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SOIL EROSION PREVENTION ON BAUXITE STRIPMINED SOILS IN HAWAII

by
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INTRODUCTION

The discovery of extensive bauxite deposits within the boundaries of the United States (Sherman, 1957) has raised considerable interest, and their possible exploitation is now under study. One of the phases of an exploitation study has been made the responsibility of the Hawaii Agricultural Experiment Station, that of determining whether stripmining would harm watersheds and the agricultural value of the land.

A study of this possibility was initiated about 1½ years ago to determine the extent of soil erosion which might occur after stripmining the land and what measures could be taken to prevent such erosion and its effect on local watershed hydrology. In addition, a range of fertilizer treatments has been applied to a number of selected crops in plots to determine the agricultural value of the subsoil exposed after stripmining.

It may be recalled that bauxite is an aluminum-rich end product of soil weathering under favorable drainage conditions in tropical regions. Consequently, the ore is concentrated near the surface and its mining requires stripping the surface soil for processing. The depth of surface soil removed will depend on the concentration of aluminum which declines with increasing depth below the surface. The depth of mining is thus determined by economics.

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* Formerly known as *Progress Notes*.

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The experimental work was concentrated on the island of Kauai in a location which appeared promising for becoming the first area to be mined. The depth of the economically-exploitable ore deposit in this area is estimated to be about 15 feet. The soil is deep and well drained. Stripping 2½ acres to the required depth left behind a subsoil with favorable physical properties, a soil which is readily tillable, of a stable structure and with a relatively high infiltration rate (in the absence of surface crust formation, between 1 and 3 inches per hour). The soil is a clay, but owing to aggregation and the inclusion of gibbsite nodules and of stones, the soil could be classified for practical purposes as a stony, silty loam.

EXPERIMENTAL PROCEDURE

Erosion assessment comprises two phases:

A. Field observations are made on the extent of soil movement in the many tons of soil pushed after stripping from flat-topped ridges onto the slopes of adjacent valleys. The valleys are usually about 300 feet deep and have slopes of about 30 degrees. It was endeavored to revegetate the resulting slopes, but in spite of fertilizer application, these attempts were only partially successful. Ultimate slopes are of about the same degree as the original ones. In addition to making periodic photographic records of the behavior of the talus slopes, the extent of silting up of the water courses in the bottom of these valleys is followed.

B. Systematic experiments on the effect of various soil treatments on soil erosion are conducted on exposed subsoil. Measurements are made in duplicate using conventional soil erosion plots, delineated by vertical metal strips, the plots having the dimensions 8 x 80 feet (figure 1). The plots are situated on about 5 percent slopes. After removal of the overlying ore, it was attempted to compact the exposed subsoil as much as possible, in order to simulate mining operations, by running a loaded dump truck up and down the experimental site for several hours. Bulk density samples were then taken from compacted and "uncompacted" subsoil. The soil losses from these plots are measured by a simplified standard technique of intercepting a fraction of the soil losses. The technique developed has been described elsewhere (van't Woudt, in press). The following treatments are applied to the compacted site:

1. Subsoil kept devoid of any plant cover by poisoning the soil.
2. Subsoil with about 6 inches topsoil replaced on it, similarly kept devoid of plant cover.
3. Subsoil covered by a layer of about 2 inches sugar cane trash (bagasse), a local waste product of little commercial value.
4. Subsoil devoid of plant cover, contour-treated (see under results).

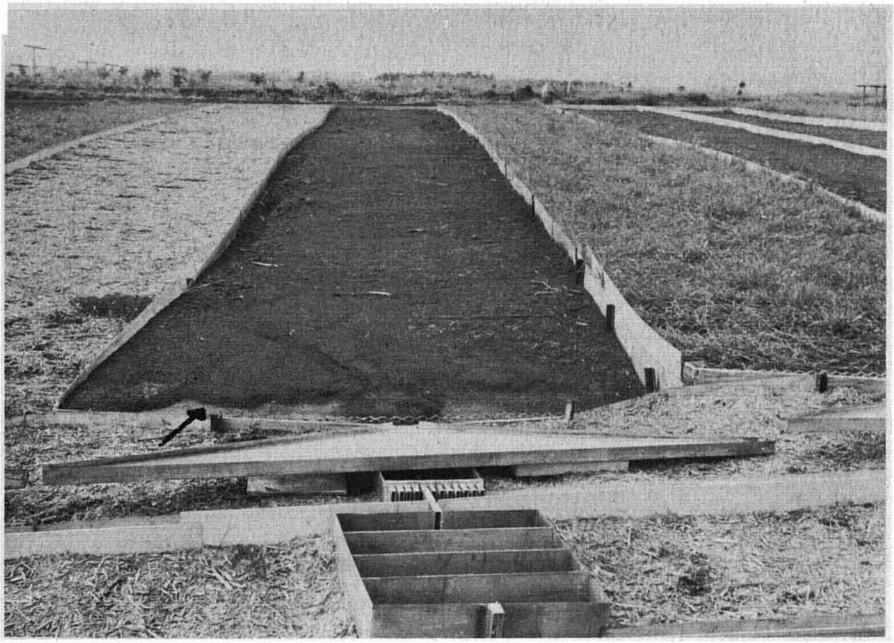

FIGURE 1. Method used to measure soil erosion under different surface treatments. (Note soil accumulation in front of measuring device, indicated by arrow.)

5. Subsoil, worked up by shallow tillage into a seedbed, fertilized and sown to pangola grass.
6. As treatment 5, but after replacement of about 6 inches of topsoil on the subsoil. (Note the replaced topsoil was applied after compaction.)
7. In a separate area which had not been stripmined, control plots were installed on undisturbed soil under native vegetation.

RESULTS

During the more than 12 months the stripmined soil has been exposed on the valley slopes, as described, several tons of soil have washed down into the valley bottom. However, in comparison to the quantity of soil dumped on the slope the losses are small. The major loss has taken place where flow concentrated in channels, which has led to some gullying on the slopes. However, where drainage water has been guided across the dumped soil by a flume to a slope in native vegetation, soil losses from the latter site appear negligible. The soil deposited in the valley bottoms has created a few local swampy spots which have tended to kill some of the native plants.

However, streams have cut across these spots and after a dry spell they are drained. Up to now the damage done to the watershed has been of negligible significance. This has been a severe test of the erodibility of this soil, as normally the mined ore would be removed to a processing plant, leaving merely the problem of disposal of waste products to safe areas. Under the experimental setup, removal of the ore was too costly, and the material had to be disposed of locally, as described.

SOIL COMPACTION

The compaction introduced by the treatment described caused the surface 2 inches of soil to be compacted by about 10 percent. The average bulk density measured of the 0- to 2-inch layer was 1.27, of the 3- to 4-inch layer 1.17, and of the 5- to 6-inch layer 1.14. Below this layer the latter value was maintained.

RAINFALL ANALYSIS

Rainfall and evaporation data during the period of measurement are shown in tables 1, 2, and 3. It is seen that during the period of measurement there were two rain storms with an intensity of 2.0 inches per hour, lasting 10 and 30 minutes; four rain storms with an intensity of 1.0 inch per hour with durations of 15, 40, 45 minutes, and 3½ hours. The remaining rain storms were generally of low if not very low intensity, even though lasting in some cases for many hours. From an erosion point of view only the rain storms occurring on April 5 and May 17, and those between August 6 and 9, are of interest. These rain storms are so infrequent that graphical presentation does not seem warranted.

The data presented show that the rainfall pattern is more than usually favorable from an agricultural, and particularly from an erosion point of view. The rainfall of 7.66 inches fallen between August 6 and 9 was the result of the passage of a hurricane, Dot, over the island of Kauai. Rain storms of this nature, and even heavier ones, pass over the islands at long intervals. The U. S. Weather Bureau, Honolulu, calculated the mean return period for rain storms of a given intensity over a 24-hour period for Lihue, about 7 miles away from the site of the erosion plots. These are:

Mean return period, years	*Total rain, inches*	*Mean return period, years*	*Total rain, inches*
2	5.6	50	16.0
5	8.9	100	18.0
10	11.1		

TABLE 1. Rainfall and evaporation in inches at the site of the erosion plots

Jan. 19 – 31	Feb.	March	April	May	June	July	Aug. 1 – 10	1959 Total
				Inches				
0.66	3.43	2.69	5.44	4.29	2.00	4.86	8.90	32.27
Cumulative evaporation over corresponding period								23.23

TABLE 2. Rainfall according to rain storm size

	Size of storm in inches						
	0.01–0.10	0.11–0.20	0.21–0.30	0.31–0.40	0.41–0.50	Over 0.5	Total
Percentage of total rain	7.0	10.8	12.0	14.2	5.8	50.0	100%
Total number of rain storms	54	22	14	13	4	14	121

TABLE 3. Intensity and duration of rain storms over 0.51 inches

Date	Storm size, inches	Storm intensity in inches per hour and its duration
1959		
2/11	0.68	0.30 for 2 hours
2/12	0.70	0.04 for 18 hours
3/1	0.78	0.07 for 10 hours
3/22	0.84	0.28 for 3 hours
4/5	1.32	2.0 for 30 minutes; 0.30 for 1 hour
4/9	1.82	0.08 for 24 hours
5/17	0.92	1.0 for 40 minutes; 0.015 for 23 hours
8/3	0.72	0.12 for 4 hours; 0.04 for 6 hours
8/6	5.08	1.0 for 3½ hours; 0.50 for 2 hours; 0.30 for 2 hours
8/7	1.08	1.0 for 45 minutes; 0.05 for 7 hours
8/8	0.72	1.0 for 15 minutes; 0.02 for 23 hours
8/9	0.78	2.0 for 10 minutes; 0.03 for 14 hours

At Kilauea, at the north side of the island, the record rain storm was 24.8 inches per 24 hours in January, 1956. These data do not give a complete picture as to the sizes of storms which can be expected. Rainfall, even though of lesser magnitude than quoted, but extending over several days, may have seriously harmful effects. However, such storms are probably as infrequent as the ones cited, and for the purpose of planning against erosion, it is believed that a consideration of the above probabilities may suffice.

SOIL LOSSES FROM THE EROSION PLOTS

The soil losses for the various treatments during the period of measurement are shown in table 4. The effect of soil cover is apparent, erosion from the bagasse- and grass-covered plots being of negligible significance. The soil losses from the six bare plots were ten times those from the six surface-protected plots.

Of interest is the observation that soil losses were most marked during the period June 15 – August 10. This is not only related to the heavy rain during this period, but also to the behavior of the eroding soil within the

TABLE 4. Soil losses as measured in erosion plots from January 19 – August 10, 1959

Soil treatment	Est. % ground cover	Period: 1/19–2/20	4/20–4/22	4/22–6/15	6/15–8/10	Total	Total average soil losses: Depth in inches	Pounds per acre	Short ton per acre
		Depth of soil in thousandths of an inch							
Subsoil, devoid of vegetation	0	1.7	4.4	1.7	7.7	15.5			
	0	0.4	2.1	0.5	5.7	8.7			
					Av.	12.1	0.0121	3,300	1.6
Subsoil, devoid of vegetation, contour treated	0	1.7	7.0	1.8	37.8	48.3			
	0	0.4	6.2	46.0	3.8	61.4			
					Av.	54.9	0.0549	14,700	7.3
Subsoil with replaced topsoil, devoid of vegetation	0	0.4	0.4	0	3.6	4.4			
	0	0.2	4.1	0	5.7	10.0			
					Av.	7.2	0.0072	1,900	1.0
Subsoil with bagasse cover	80	0.3	0.3	0.7	2.2	3.5			
	80	0	0.3	0.2	0.6	1.1			
					Av.	2.3	0.0023	600	0.3
Subsoil, fertilized and sown with pangola	75	0.1	0.6	0.2	2.1	3.0			
	75	0.2	0.3	0.1	1.9	2.5			
					Av.	2.3	0.0023	600	0.3
Subsoil with replaced topsoil, fertilized and sown with pangola	85	0	0.3	0.3	1.1	1.7			
	85	0	0.4	0	3.5	3.9			
					Av.	2.8	0.0028	700	0.4
Control Undisturbed surface soil with native vegetation	90	0.4	0	0	0	0.4			
	90	0.8	0.2	0	0	1.0			
					Av.	0.7	0.0007	200	0.1

plots. However smooth the transition between the soil surface at the lower end of the plot and the entrance of the measuring device, there is a tendency for some barrier to soil movement to be created at this site. From 24 metal stakes, systematically inserted throughout the extent of each plot, it was learned that some of the soil removed from the surface at the middle and upper ends of the plots tends to be deposited at the lower end. In two cases the build-up of soil here was as much as 2 inches. This material is unconsolidated and a heavy rain storm tends to push much of it into the measuring device, thus causing high soil losses to be measured.

The control plots on undisturbed surface soil under native vegetation did not show any erosion, except just after their installation. The bagasse and pangola grass plots were comparable. Bagasse is particularly suited for establishing an immediate soil cover. However, this cover is not permanent owing to decomposition of the bagasse; after 6 months, replacement was required. It should be pointed out that the grass plots with surface soil replacement were superior to those without surface soil in that the grass was earlier established and that their sward was somewhat denser.

WATER RUNOFF

Water runoff for all the treated plots was measured by guiding the total outflow from the measuring devices of all 12 plots through a recording Parshall flume with 6-inch throat. The only outflow recorded during the period of measurement was on April 5, at that time of negligible significance, and on August 6. On the latter date the flume measured an average flow of 0.15 c.f.s. for about 2 hours. In order to make this figure more intelligible it is assumed that water losses during the period 6/15 to 8/10 were proportional to measured soil losses for each plot. Table 4 shows that the total soil losses from the six plots in bare soil represented 0.1482 inches depth of soil and from the six surface-protected plots, 0.0148 inches. On that basis practically all the rain fallen on the plots with bare soil ran off during 2 out of the 3½ hours the intensity of the storm was 1 inch per hour.

CONTOUR TREATMENT

Contour treatment in small plots is difficult to apply. Six-inch-high berms across the two plots, spaced at 20-foot intervals in the lengthwise direction of the plot indeed caused runoff water to be held back. However, excessive rain led to overtopping of the berms, after which the flow remained concentrated in channels leading to "gullying" and consequent heavy soil loss. Changing the berms to ditches did not improve the surface storage as fine soil soon filled up the ditches. The possibility of contour treatment is now being further studied from another angle.

Up to now this treatment has shown, however, that it may be recommendable to leave the surface as smooth as possible, as any unevenness will cause concentration of runoff water and soil losses from gullying.

CONCLUSIONS

Owing to apparent erosion-resistant properties of the soil and a favorable rainfall pattern, erosion in the stripmined area has been of small significance during seven months of observation. Relatively small soil losses from bare subsoil can be largely prevented by rapid revegetation, or by bagasse cover. Soil losses from bare soil were found to be reduced to 1/10th by surface protection. These conclusions may be modified in the future, as the effect of infrequent, very heavy storms has not yet been assessed.

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