more. When the gullies are

relatively small, these can be filled and controlled with terraces made with the aid of a roadgrader. But when gullies have grown to a depth of more than 0.5 meter our recommendation is to use the D-7 Caterpillar for filling before terraces are constructed by roadgrader.

Rainfall Records

Associated helpfully with the terrace construction within an area are rainfall record. The longer records have been kept, the better, because it helps us to plan ahead for the future in the construction of terraces. We may know the intenisty, duration, frequency and seasonal distribution of the rainfall over an average number of years for an area and aids us to know during which part of the year we may be able to have a period dry enough to effect construction of terraces with use of heavy machinery without being hindered by rainfall.

In our area the information is furnished by the local airport authority which has been maintained for nearly, 34 years. Refer to the details presented in Table 1. The record of rainfall data for the past five years has been very important for planning of erosion control for the future. It will be noted in Table 2 that the average monthly rainfall for the six critical months of October thru December and from January thru March has been responsible for the accompanying serious erosion damage to fields, roads, railroad, streets in Yacuiba and other outlying village and watershed areas. This year 1984 hit a new high for the month of March, during which a record rainfall of 725 mm. was registered in only 13 days. It was during this relatively short pe-

riod that the greatest erosion damages occurred extensively throughout the Yacuiba valley area. More farmers than ever have been prompted to think more seriously about obtaining technical help in battling this serious problem and have been asking for construction of terraces on their properties.

Construction of Terraces

Terraces construction was initiated in July 1983 on the finca of Antonio Mogro in Yacuiba valley, 6 terraces, totaling 2980 meters in length, in a field of 20 hectares, with a varying 4-6 % slope. Before this initial attempt we had made a close study of the terrace construction program of Julio Luna and his technicians of the INTA (Instituto Nacional de Tecnologia Agropecuaria) organization in the vicinity of Metan in province of Salta in Northern Argentina.

Experience during the dry season of construction in 1983 - 1984 helped us to arrive at the following specifications for terraces:

- Width of terrace (26')
  8 meters

- Slope of Canal of 0.3%

the terrace

- Altitude difference between ridge and canal in finished terrace at completion of construction of guard terrace	0.8 Meters (31") (highest)
- Altitude difference between ridge and canal in all over terraces,.	0.5 Meters (20")

It should be noted that terrace construction should actually begin near the highest elevation in the field, and should be checked with a level for this point if not readily determined by visual inspection.

The first or highest terrace constructed in the field, 0.8 meters in height is designated a guardian terrace, designed to intercept runoff from the area above, and therefore the ridge is constructed higher than the terraces below by 30 centimeters or more. All terraces below terrace one-or guardian terrace usually have at least 0.5 meter of elevation which seems to be adequate. However the trained road grader operators seem to be able to average nearly 0.8 meter for all terraces.

The second important item is to ascertain there is drainage of the terraces from the field on either side. They may be a natural drainageway established on one or both sides, or it may be necessary to establish a grass waterway on the edge of the field on either side to receive the drainage outflow from the common ends of the terraces when excess water flows from excessive rainfalls. One has been built here

on the middle of the farm of Alberto Quiroga by use of a road grader. The grass specie of Cynodon dactilon is locally available which could be used to plant vegetatively over this waterway, but will have to be accomplished at the beginning of the rainy season because of non-availability of water during the dry season.

Grass Waterways

It is important to note that grass waterways in themselves do not protect large portions of a given field from erosion. They are designed to work in combination with other soil and water conservation practices, such as terraces, contour farming and diversions which direct water into grass waterways. The waterways conduct this concentrated flow off the field with minimal damage to the soil. Grass waterways are always planted in those sloping fields where water concentrates naturally or which will concentrate on the edge of fields from terraces, where gullies are most likely to form.

Other grass species which need to be considered and tried in this area for cover for grass waterways are Paspalum notatum, Dactillis glomerata, and Clorys Sp.

Distance between Terraces

The third item to consider in construction of terraces is to calculate the distance between terraces. Distance is related to the average slope which can be determined by use of the hand level and the following Table 3 can be a guide for terraces in each field. Measurement down the slope can be made from the begin-

ning stake of the first terrace.

Table 3

Distance between Terraces

Average slope	Distance between terraces
%	Meters
0 - 3	100
3 - 5	80
5 - 8	60

Use of Level

The level instrument and leveling rod with use of prepared field stakes can be used to locate the points along each terrace. Two persons may measure off 20 Meters from the beginning point, with the person at the far end of a 20 meter line also holding the rod. After the rod is read by the levelman, the two individuals advance every 20 meters until the end of the terrace is reached on the other side of the field. A stake is driven at the end of each 20 meter measurement to mark the location at every 20 meters of the terrace to be made. Readings of the levelman at each location is the key to maintaining a descending slope in the terrace from the beginning to the end. In order to have sufficient slope to move excess water along the canal of the terrace in case of rainfall runoff, a slight slope of 0.3 % must be built into the terrace. This is accomplished by reading 6 centimeters more on each rod reading for every 20 meters distance along the surveyed terrace line. For example if the beginning rod reading is 1.20 meters (1 meter 20 centimeters), the second reading is 1.26, the third reading

1.32, etc. until the end of the terrace. Terraces should not be longer than 500 meters in length because of the volume of water that can accumulate in the canal of a terrace. Longer terraces would not therefore be wise because too much water would be intercepted to flow which might cause an erosion problem not fully anticipated. Longer distances can have terraces overlaped and have the water flow the opposite way from the middle of a field wider than 500 meters. This would assume that there would be a natural drainage to take care of the extra length terraces over 500 Meters. If a natural drainage was not present, grass waterway would need to be established to take care of the extra drainage water from the other side of a large field with widths greater than 500 meters. For example, with a field of a width of 600 meters, a terrace can be surveyed so that the water will flow 300 meters to one drainageway and the water in the other 300 meters would flow from the middle in the opposite direction to the other drainageway.

Roadgrader Construction

Construction of terraces can begin as soon as several terraces are staked ahead rather than wait until a complete field is staked with terrace locations. The roadgrader operator can trace the location between stakes by using the corner of the roadgrader blade, if a person can extract each stake from the field just before the wheel of the road grader gets to it. An operator must be well trained to construct a terrace by making 8 passes (Figure 1) with the road grader along the line of the terrace. The line originally traced in the field locates the middle of

the terrace.

Four passes will be made on each side as illustrated in Figure 1, a scheme for construction. The difficult part of the construction for the roadgrader operator are the final passes to keep the wheels of the frontend of the roadgrader up on the ridge of the terrace so the blade can push the soil up to the highest extent possible - usually 0.8 Meter above the canal bottom level.

Checking Terrace Elevation

Terraces should be checked with a level and rod along the length of the terrace. Readings should be made first in the bottom of the canal and then opposite at the top of the ridge at several intervals for the full length of the terrace. This difference should be 0.8 Meter in a guardian or first terrace, or 0.5 in the terraces below this in the field. Special attention should

Aqui viene Figura 1

be made in those areas where a terrace has crossed a gully, or low area, that the ridges height is maintained 0.5 - 0.8 M. over the canal bottom. In a field where there are gullies to be filled it is better that these be filled before hand with a roadgrader (for shallow ones) and Caterpillar tractor with dozer blade to fill the deeper ones. The terrace construction should follow after these gullies are filled. In a field where there are no gullies yet formed, terrace construction can proceed with roadgrader with a Caterpillar tractor following to fill in on the ends of the terraces, where the road grader is too long to reach to the end. When all

terraces are complete from end to end and ridge height over canal is up to the minimum elevation for both the guardian canal and all canals below it in the field, terracing is complete. A field of terraces will appear similar to the aerial photo of terraces in the Yacuiba valley, illustrated in Figure 2.

The sight of the bright orange colored roadgrader becomes a visual symbol of terrace construction in our erosion control program and is often seen as depicted in Figure 3, at some location in the valley.

Aqui viene Figura 2

Luego Figura 3

Cost of Terrace Construction

Terraces in a field are well located so that visual inspection by others is often noted and becomes a good demonstration for other farmers to make note of to see how the terraces actually help to present rill and gully erosion from becoming serious. This is an important aspect of terrace construction - to give an example for others to follow. However there is the cost to be considered. The cost has been arranged on a shared construction basis, first - to promote the building of terraces for the purpose of demonstration, secondly to assist the farmer during these rather difficult economic times to build terraces to protect his land in the future.

In Table 4 these values are tabulated:

Table 4

Cost - Terrace Construction

Lineal Distance	Time for Construction	Cost per hour
Meters	Hours	$US.
1000 (3281')	3.6	30
TOTAL Cost =	$US	108.oo

The above costs are basic, for roadgrader but the total cost of construction is somewhat variable because of the high inflation rate in South America countries and the value of the US dollar to the Bolivian peso. Another variable is in use for the D-7 Cost of D-7/hour = $ 50.oo to complete terraces by filling the deeper gullies and filling in the end of the terraces which cannot be reached by the long carriage of the roadgrader. Some fields have no gullies or small gullies which can be filled in by the roadgrader. Where gullies are deeper than 50 cm a Caterpillar tractor with dozer blade must be used. Average costs of terrace construction in the Humid Chaco, including both roadgrader and Caterpillar is about $ 22.50 per hectare ($9.11/acre).

The financing in southern Bolivia is on a shared basis. In order to assist the cooperating farmer, economically, because of the difficult economic times in Bolivia, and at the same time complete a demonstration in erosion control for others to see who are not yet cognizant of the program, the program pays 1/2 the total cost of construction. This includes the total cost for both the roadgrader and Caterpillar tractor with dozer blade for

construction of all terraces on the farm. The larger the farm the greater the number of terraces necessary and the greater the cost to the farmer. But in every case the cost is on shared-cooperative basis.

Future Program

Financing

Plans have developed to continue the roadgrader with assistance from Caterpillar tractor with dozer blade. Increasing damages from erosion of farm fields, roads, railroad, airport, farm properties, highways, town and village streets and small watersheds, make it imperative to continue a planned and well executed effort in erosion control, each year in the future. The financing needs to be more adequately provided for, to assure farmers that they have the financial backing for terrace construction. All involved need to also be assured that all maintained heavy machinery is available at all times to do the terracing -for the minimum, one roadgrader, and one Caterpillar tractor with dozer blade. Because of the vast damages which have occurred this past two years in several of the small watershed areas, financing still needs to be secured to control major gullies which have developed as well to repair all the damages to roads, highways, railroad and other public facilities. Only a well planned and financed program can adequately do the job.

Conservation Tillage

Introduction

Conservation tillage simply defined, is a system of tillage that leaves protective of crop

residue mulch on the soil surface throughout the year. It can be classified into three groups, no till, strip till, and chisel.

No Till

With no-till also referred to as zero tillage, seed bed preparation and planting are completed in one operation. The soil is disturbed only in the seed row, an area no wider than 8 centimeters. About 90% of crop area is left with protective crop residue, depending on the previous crop. A no-till planter is used which is equipped with coulters to cut through the covering vegetation to deposit the seed in a limited area.

Strip Tillage

With strip tillage the seedbed is prepared and seed is planted in one operation as is in no-till but the row area is wider; it makes up as much as one-third of the field and is cleared or tilled of vegetation. The areas between the seed rows are left untilled with protective cover of crop residue.

Chisel

With the chisel enough residues are left on the surface after planting to effectively reduce erosion. In the chisel system the entire seedbed is loosened and part of the residue is incorporated in the top few centimeters of soil. Seed preparation and planting can be done in one or separate operations, with a no-till planter.

Extensive research has proved the value of conservation tillage for soil erosion control. Conservation tillage improves water quality in our streams and lakes because it reduces the

battling this serious problem and have been asking for construction of terraces on their properties.

Construction of Terraces

Terraces construction was initiated in July 1983 on the finca of Antonio Mogro in Yacuiba valley, 6 terraces, totaling 2980 meters in length, in a field of 20 hectares, with a varying 4-6 % slope. Before this initial attempet we had made a