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Corrective Measures Technology for Shallow Land Burial at Arid Sites: Field Studies of Biointrusion Barriers and Erosion Control

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Prepared by Mary Moore, HSE Division, and Sylvia Gonzales, Group HSE-12

Cover photo: Low-level radioactive waste disposal site (Area B) at Los Alamos, New Mexico, prior to the 1982 removal of tree and shrub cover.

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CORRECTIVE MEASURES TECHNOLOGY FOR SHALLOW LAND BURIAL AT ARID SITES: FIELD STUDIES OF BIOINTRUSION BARRIERS AND EROSION CONTROL

by

J. W. Nyhan, T. E. Hakonson, and E. A. Lopez

ABSTRACT

The field research program involving corrective measures technologies for arid shallow land burial (SLB) sites is described. Results of field testing of a biointrusion barrier installed at a close-out waste disposal site (Area B) at Los Alamos are presented. Soil erosion and infiltration of water into a simulated trench cap with various surface treatments were measured, and the interaction between erosion control and subsurface water dynamics is discussed relative to waste management.

I. INTRODUCTION

The overall purpose of the Corrective Measures-Arid Task of the National Low-Level Waste Management Program (NLLWMP) is to develop and test methods that can be used to correct any actual or anticipated problems with new and existing SLB sites in an arid environment. These field tests will not only evaluate remedial actions but will also investigate phenomena suspected of being a possible problem at arid SLB sites. For some processes, such as erosion, research and experiments will be conducted to determine the nature and scope of the problem as well as to field test solutions to the problem.

A particularly important aspect of erosion control methods, for example, is that they are often effective because they enhance infiltration rates and reduce surface runoff rates. Although this may reduce erosion rates it can cause additional problems with moisture balance and seepage or percolation through the trench cover profile. Research is needed to quantify and predict the interaction between erosion control technologies and water balance in the soil profile.

Specifically, the research performed for this entire task has identified, evaluated, and modeled erosion control technologies; field tested second-generation biointrusion barriers; determined by field experiments the extent of upward radionuclide migration due to moisture cycling; measured the effects of subsidence on remedial action or other system components; and field tested methods that could be used to correct any other actual or anticipated problems with new and existing SLB sites in arid and semiarid environments. The CREAMS model (A Field Scale Model for Chemicals, Runoff, and Erosion From Agricultural Management Systems) was used to model the surface processes and will be validated for soil profiles typical of those in SLB facilities (Nyhan and Lane 1982, Lane and Nyhan 1981, Hakonson et al. 1984). Moreover, the erosion component of CREAMS will be directly related to interactive factors operating with respect to the hydrology or water balance component of interest in corrective measures.

The data collection and analysis activities presented in this report will involve field experiments on second generation biointrusion barrier testing and on erosion control technologies and their interactions with water balance relationships.

The purposes of the second generation biointrusion barrier testing experiments were to apply biobarriers developed in previous studies (Hakonson 1986) to old burial sites that need corrective measures and to perform experiments on biobarriers already developed to optimize system design in terms of the effect of the biobarrier on the water balance. In FY 1982, a cobble-gravel biobarrier system was installed at Area B, a burial site at Los Alamos, which was closed out initially in 1947. The performance of this system has been monitored both in terms of effects on the water balance and in the prevention of contaminant uptake by plants. These results are presented in the next section.

The purpose of the erosion control research presented in the final section of this report was to provide experimental data on erosion control technologies suitable for arid SLB sites, as well as information on the effect of erosion control technologies on the surface and subsurface component of the water balance. The results obtained in these experiments will permit the comparison of these results with the results obtained in similar experiments by the U.S. Department of Agriculture (USDA) and will provide the interface to use the data obtained from agricultural systems for application to SLB. The data collected at Los Alamos to determine the cover management factor (C) and the soil erodibility factor (K) of the Universal Soil Loss Equation (USLE) will be compared with similar data collected at the USDA plots in Tombstone, Arizona, and Boise, Idaho, as well as at the Nevada Test Site. These experimental results will allow the NLLWMP to make more specific and meaningful statements about remedial actions for SLB involving soil erosion and hydrologic processes across a multitude of arid sites in the US, and not just for SLB sites at Los Alamos, New Mexico. The water relationships beneath the eight erosion plots in Los Alamos are presented, showing variations in soil water content in the trench cap as influenced by seasonal effects and cover treatments (gravel, gravel plus wheatgrass, bare soil, and cultivated surfaces).

II. AREA B STUDY

A. General Description and Waste Use History of Area B

Area B was probably the first common solid waste burial ground for the Los Alamos Laboratory. Old memos dated July 5, 1945, through January 31, 1952, indicate that Area B is actually a series of pits (Rogers 1977). Approximate acreage is 6.03, with the area being located on the south side of DP Road, approximately 488 m east of the intersection of DP Road and Trinity (SE 1/4 sec. 15, T. 19N., R. 6E., and SW 1/4 sec. 14, T. 19N., R. 6E.). The western two-thirds of Area B is presently covered by a layer of asphalt and is leased by Los Alamos County for storage of privately owned boats and recreational vehicles.

Area B is located on the same narrow, eastward-trending mesa as Areas A and T. The south side of Area B is approximately 30 m from a canyon tributary to Los Alamos Canyon. The Area B pits are probably cut in Unit 3a of the Tshirege Member of the Bandelier tuff. The thickness of the Bandelier tuff beneath the disposal pits is estimated to exceed 243.8 m. The tuff is in the zone of aeration, with the zone of saturation (water table) at a depth of approximately 365.8 m below the surface of the mesa.

Opinions on the waste materials buried at Area B vary (Rogers 1977). On January 30, 1952, the waste was said to be predominately long-life alpha accompanied by slight amounts of beta and gamma. On January 31, 1952, the following was stated (Rogers 1977):

> The contamination on materials in these pits consists of all types of radioactive materials used at Los Alamos. Some of the known types of activity are: plutonium, polonium, uranium, americium, cerium, RaLa (radioactive lanthanum), actinium, and waste products from the Water Boiler. No attempt has been made to keep the various materials separated.

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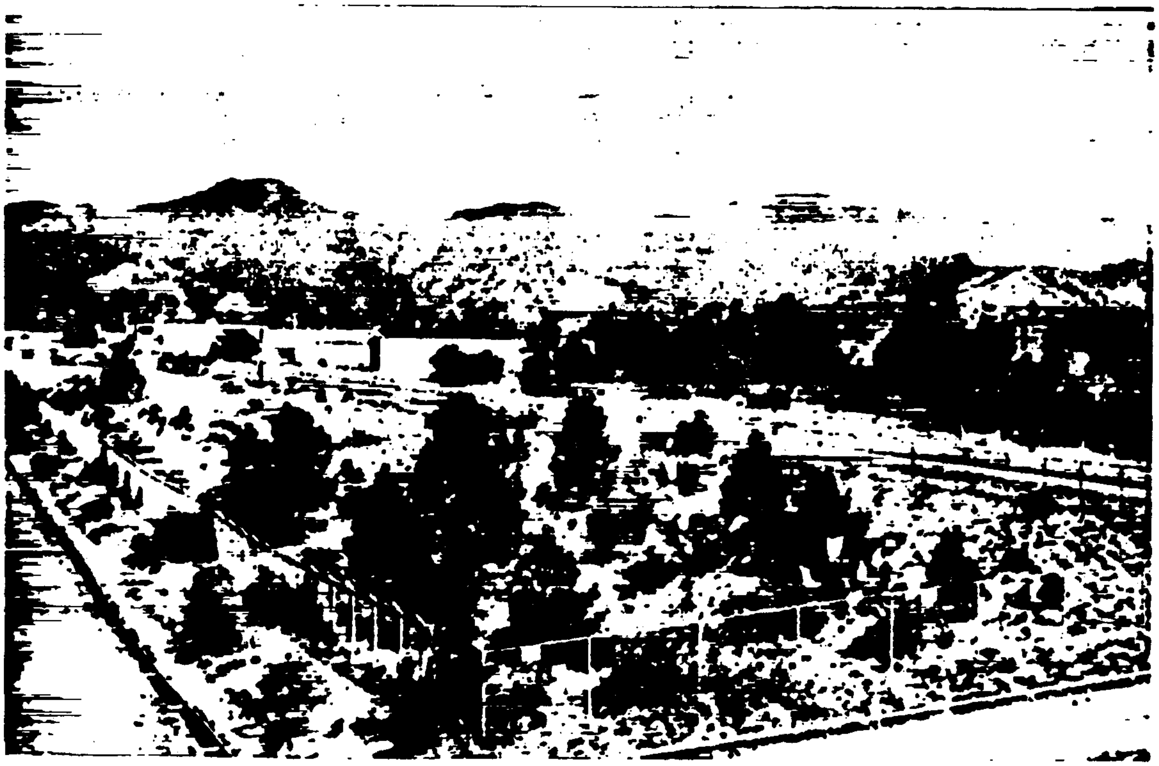

Fig. 1. Area B low-level waste site (fenced area) prior to removal of tree and shrub cover. Area B was decommissioned in 1947 and received new site cover during the fall/winter of 1982.

The monitoring study designed for Area B, which was funded by the NLLWMP, addressed two questions:

1. Does the cobble-gravel biointrusion barrier-cap design perform any better than the soil/crushed-tuff cap at field-scale, under natural precipitation regimes, and native grass cover?
2. Does the cobble-gravel trench-cap design act as a capillary barrier to percolating water?

The remedial action performed by waste operations consisted of applying a new trench cap on top of the existing cap in order to cover radionuclide contamination present on the ground surface. All trees and large shrub cover were removed prior to beginning construction activities.

Two test plot areas were established at Area B, as shown in Fig. 2. The performance of the two designs in limiting plant root intrusion was evaluated using cesium tracer. About 16 kg of cesium chloride was applied to a 6- by 40-m area in each plot on top of the existing trench cap for an application rate of 240 g/m^2. After the tracer was applied, a 15-cm layer of uncontaminated soil was spread over the entire area to prevent cross contamination of the earth-moving machinery, and the rest of the cap materials (biointrusion barrier or crushed tuff) added to this layer. Stable cesium, which is readily absorbed by plant roots and translocated to above-ground parts, was thus applied as a simulated waste. Samples of vegetation were collected over time and analyzed for cesium, using neutron activation techniques, to give us an indication of root penetration through the biointrusion barrier.

Neutron access tubes were installed at four locations along the slope in each plot (Fig. 2). The tubes extended 100 cm into the old trench cap to provide access for measuring the moisture content of soil underlying the new caps.

The cap profile in the control plot consisted of about 75 cm of crushed tuff covered with 15 cm of topsoil. The improved cap design consisted of 75 cm of 10- to 30-cm-diameter cobble covered with 25 cm of 2-cm gravel (Fig. 3), all covered with 60 cm of Hackroy-series clay-loam topsoil. Both plots had a surface slope of about 2-3% to allow for some surface runoff.

The surface of the entire area was seeded with a mixture of native grasses and covered with straw mulch used to minimize erosion during establishment of the plant cover. Because the plot was constructed late in

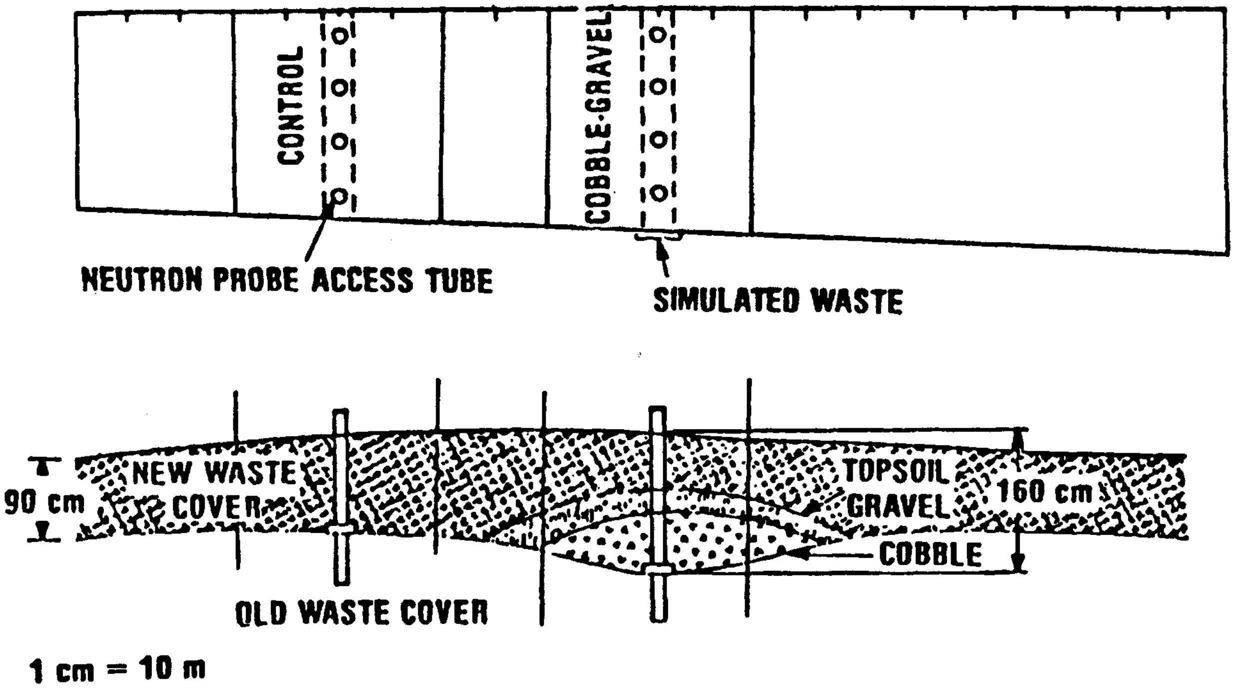

Fig. 2. Schematic of plot configurations for the Area B biointrusion barrier study initiated in the fall of 1982. Control treatment represented the conventional cap design constructed on Area B. The intrusion barrier design consisted of topsoil over layered rock.

1982, plant cover did not become established until the spring of 1983. The dominant plant species covering the site in 1983 was wheat (Triticum aestivum), whose seeds were introduced in the straw mulch (Fig. 4). In the fall of 1983 and during the growing season of 1984, perennial grasses and yellow sweet clover (Melilotus officinalis) dominated the plant cover.

As part of an Environmental Protection Agency (EPA) sponsored program to be terminated in FY 1986 ("Maintenance Free Vegetation Systems for Landfill Covers"), several additional cover treatments were added in 1984 to this low-level radioactive waste disposal site resulting in the following site closure covers (Fig. 5), in addition to the original treatments:

I. Soil profile: top soil, crushed tuff ("control profile").

Cover treatment

A. bare soil

B. sand dropseed (*Sporobolus cryptandrus*), sparse (1 plant/5 ft^2)

C. sand dropseed, dense (1 plant/ft^2)

D. rabbitbrush (*Chrysothamnus parry howardi*), sparse (1 plant/25 ft^2)

E. rabbitbrush, dense (1 plant/5 ft^2)

F. sand dropseed, sparse and rabbitbrush, sparse.

II. Soil profile: top soil, crushed tuff, cobble ("biobarrier/wick profile").

Cover treatment

A. bare soil

B. sand dropseed, dense (1 plant/ft^2)

C. rabbitbrush, dense. (1 plant/5 ft^2)

III. Soil profile: crushed tuff.

Cover treatment: pavement.

As part of an effort to develop and test approaches to understanding and controlling water balance relationships in landfill cover treatments caused by different vegetation and soil types, 25- by 80-ft plots were emplaced with neutron access tubes and lysimeters. Rabbitbrush (in 1-gallon-size containers) and sand dropseed (in 1- by 3-in plugs) were also planted in 1984.

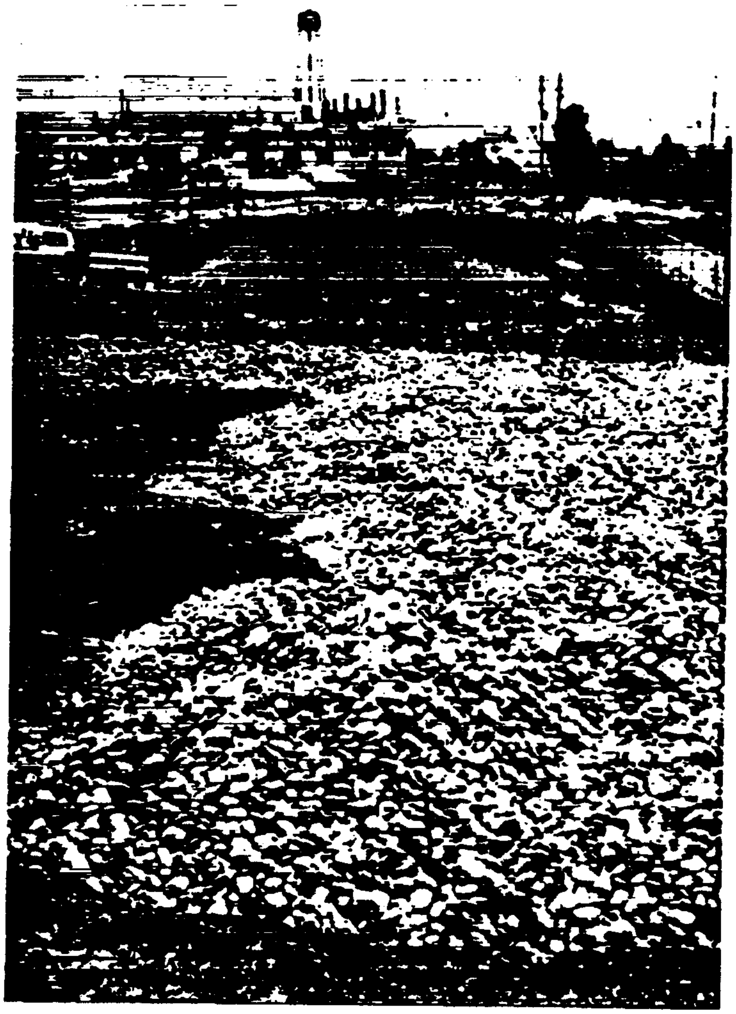

Fig. 3. Installing the biobarrier at Area B in 1982.

Fig. 4. Wheat cover at Area B biointrusion barrier study plots during 1983. Some grass cover did become established in 1983 and dominated the cover in 1984.

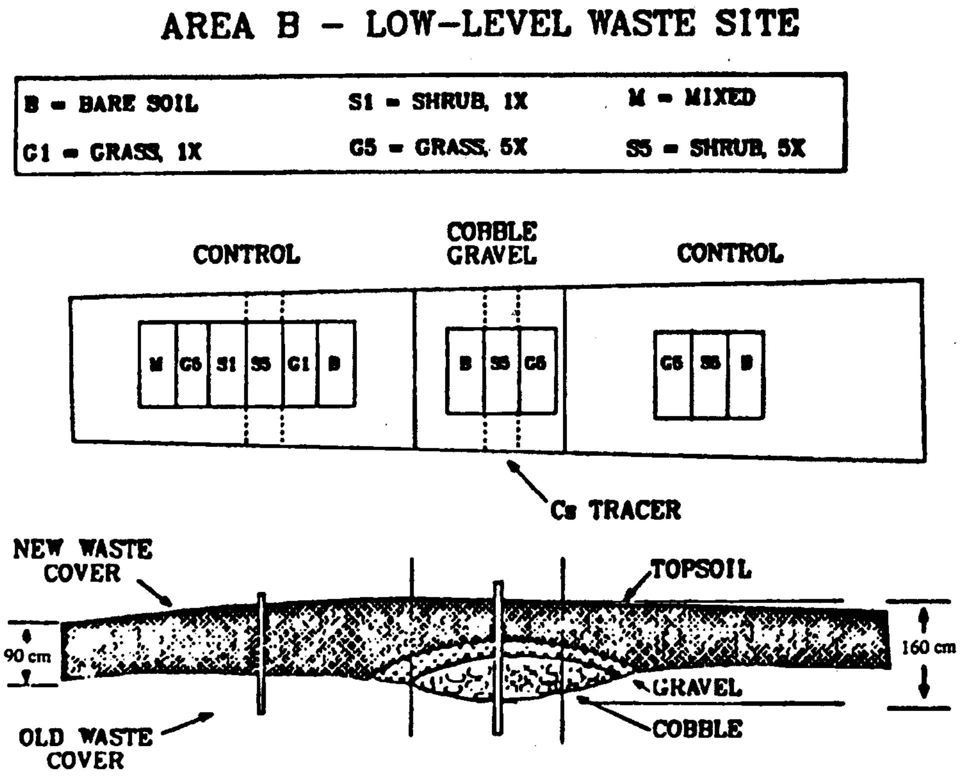

Fig. 5. Schematic of plot configurations for the Area B biointrusion barrier study initiated in 1985 as part of the EPA field program.

2. Results and Conclusions. The cesium concentrations in plant samples collected during the growing season from June 21 through November 8, 1983, (Hakonson 1986) all averaged less than the 1 ppm background level (recall that the plant cover during the 1983 growing season was dominated by wheat).

Plant samples collected from December 12, 1983, through July 3, 1984, showed essentially the same results. Only one sample from the intrusion barrier plot contained a slightly elevated cesium concentration, whereas none of the control plot samples contained above-background cesium levels. These results indicate that after two growing seasons, the plant roots still had not penetrated the cesium layer even in the control plot; therefore, the effectiveness of the intrusion barriers was not truly tested.

An additional set of 24 samples was collected at Area B on August 16, 1985, toward the end of the third growing season. These samples consisted of clover and deep-rooted perennial grasses, which had survived the disking the entire area had received in late 1984 when the cover treatments (Fig. 5) were applied in the EPA project. Sixteen per cent of the samples collected over the control plot contained elevated levels of cesium, whereas all of the samples from the intrusion-barrier plot contained background cesium concentrations. These results indicate that after almost three growing seasons, the plant roots finally started to penetrate the cesium layer in the control plot, and the rock barriers had successfully and effectively kept plant roots from penetrating the trench cap.

The most interesting feature of the soil moisture data from Area B is that snowmelt dominated over rainfall in recharging topsoil moisture and in contributing to percolation through both cap designs. For example, major increases in topsoil moisture during the winter (Figs. 6 and 7) were all correlated with periods of snow cover, whereas rainfall, which occurred primarily during the summer, produced no measurable increase in topsoil or backfill moisture. In fact, during the period from May 1 to November 1, 1983, when 18.5 cm of rain fell on Area B, topsoil volumetric moisture steadily declined from about 15-18% to 7-10%, depending on the cap design. The decrease in soil moisture, which we have previously shown to be due to evapotranspiration, not only completely used that part of the 18.5-cm rainfall that infiltrated into the topsoil (i.e., all that was not runoff), but also used significant amounts of soil water in storage before May 1, 1983. As previously mentioned, major increases in topsoil moisture were sometimes

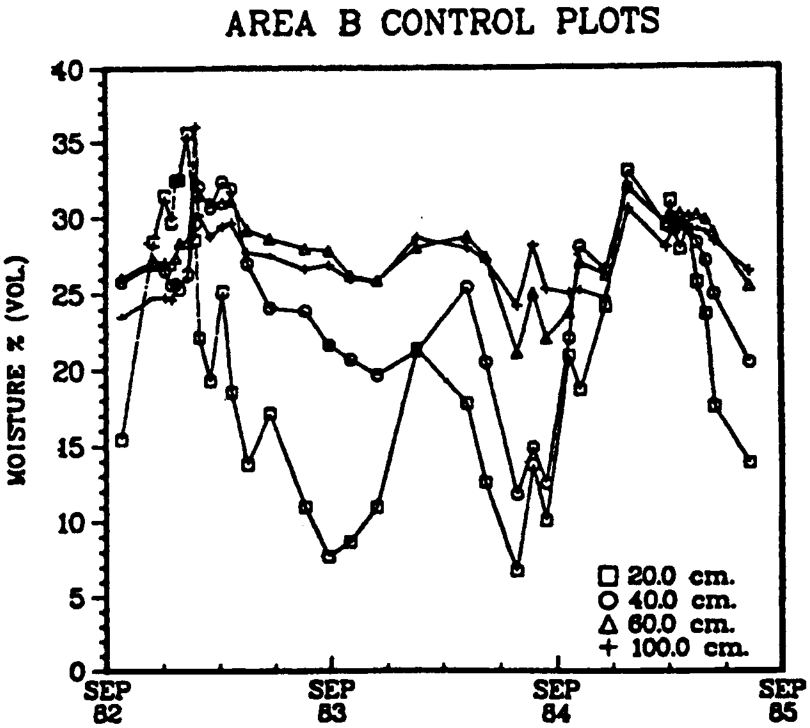

Fig. 6. Moisture contents in control plots.

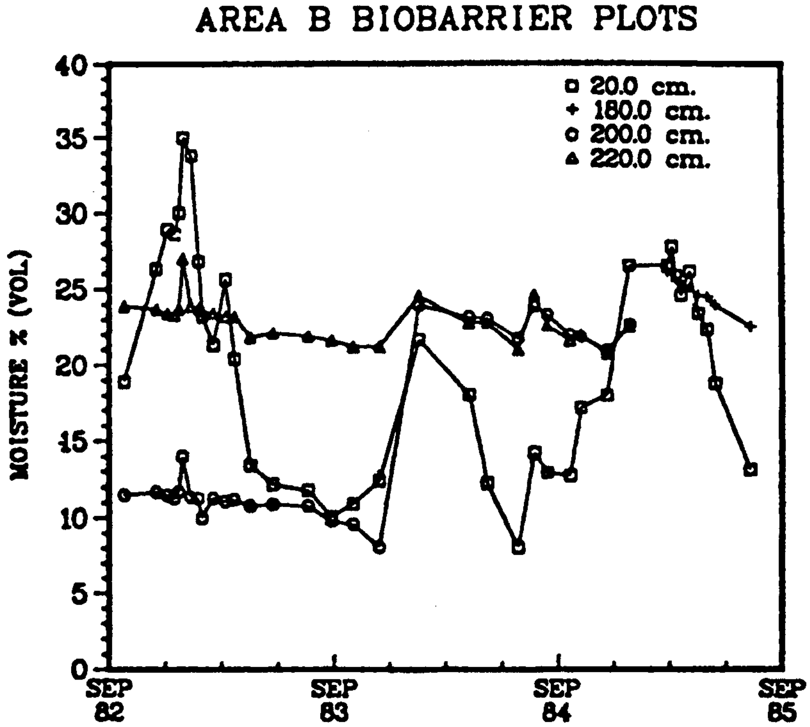

Fig. 7. Moisture contents in biobarrier plots.

followed by smaller moisture increases in the soil underlying the trench caps. This was especially apparent during the winter when a very sharp increase in backfill moisture occurred following the rapid rise in topsoil moisture due to snowmelt.

The data for the backfill underlying both cap designs (Fig. 6: 100 cm for control plots; and Fig. 7: 200 and 220 cm for biobarrier plots) also support the latter statement. Backfill moisture under the soil/tuff cap design increased after all but one of the several snow storms occurring during the study, a fact suggesting that percolation through the soil/tuff cap design had occurred. In contrast, backfill moisture under the rock barrier did not respond to most of these snowmelts. For example, snowmelt from storms occurring in December 1982, January 1983, February 1983, late March and April 1983, and several times during the winter of 1984, all resulted in observable changes in backfill moisture under the soil/tuff cap design. However, only two measurable increases in backfill moisture under the soil/rock barrier occurred during the same interval. The lack of percolation through the rock barrier, when it had occurred through the tuff barrier, should result in higher topsoil moisture over the rock barrier. As mentioned, the data in Figs. 6 and 7 indicated that topsoil moisture over the rock barrier was higher than that over the tuff barrier, lending some support to the potential use of the soil/rock cap design as a capillary barrier to percolation. Additional soil water data are listed for other sampling depths in Appendix A.

Thus, major results from the field-scale biointrusion barrier study at Area B can be summarized as follows:

- Both cap designs prevented plant root intrusion to the simulated waste underlying the caps.
- Snowmelt dominated rainfall in soil water recharge and led to all the

observed incidences of percolation into the backfill underlying the cap designs.

- The soil/rock barrier system appeared to function as a capillary barrier that resulted in a lower incidence of percolation and in lower soil moisture in the backfill under the cap than in the backfill under the soil/tuff cap design.
- Evapotranspiration effectively prevented percolation into the backfill during the summer months regardless of cap design.

III. EROSION CONTROL STUDY

A. Introduction

Our study investigated the water balance and erosional behavior of SLB trench caps for several cover conditions. Plots were established at the Los Alamos Experimental Engineered Test Facility (EETF) and were subjected to simulated rainfall to generate infiltration, runoff, and erosion. The effects of antecedent soil water content on erosion rates were evaluated, and the soil erodibility factor, K, and the cover management factor, C, of the USLE were estimated for our trench-cap configuration. In addition, using neutron moisture-gauge techniques, fluctuations in soil water content within and below the trench cap were monitored as a function of time and cover treatment.

B. Description of Field Experiment and Experimental Techniques

A 15- by 63-m simulated trench cap was constructed at the EETF in Los Alamos, New Mexico (DePoorter 1981) to closely match trench caps used for shallow land burial at Los Alamos (Warren 1980). The configuration of this trench cap consisted of a 15-cm layer of backfilled Hackroy series topsoil, which had been stockpiled at the site, underlaid by a 90-cm layer of crushed Bandelier tuff backfill that was classified as belonging to geologic mapping unit 3 (Rogers 1977). Both layers were installed with dominant downhill slopes of 7%.

The criteria for erosion plot selection were based on the requirements set forth during the original development of the USLE on rangelands (Wischmeier and Smith 1978) and on the constraints of the rainfall simulator (Simanton and Renard 1982). The eight experimental plots on the simulated trench cap were all 3.1 by 11 m, with the long axis parallel to the slope. The plot pairs on the trench cap were constructed on centers located 17 m apart and with metal plot borders as described previously (Simanton and Renard 1982).

The soil water content beneath the surface of the trench cap was monitored with a Troxler Model 3221-A moisture gauge. A total of three moisture-gauge access tubes (with a length of 1.67 m, outside diameter of 5.1 cm, and wall thickness of 1.7 mm) were emplaced in each erosion plot at distances of 1.8, 5.3, and 8.9 m from the upper end of each plot.

In 1982, three treatments were imposed on the eight plots on the trench cap (Nyhan et al. 1984). Two plots received an up- and downslope disking (cultivated treatment). Both standard tilled plots were comparable, except for lengthened slope, to the 22.1-m USLE unit plot of continuous tilled fallow (used to determine the USLE soil erodibility factor). Two additional plots were not tilled and also had no vegetative cover (bare soil treatment). To determine the influence of vegetation on soil erosion, four plots were seeded with barley (Hordeum vulgare L.) at a seeding rate of 22 g m^{-2} and received a simultaneous surface application of 20-10-5 (N-P-K) fertilizer at a rate of 13.5 g m^{-2}.

Four treatments were imposed on the eight erosion plots by the end of July 1983 (Nyhan and Lane 1986). As in 1982, two plots received a new up- and downslope disking (cultivated treatment). Both standard tilled plots (Fig. 8) were thus again comparable to the standard USLE plot used to determine the soil erodibility factor. A second year's data were collected on the two plots that were not tilled (Fig. 9) and had no vegetative cover (bare soil treatment). To determine the influence of partial gravel covers on soil erosion, two plots were prepared as for the bare soil treatment, and they then received a gravel (<13-mm diameter) cover (Fig. 10) at an application rate of 60 t/A (gravel cover treatment). The influence of partial gravel covers plus vegetation on soil erosion was determined on two plots (Fig. 11) that were first seeded with Western Wheatgrass (Agropyron smithii Rydb.) at a seeding rate of 13 g m^{-2} and received a simultaneous surface application of 18-24-6 (N-P-K) fertilizer at a rate of 13.5 g m^{-2}. Both plots then received the same gravel application rate as the gravel cover treatment (gravel and plant cover treatment).

Measurements of soil water content were collected in three locations in each of the eight erosion plots, as well as in two 3.1- by 11-m locations between the plot pairs that had received an 8-cm-thick cover of base course on top of the trench cap (base course treatment).

C. Subsurface Soil Water Monitoring Data and Discussion

Because the hydrologic processes at the surface of a SLB trench cap influence the management of the subsurface hydrologic processes, we decided to monitor the long-term changes in soil water content beneath the erosion plots. Basically, surface treatments that increase evaporation and evapotranspiration processes would seem to be favorable waste management alternatives. However, the actual choice of a means for increasing evaporation at a SLB site depends on the stage of the process one wishes to regulate, whether it be the first stage, in which the effect of meteorological conditions on the soil

Fig. 8. One of the plots that received standard cultivated treatment in 1983.

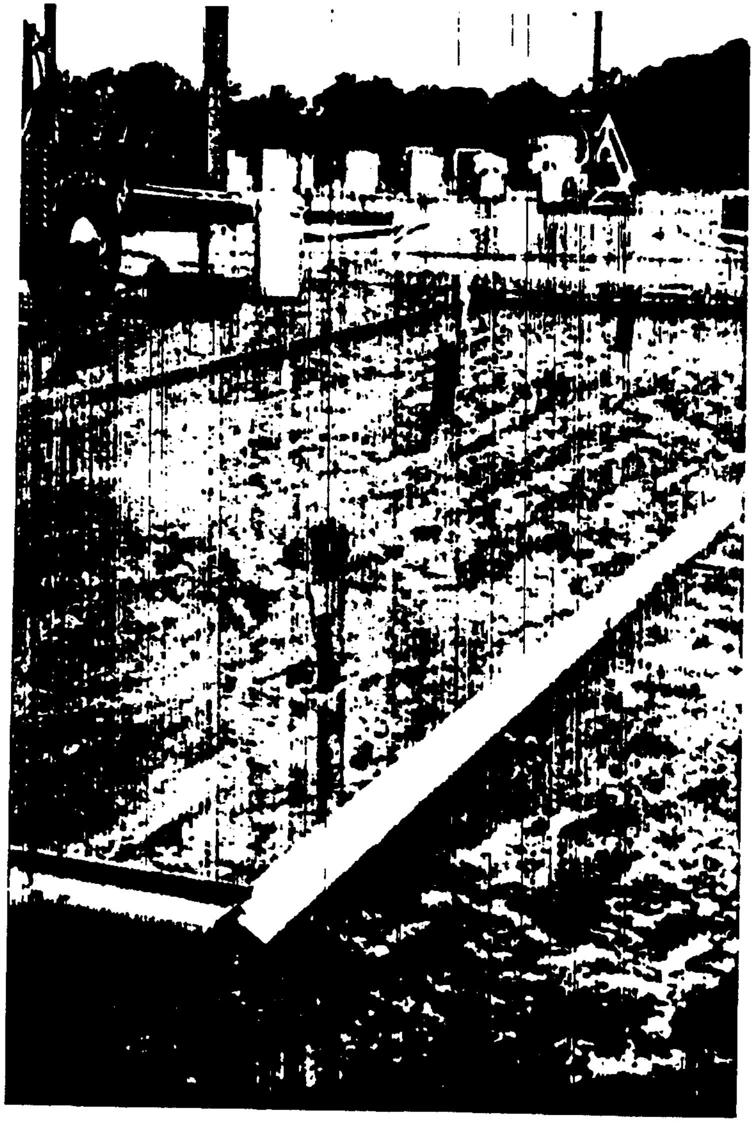

Fig. 9. Bare soil surface treatment in 1983.

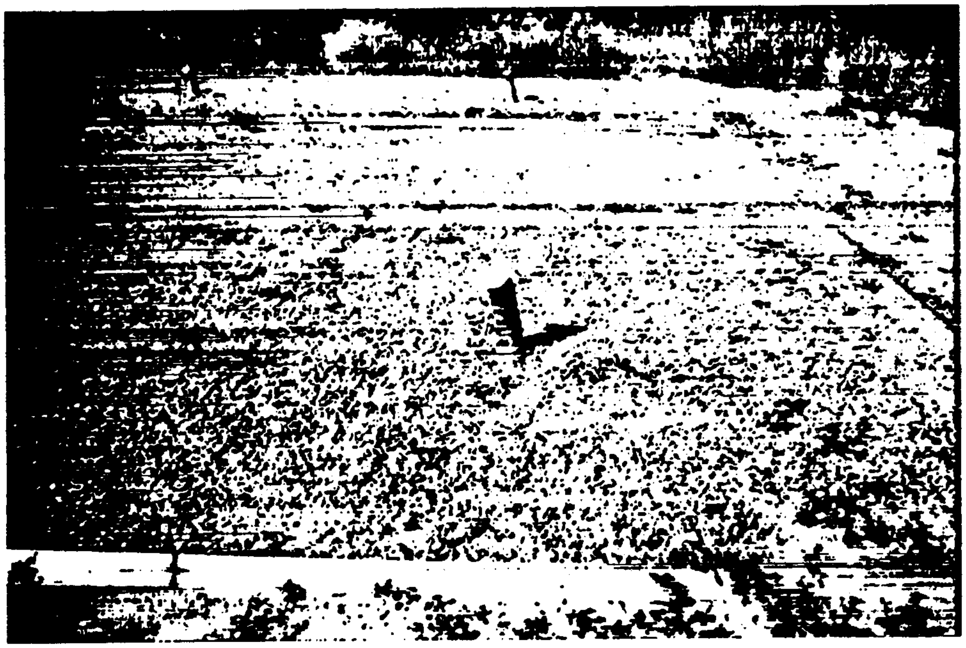

Fig. 10. Gravel cover treatment in 1983.

Fig. 11. Gravel plus wheatgrass cover treatment in 1983.

surface dominate the process, or the second stage, in which the rate of water supply to the trench cap surface, determined by the transmitting properties of the profile, becomes the rate-limiting factor (Hillel 1980). Methods designed to influence one of these two stages do not necessarily influence the other stage. In addition, an entirely different set of parameters influences the rates and amounts of water transpired by plant cover.

The soil water content within and below the simulated trench cap was monitored using neutron moisture-gauge techniques (see Appendix B). Soil water determinations were performed at sampling depths in the topsoil (15-cm depth), in the crushed tuff (30-, 46-, 61-, 76-, 91-, and 107-cm depths), and in the undisturbed tuff beneath the simulated trench cap (122-, 137-, and 152-cm depths).

Neutron moisture-gauge data (average values for three plot locations) collected from April 1982 through August 1985 are presented in Fig. 12 for erosion plot 6, which received the smooth bare soil treatment. These data confirm that, for the bare soil treatment, very little infiltration of water occurred during the 1982 rain simulator runs. Thus, in spite of the fact that approximately 110 mm of water was applied to each of these plots on June 22 and 23, very little increase in soil water was detected at any depth over that observed before the simulated rainfall on June 21. Interestingly enough, after the December 14 readings, large increases in soil moisture were found up to 122 cm below the surface of the trench cap as a result of melting snow. As the spring and summer of 1983 passed, the soil water levels in the top 76 cm of the trench cap decreased because of evaporation (no increases in soil water content were observed during the August 1983 simulator runs), and then again increased to greater than 30% water with the addition of precipitation to the trench cap in the 1984 late summer rainy season. The final soil water content

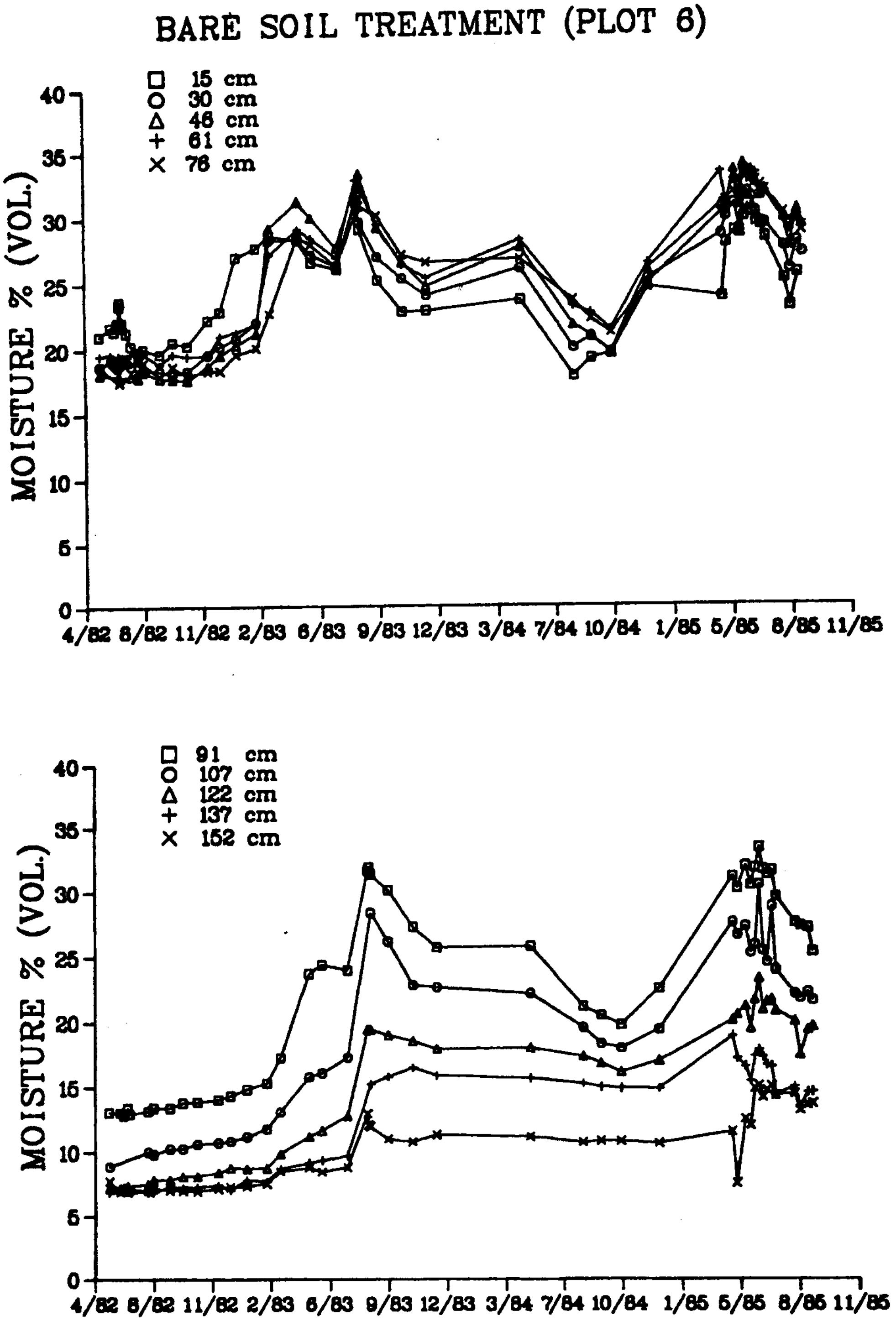

Fig. 12. Subsurface water content data for plot 6 with bare soil cover treatment.

at the bottom of the trench cap (91- to 107-cm depth) increased during this same period to 23-27%, and the undisturbed tuff beneath the trench cap attained water content values of 12-16% (Fig. 12).

The most outstanding observation to be made about the winter and spring of FY 1985 was that this period was 241% wetter than normal for Los Alamos! This resulted in gradually increasing soil moisture levels from October 1984 through May 1985 in not just plot 6 (Fig. 12) but in all of the erosion plots. This resulted in near-saturated conditions within the trench cap and even in substantial increases in water content beneath the trench cap. In fact, by May 1985, the average volumetric water content within the trench cap under all erosion plot treatments ranged from 32-33%: this represents a 45-46% increase in the water content of the trench cap since August 1984!

Tillage for seedbed preparation, weed control, or other purposes is the most common soil management process. We observed on our erosion plots with the cultivated treatment that the disking process resulted in an opening and loosening of the tilled layer and decreased the occurrence of the extensive cracks observed at the surface of the erosion plots with the bare soil treatment. The soil water values from an erosion plot that was tilled (both in June 1982 and July 1983) increased because of snowmelt and, generally similar trends were observed as for the bare soil plot. However, by July 1984, the soil water content at the bottom of the simulated trench cap and beneath the cap was considerably less for the cultivated plot than for the bare soil plot, i.e., water content values ranging from only 14-20% were observed at the bottom of the trench cap, and values ranging from only 8-10% were observed beneath the trench cap in July 1984 (Fig. 13). Thus, the overall effect of tillage on the trench cap seemed to be that of enhancing desiccation of the SLB-trench cap.

This desiccation effect of tillage might have been much less dramatic if a longer time interval for reconsolidation had occurred between tillages of the erosion plots. We observed very little difference in the appearance of the bare soil treatment and the tilled plots after the tilled plots were exposed to one snowmelt sequence in both 1983 and 1984. Thus, the net effect of tillage might have depended on the duration of this process and concurrent decreased soil cracking, as well as the documented effects of depth, degree, and frequency of tillage (Hillel 1980).

However, just like the bare soil treatment (Fig. 12), the cultivated treatment (Fig. 13) demonstrated extremely wet conditions within the winter and spring of 1985. The volumetric water content beneath the trench cap doubled during this time period!

Gravel mulching is an old method of reducing soil erosion and can be very effective in water conservation, both by enhancing infiltration and by suppressing evaporation, even in layers as thin as 5-10 mm (Hillel 1980). The initial evaporation rate under a mulch is usually reduced (Hillel 1980), so water would be saved in a SLB-trench cap with gravel cover if rains are frequent. However, for the extended dry periods found in some parts of the arid and semiarid portions of the western US, a gravel mulch may keep the soil surface more moist but may result in no net increase of water in the soil profile.

Our field studies involving gravel covers included three surface treatments on the simulated trench cap. An 8-cm-thick cover of base course was emplaced in 1982, and two erosion plots received a partial gravel cover treatment in 1983. Because we initially anticipated that these two surface treatments would result in larger amounts of water infiltrating the trench cap, we decided to add a third treatment (gravel plus wheatgrass), in which

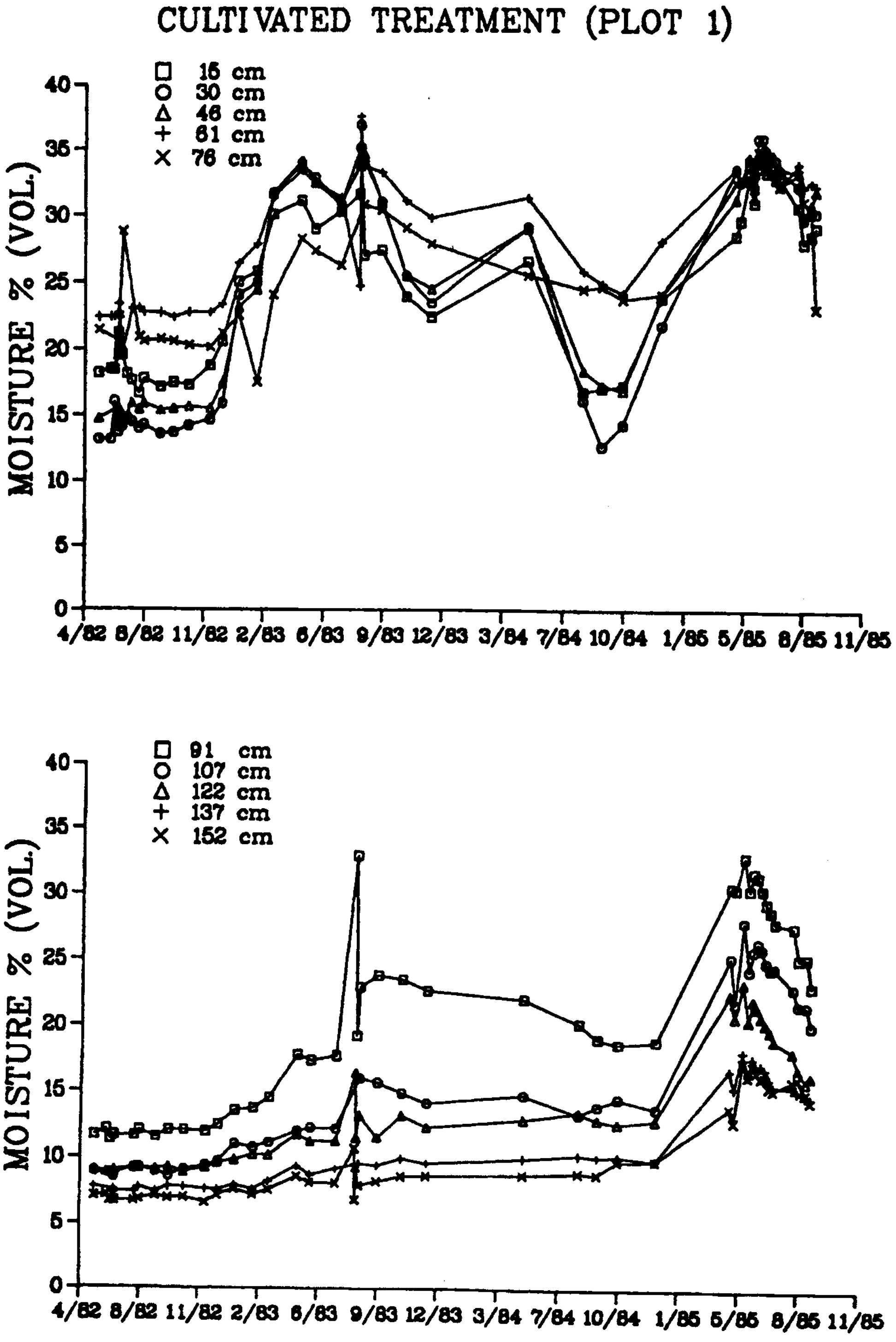

Fig. 13. Subsurface water content data for plot 1 with the cultivated cover treatment.

the wheatgrass might eventually transpire a portion of this additional water infiltrating the trench cap.

The base course treatment exhibited some interesting trends in soil water content (Fig. 14). Unlike any of the other surface treatments on the trench cap, the base course treatment resulted in a large amount of water infiltrating the upper layers of the trench cap during the 1982 and 1983 rain simulator runs, as well as when natural rain and snowmelt occurred (Fig. 14). After about two years, this resulted in volumetric water content values ranging from 27-33% in the top 76 cm of the trench cap, 17-21% at the bottom of the trench cap (91 and 107 cm), and from 11 to 12% beneath the trench cap. Thus, the overall effect of the base course was to immediately enhance the water content in the upper layers of the trench cap relative to the bare soil treatment. However, by July 1984, lower water content values were observed from 91-152 cm under the base course treatment than at similar depths in the erosion plots with the bare soil treatment. Although additional data analysis is currently underway, it already appears that this base course effect is probably caused by (1) considerable evaporation of most of the water added to the trench by a large number of small rainstorms upon interception of the rain water by the base course and (2) horizontal flow of water from larger rainstorms beneath the base course layer. The latter effect was further verified by what happened to the water content beneath the trench cap in the base course plot (Fig. 14) compared with the bare soil plot (Fig. 12) during the very wet period between October 1984 and May 1985.

The second surface treatment consisted of a 71-75% gravel cover of less than 13-mm-diameter gravel, which was applied to the erosion plots in 1983. The field data for this gravel treatment show a dramatic decrease in soil erosion but an immediate increase in water infiltrating the trench cap

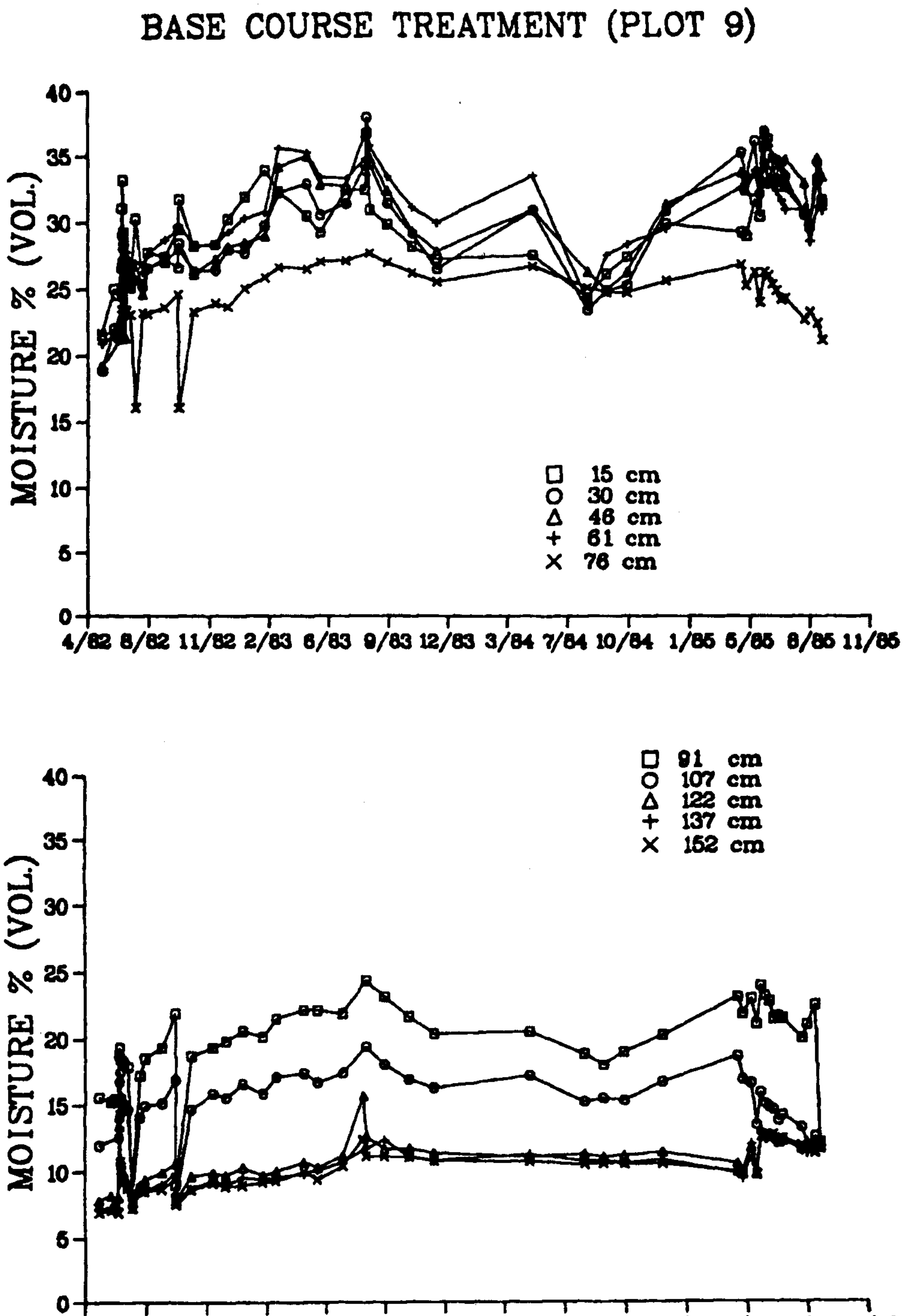

Fig. 14. Subsurface water content data for plot 9
with the base course cover treatment.

during the 1983 rain simulator runs, a condition that is apparent from the neutron moisture-gauge data collected for this treatment (Fig. 15). Just as was observed for the base course treatment, the soil water content under the gravel treatment after the 1983 simulator runs was near saturation in the upper layers (15- to 76-cm sampling depths) of the trench cap and only decreased to values of 26 to 30% by March 1984. A little less infiltration was observed with depth for the gravel treatment than for the base course treatment, i.e., lower values of soil water content were observed at the 91-cm depth for the gravel treatment than for the base course plots. Otherwise, the amounts of water that infiltrated the entire trench cap into the underlying, undisturbed tuff for these two treatments were both similar and less than the corresponding amounts of water that infiltrated the trench cap with the bare soil treatment. This trend continued even after and through the very wet period from the winter of 1984 through the spring of 1985.

The soil water data for the third gravel-related cover treatment, a cover of gravel plus wheatgrass, are presented in Fig. 16. No significant differences in the vertical distribution of water in the trench cap were observed between this surface treatment and the gravel cover treatment during the growing season. Similarly, no significant differences were observed during the 1982 growing season in the vertical distributions of water between the erosion plots with the bare soil treatment and the plots with the barley cover. Thus, the amount of water transpired by either the relatively young cover of wheatgrass in 1983 or the barley cover in 1982 was evidently small enough that this change could not be observed. However, in 1985 as in 1984, the gravel plus wheatgrass treatment exhibited decreased water content between May (33%) and August (26%) within the trench cap. This decrease occurred because of transpiration water losses caused by the enhanced wheatgrass cover that has developed on this plot (Fig. 17: compare with Fig. 11). It is also interesting to notice that a more long-term trend is starting to develop--the water content beneath the trench cap with the gravel plus wheatgrass is remaining less than that beneath the gravel cover.

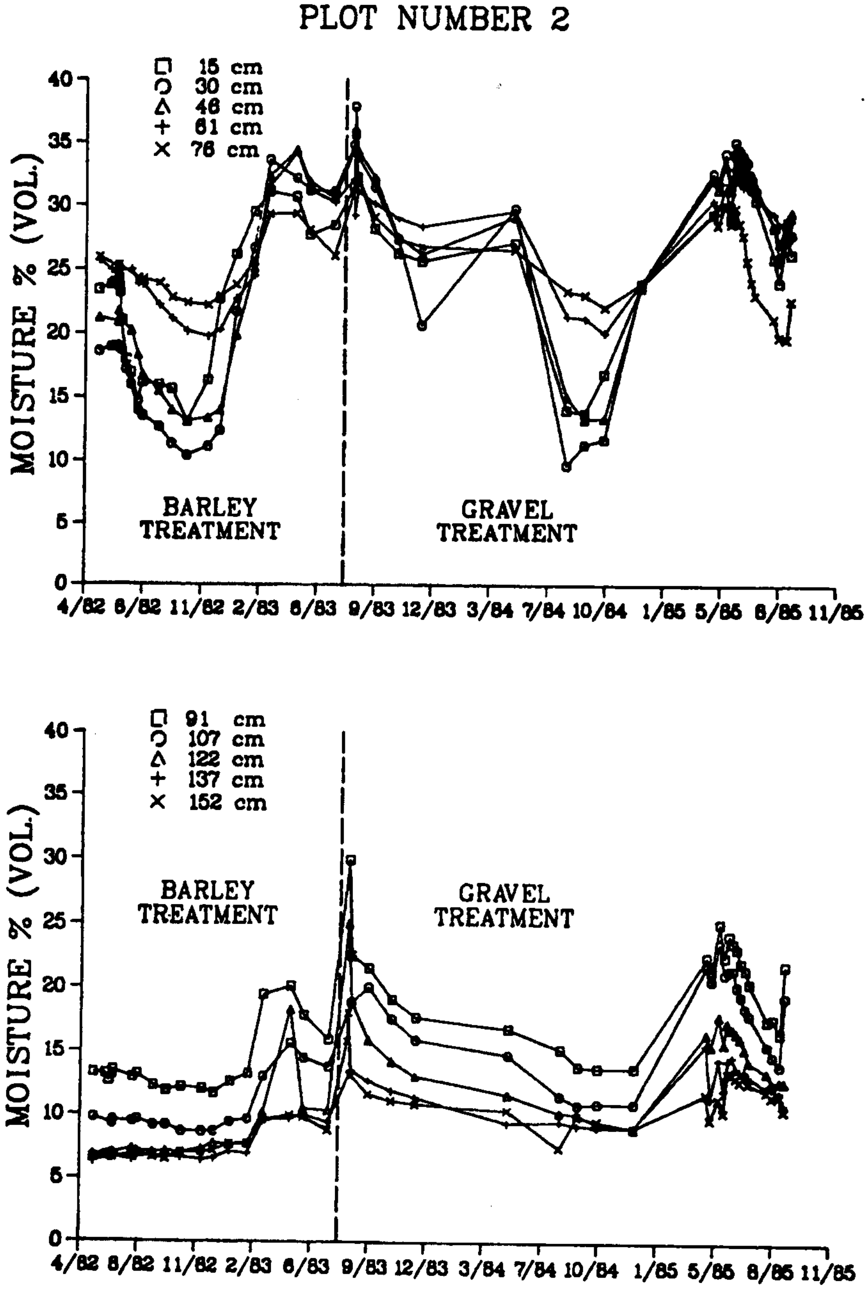

Fig. 15. Subsurface water content data for plot 2 with the gravel cover treatment.

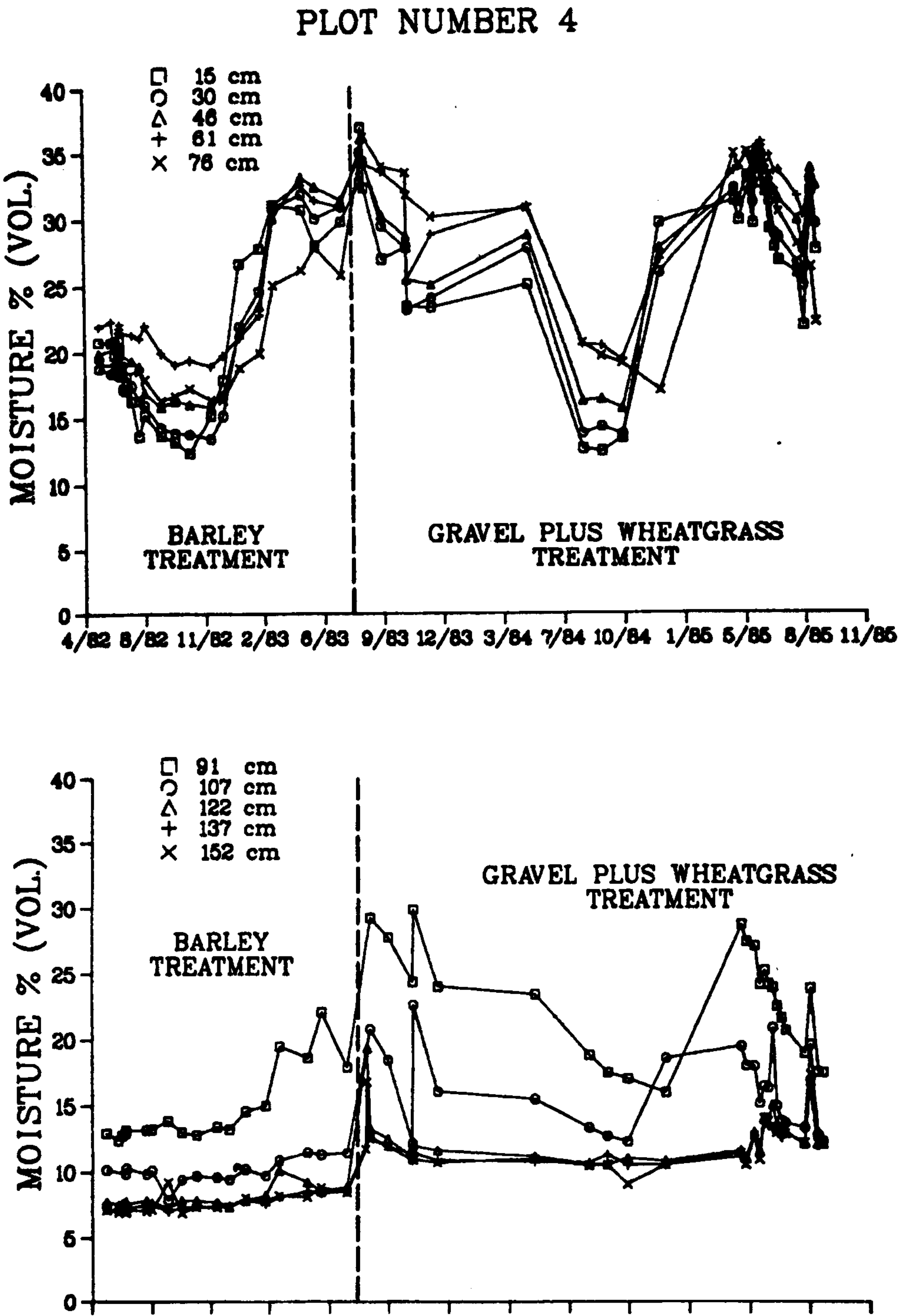

Fig. 16. Subsurface water content data for plot 4 with the gravel plus wheatgrass treatment.

Fig. 17. Gravel plus wheatgrass cover treatment in 1985.

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APPENDIX A

VOLUMETRIC WATER CONTENT DATA BASE FOR AREA B

DESCRIPTION OF VOLUMETRIC WATER CONTENT DATA BASE FOR AREA B

Eight access tubes were emplaced at Area B for the determination of volumetric water content using a neutron moisture gauge. These data were collected as a function of soil depth and of time.

Four access tubes were located on the study plot with the cobble-gravel treatment and four tubes were emplaced in the control plot, which did not contain a biointrusion barrer (see Fig. 2 in text). Proceeding from north to south, the access tubes on the biobarrier plot were numbered consecutively 601 through 604, with tube 601 located 9.2 m from the northern fence site boundary (DP Road is parallel to this fence) and with tube 604 located 11.2 m from the southern fence site boundary; the distances between access tubes 601 and 602, 602 and 603, 603 and 604 are 6.15 m, 6.20 m, and 6.10 m, respectively.

The access tubes on the control plot are numbered consecutively from 605 through 608, again proceeding from north to south. In relation to the biobarrier plot, access tube 605 is positioned 58.6 m approximately west of tube 601, and tube 608 is located 60.1 m approximately west of tube 604. The distances between tubes 605 and 606, 606 and 607, 607 and 608 are 6.3 m, 6.1 m, and 6.1 m, respectively.

In March 1985, access tubes 601 through 604 were renumbered 640 through 643, and tubes 605 through 608 were renumbered 652 through 655.

Sampling Date	Depth From Surface (cm)	Volumetric Moisture Content (%)
-----------------Biobarrier Plot Tube	Tube Number=601-----------------	
16FEB84	20	16.1
16FEB84	40	12.2
16FEB84	110	30.4
16FEB84	130	25.4
08MAY84	20	14.8
08MAY84	40	12.5
08MAY84	110	26.6
08MAY84	130	22.6
07JUN84	20	11.8
07JUN84	40	12.9
07JUN84	110	26.4
07JUN84	130	22.8
27JUL84	20	7.3
27JUL84	40	8.5
27JUL84	110	24.5
27JUL84	130	20.7
22AUG84	20	8.9
22AUG84	40	8.9
22AUG84	130	23.9
12SEP84	20	9.3
12SEP84	40	9.6
12SEP84	110	26.5
12SEP84	130	22.0
19OCT84	20	10.1
19OCT84	40	10.2
19OCT84	110	24.9
19OCT84	130	21.6
06NOV84	20	14.3
06NOV84	40	14.1
06NOV84	110	24.3
06NOV84	130	21.8
18DEC84	20	14.2
18DEC84	40	14.2
18DEC84	110	23.4
18DEC84	130	19.7
25JAN85	20	24.9
25JAN85	40	20.7
25JAN85	110	25.6
25JAN85	130	21.6

Sampling Date	Depth From Surface (cm)	Volumetric Moisture Content (%)
-----------------Biobarrier Plot Tube	Tube Number=602-----------------	
16FEB84	20	23.7
16FEB84	40	17.4
16FEB84	110	14.2
16FEB84	130	13.8
08MAY84	20	18.6
08MAY84	40	15.3
08MAY84	110	11.8
08MAY84	130	11.2
07JUN84	20	11.9
07JUN84	40	15.3
07JUN84	110	12.2
07JUN84	130	11.4
27JUL84	20	10.3
27JUL84	40	10.1
27JUL84	100	4.1
27JUL84	110	11.9
27JUL84	130	10.8
22AUG84	20	15.7
22AUG84	40	13.6
22AUG84	110	13.1
22AUG84	130	12.2
12SEP84	20	14.4
12SEP84	40	13.8
12SEP84	110	12.0
12SEP84	130	11.0
19OCT84	20	14.3
19OCT84	40	13.3
19OCT84	110	11.1
19OCT84	130	10.8
06NOV84	20	17.6
06NOV84	40	18.2
06NOV84	110	11.3
06NOV84	130	11.1
18DEC84	20	17.4
18DEC84	40	19.0
18DEC84	110	11.3
18DEC84	130	10.4
25JAN85	20	26.0
25JAN85	40	25.0
25JAN85	110	12.1
25JAN85	130	11.2