ENHANCED VEGETATION COVERS FOR RECLAMATION OF CONTAMINATED SITES[1]

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Extended Abstract. There has been renewed interest in vegetated soil caps as an alternative for landfill closures because modeling studies and limited experimental data suggest that they can be effective in controlling site water balance, particularly in arid and semiarid locations. Additionally vegetated soil caps, sometimes called evapotranspiration caps, can reduce construction and maintenance costs compared to more complex, multi-layered cover designs.

This paper reports on a 4 year field study of vegetated soil caps to evaluate the influence of various combinations of vegetation species and surface gravel mulch on runoff, erosion, and soil moisture status. In mid-1987, 8 3.1 x 10.9m plots were constructed with a 4% surface slope to include two replicates of four randomly assigned treatments as follows: 1) a grass cover (designated as G); 2) a grass cover with a gravel mulch (GG); 3) a grass and ponderosa pine tree cover (GP); and 4) a grass, ponderosa pine tree and gravel (GGP) mulch cover. The gravel mulch consisted of a ~2cm thick layer of ~2 cm diameter crushed rock broadcast onto the plot surface to create about a 70% ground cover. Grasses were seeded into each plot on August 3, 1987 and fertilized with NPK at a rate of 400 kg ha^{-1}. In four of the plots, eight ponderosa pine trees *(Pinus ponderosa*), about 1.2 m in height, were also planted on October 27, 1987. The trees were evenly spaced in two rows of 4 trees per row along the 10.1 m plot axis. Each row was located 75 cm in from the plot border.

Data collection began 11/4/87 and ended on 9/11/91. Due to the lack of under-drains, it was not possible to construct a complete water balance from the monitoring data because the percolation and evapotranspiration terms in the water balance equation could not be estimated separately. Runoff and sediment yield were measured on only one replicate of each cover treatment using a collecting trough set level with the soil surface on the downslope end of each plot. The trough emptied into 205L steel drums set underneath the trough drain spout. Total volume of runoff and mass of sediment was recorded after each runoff event during the 4 year period.

Additional Key Words: Evapotranspiration covers, soil covers, soil cover performance

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Volumetric water content was measured with time on the 8 plots using a Model 503 Campbell-Pacific neutron moisture gauge**.** The probe was lowered into each of three aluminum access tubes set vertical at evenly spaced distances along the 10.9m axis of each plot. Moisture data were acquired at depths of 20, 60, 100, and 120 cm in each access tube. The moisture gage had been previously calibrated for crushed tuff and Hackroy sandy loam soil. A Universal Rain Gauge (Belfort Instrument Co.), with a heater and windscreen, was used to measure both rain and snow sources of precipitation.

During July, 1992, after the soil moisture measurements had ceased, canopy and ground cover, Leaf Area Index (LAI), and biomass of the vegetation was measured on each plot. A point frame was positioned across the plot at 10 equi-distant locations down the 10.9 m axis. Thirty one pin drops were recorded at 10 cm intervals at each location for a total of 310 measurements per plot. The first pin contact with above ground vegetation was recorded as canopy cover. Pin contact with the ground surface was recorded as litter, rock, or bare ground. LAI and plant biomass were measured on 5, $0.1m^2$ (20 x 50cm) subplots that were located along the center line in each plot. All of the herbaceous vegetation on the subplots was clipped, chilled to prevent leaf curling, and fed through a LICOR leaf area meter to obtain an estimate of LAI. The vegetation was then oven dried to obtain biomass estimates. Dimensional measurements on the Ponderosa Pine were used to estimate tree volume. Volume was converted to biomass using the relationship between tree mass (TM) in kg and bole diameter (BM) in cm (i.e., $TM= (0.3 \times BD)^2$.

A two factor, two level design (2 by 2) with replicates was used to study the effects of vegetation cover and gravel mulch on runoff, erosion, and soil moisture status from simulated landfill caps. The four treatment combinations were randomly assigned to the 8 plots. Because runoff, erosion, and soil moisture were assessed repeatedly over the study period, a repeated measures multivariate analysis of variance (MANOVAR) was used (SAS PROC GLM) to analyze the data and to correct for autocorrelation of error terms over time. Independent variables (i.e. factors) were mulch treatment (with and without) and vegetation cover (grass versus grass and pine trees) while dependent variables were runoff, sediment yield, and soil moisture by depth. An alpha of 0.05 was used to detect significance. Two way ANOVA procedures were used to test vegetation cover, biomass, and LAI for treatment differences.

The results of the study shows that the addition of complexity to the cover by supplementing a grass cover with evergreen trees and/or a gravel mulch reduced runoff, erosion and the potential for deep percolation over that measured in non-mulched grass treatments. The mechanisms for these decreases include a decoupling of erosion from runoff by protecting the soil surface from impacting raindrops and by enhanced removal of soil moisture through increase biomass production and evapotranspiration.

Runoff decreased by a factor of 10 (Table 1) as the amount of vegetation cover, biomass, and rock cover increased by factors of 1.5, 10, and 45, respectively. The most runoff (averaging 2.5% of the total precipitation) came from the G treatment which had the lowest cover, biomass, and rock cover and the most bare soil. The GGP treatment had a factor of 10 lower runoff (averaging 0.2% of precipitation) than the G treatment while runoff from the GG and GP treatments were very similar at about 30-50% of the G treatment. A total of 18 runoff events occurred during the study on all of the treatments except GGP where only 13 events were recorded.

The patterns in sediment yield (Table 1) were similar to runoff in that amounts decreased as complexity of the cover increased. Total sediment yield was highest from the G plot (averaging 28 g/m^2) followed by the GG and GP treatments at 18 g/m^2 and 8.3 g/m^2, respectively (Table 2). Erosion from the GGP treatment was 1.4 g/m^2 or only 5% of that from the G treatment. A total of 13 of the 18 runoff events (or 72%) from the G treatment produced measurable sediment while the GG, GP, and GGP produced sediment from 12 of 18 (67%), 12 of 18 (67%), and 6 of 13 (46%) of the runoff events, respectively.

The importance of late Winter and Spring sources of precipitation) in soil moisture recharge was attributed primarily to snowmelt. Snow sources of precipitation were recorded in real time during individual snowstorm events with the heated precipitation gauge used in this study. However, moisture associated with snow did not immediately contribute to soil moisture recharge because of frozen soil and cold air temperatures. This led to the input of a pulse in soil moisture over a relatively short period during Spring snowmelt contributing to large increases in soil moisture in the upper depth profiles.

Table 1. Total runoff and erosion for cover plots from 11/4/87 – 9/11/91.

	Grass	**Grass-gravel**	**Grass-Pine**	**Grass-Pine-Gravel**
Runoff				
liters	1470	485	642	141
mm	43	14	19	4
# runoff events	18	18	18	13
Erosion				
grams	947	599	285	47
g/m^2	28	18	8.3	1.4
t/ac	0.13	0.08	0.04	0.006
# erosion events	13	12	12	6

Soil moisture response to precipitation inputs in the Spring were pronounced in the upper portion of each soil profile and dampened at the lower depths as shown by the soil moisture data at the 110cm depth in Fig. 1. This input of soil moisture occurred on all cover treatments during a period when evapotranspiration was low due to the senescence of the perennial grasses that were growing on the plots.

Over the study period, lower soil moisture levels were observed in treatments incorporating gravel mulch than those measured in the non-mulched G treatments (Fig. 1). While the effect of the gravel mulch treatments was to increase infiltration (and likely decrease evaporation from the soil surface), the higher available soil moisture resulted in increased plant biomass production and indirectly to increased transpiration. The net result was a factor of about 30 and 100% lower soil moisture in the mulched GG and GGP treatments, respectively, over that measured in the G treatments. Biomass data support this interpretation in that the grass biomass was about 30% and120% higher on GG and GGP treatments respectively. Previous studies by the U.S. Department of Agriculture have shown that gravel mulches increase plant available soil moisture, herbage yields, and decrease soil erosion.

The patterns in soil moisture with depth in the soil profile indicated that the grass and trees in the plots were exploiting moisture at different depths. For example, soil moisture in the GGP versus GG and GP versus G treatments before the end of 1989 tracked closely at the 20cm and 60 cm depths but began to differ at the 80 cm depth. At the 110 cm depth (Fig. 1), soil moisture in the GGP and GP treatments averaged about 60% less than the treatments without trees. We interpret this to mean that the grass cover primarily exploited soil moisture in the upper portions of the cover profile while the trees used moisture from the lower depths.

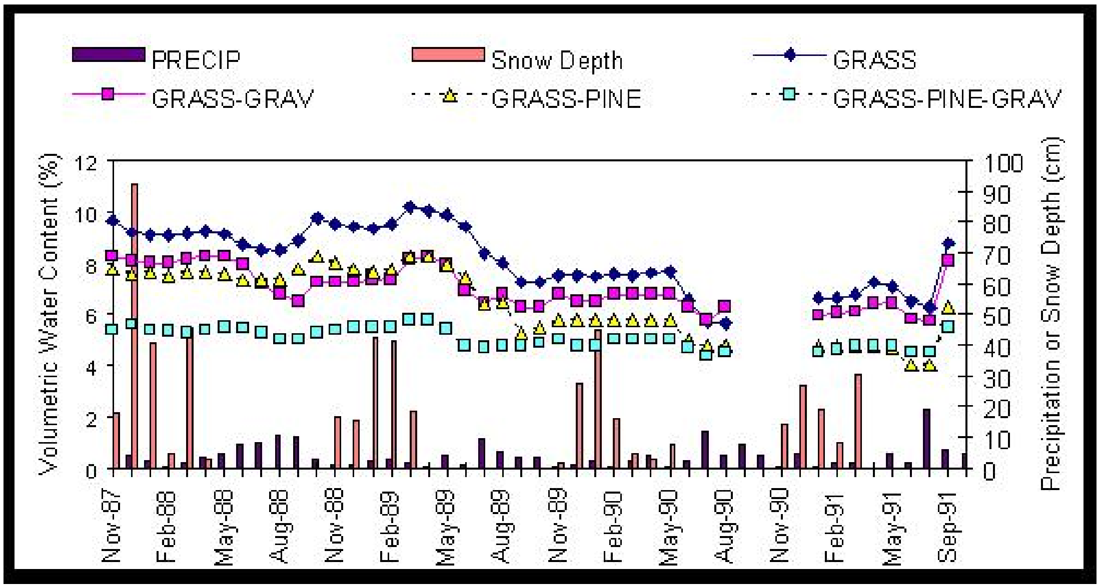

Figure 1. Soil moisture status at the 110 cm depth in cover plot treatments at Los Alamos, NM.

Further evidence for the species differences in allocation of moisture in the soil profile is shown by the soil moisture response in the GGP treatments after the pine trees had died 1 year after the study began. By the end of the study in 1991, soil moisture at the 60cm and 80cm depth in the GGP treatments closely tracked those measured in the GG treatments. However, soil moisture in the GGP treatment remained at the wilting point for Bandelier Tuff of about 5%vol/vol throughout the entire study period (Fig. 1). Although it took 2.5 years, the pine trees in the GP treatment also reduced soil moisture at the 110 cm depth to wilting point where it remained for the duration of the study (Fig. 1).

The enhanced effectiveness of the GGP versus the other treatments in controlling soil moisture led to moisture stress that killed the pine tree component of the GGP cover design. This leads to the conclusion that ET covers using multiple species must carefully consider the species mixed used as the least drought resistant species in the vegetation cover may not survive dry periods. Consequently, ET covers that involve complex vegetation mixtures to maximize soil water use must be closely tailored to the local climate and particularly the probable extremes in moisture input and its effect on soil moisture status. In the arid west, drought tolerance of the vegetation community would be an essential design specification in order to increase the probability of long term stability of the vegetation cover. At Los Alamos this may involve substituting more drought tolerant pinyon pine or juniper for ponderosa pine.

The feedback between the type of vegetation cover and soil moisture is important for developing strategies for managing water in landfills where production of leachate is a regulatory issue. We have shown that the type of vegetation cover with and without gravel mulch can influence soil moisture status and the potential for deep percolation. We have also shown that gravel mulches not only control erosion from the cover also significantly reduce the potential for percolation due to the feedback between soil moisture and plant production. Complex plant covers that exploit soil moisture throughout the cover profile and over the longest period during the growing season, should result in lower soil moisture levels and decreased potential for percolation of soil moisture into underlying waste.