Using Vetiver Technology to Reduce Watershed Sedimentation for Water Quality Improvement Downstream in Southern Guam. Mohammad H. Golabi*, Dwayne Minton, and Clancy Iyekar. University of Guam and US-Forestry Division in the Pacific. mgolabi@guam.uog.edu.

Abstract

Sedimentation as a result of runoff is the principal human-caused threat to the environment in general and to water quality in particular on the Pacific island of Guam. Runoff takes the form of flash floods of high velocity but short duration. The rapid flow is attributed to low soil infiltration, a high proportion of rain converted to overland flow, and scanty or absent vegetation cover due to wildfires. In the areas where protective vegetation cover is lowest, the soil is subjected to high shearing forces by such overland flow.

Erosion damage is a serious problem to the environmental ecosystem of the island. Sediment lost to erosion clogs rivers, lakes, and waterways. Erosion and sedimentation loss are also a major source of water-quality problems in Guam. Sedimentation provides a vehicle for the transport of agricultural chemical residues into canals, streams, rivers, and eventually near-shore ecosystems, where it damages coral reefs.

The objective of the project reported here was to assess the sediment-loading rate to the near-shore coral reef originating from the upland watershed. The effectiveness of Vetiver grass as a sediment trap and its effect on quality of the water leaving the upland watershed were evaluated. Four plots (each 72× 5.5 ft.) were laid out on a uniformly sloped (12%) watershed for estimation of sedimentation rates. Each plot was equipped with an 8-inch-high flume wall that separated its surface from those of the other plots and their surroundings. Flumes were equipped with cone-shaped weirs that directed the runoff and sediments into a collecting tank beneath the weirs.

Keywords: Vetiver, Sediment loading rate, Water quality, Coral reef

INTRODUCTION

Guam is the southernmost island of the Mariana’s chain in the western Pacific. It is 2600 km east of Manila, Philippines, and about the same distance south of Tokyo. The inland is about 48 km long and 6 to 9 km wide. The southern part of Guam is mostly volcanic, mountainous, and deeply bisected by many rivers. The northern part is coralline, relatively flat, and devoid of rivers (R. Muniappan, G. Wiecko, and P. Singh, pers. comm.).

Volcanic and mountainous southern Guam is prone to soil erosion by water. Because of severe erosion of the soil in upstream areas during heavy rains; muddy fresh water is commonly observed mixing with the seawater at the river mouth and damaging the coral reefs. Guam receives about 2200 mm of rain per year, and over 75% of it falls from June through November (Muniappan et al., pers. comm.). Wildfires are frequent during the dry season (December through May) and expose bare soil to sunlight as well as rainfall, leading to severe erosion of these areas (Khosrowpanah, 1991).

Runoff on Guam takes the form of flash floods of high velocity but short duration (Duenas et al., 1986, Young, 1988). The rapid flow is attributed to low soil infiltration, the high proportion of rain converted to overland flow, and scanty or absent vegetation cover due to wildfires. In the areas where protective vegetation cover is lowest and the soil quality is poor (organic-matter content is low) the soil is vulnerable to the high shearing forces of such overland flow.

Through soil removal or sediment deposition and nutrient removal, erosion alters the inherent physical and chemical properties of soils (Lal, 1987, Nearing et al., 1994, Lal et al., 1997). This alteration may result in degradation, in turn affecting the environment as well as the processes that regulate the productivity and sustainability of the ecosystem.

Erosion damage is a serious problem to environmental ecosystem of the island, especially in the southern regions. Sediment lost to erosion clogs rivers, lakes, and waterways. It reduces the water-storage capacity of reservoirs and canals and increases flooding. In addition, erosion and sedimentation loss are a major source of water-quality problems on Guam, and sedimentation damages the island's near-shore coral-reef ecosystem.

Sedimentation from terrestrial runoff is the principal human-caused threat to the water resources and the near-shore coral-reef ecosystems of Guam and other Pacific islands. The nonpoint source pollution (NPS) that results sedimentation is one of the most significant threats to near-shore water quality as well as coral reef ecosystems on Guam (Richmond, 1993).

The impact of sediment-laden runoff on fringing coral reefs has been the subject of intensive research, yet knowledge of the effects remains qualitative (Wolanski et.al., 2003). Because sediment can literally bury coral, sedimentation is a major cause of mortality in the initial life stages of hard corals (Wolanski et.al., 2003). It can effectively reduce recruitment rates and, at higher concentrations, affects a range of life-history parameters in juvenile and adult corals (Richmond, 1994). Over the last few decades, increases in population and changes in land use have led to significant increases in surface runoff and associated decline in water quality, which has threatened the well being of coral reefs (Richmond, 1994, 1995, National Resource Conservation Services, 1996).

Control of soil erosion resulting from intensive rainfall is an important and challenging task for the soil scientists, conservationists, and foresters in these areas. Their task is to select, employ, and evaluate vegetative systems that can form dense hedges on the contour, have strong and dense leaves and stems, and are resistant to wildfire, drought, flood, insects, and disease. Among the plants considered for this purpose is Vetiver grass (V*etiveria zizanioides*). Vetiver grass is a dense, bunch-type grass with stiff stems and an extremely strong root system (up to 15 ft deep) that grows to a height of several feet. It does not spread by stolons or rhizomes and does not produce fertile seeds, so it poses no danger of becoming a weed (G. Wiecko, pers. comm.). The crown of Vetiver grass is located a few inches below the soil surface, making it resistant to fire and grazing wildlife (Wiecko, pers. comm.), and the species has not been reported to host diseases, insects and other pests (Wiecko, pers. comm.). It grows on all continents in tropical and subtropical regions, tolerates a wide range of soil pH and low fertility, and does well even on very shallow, rocky soils. It is both a xerophyte and a hydrophyte, and once established it can withstand drought, flood, and long periods of water logging (Wiecko, pers. comm.). It does not compete with other plants, and the nitrogen-fixing mycorhiza associated with its roots permit green growth throughout the year. When individual seedlings are planted 4–5 inches apart, they form a dense 15- to 20-inch-wide permanent hedge capable of trapping the sediment in runoff and stopping soil erosion in situ.

We evaluated the effectiveness of Vetiver grass in mitigating soil erosion from a watershed in southern Guam, as well as the effects of different soil-surface conditions on its performance

OBJECTIVES

The objectives of our study were to quantify sediment loss from the study plots to estimate the sedimentation from the entire watershed under investigation, to evaluate the effect of different soil-surface conditions on erosion and sediment loss and provide recommendations for the restoration of these lands, and to evaluate the effectiveness of Vetiver for trapping sediments to mitigate sediment transport of a typical watershed in southern Guam.

MATERIALS AND METHODS

In May 2003, four plots, each 72 ft × 5.5 ft, were laid out on a uniformly (12%) sloped watershed. Each plot was equipped with an 8-inch-high flume wall that separated it from other plots and the surrounding slope. The flumes ended in cone-shaped weirs, in turn attached to end troughs that extended 8 inches into collecting tanks beneath the weirs, where runoff and sediments were collected. Sediment samplers were suspended in the collecting tanks to measure sediment discharged from the flumes. Each tank's storage capacity (450 gallons) was sufficient to contain 100% runoff from a 10-year, 24-hour storm event.

Analyses conducted at the beginning of the experiment (in February of 2004) revealed that the soil under study contained 54.4% clay, 20.7% silt, and 24.9 % sand, so it fit the definition of a clay soil (Table 1); organic-matter content averaged 3.9% (Table 1).

The native vegetation on the study plots was the savanna, typical of southern Guam. This savanna is for the most part a xeric ecosystem that is dominated by grasses, low shrubs, and scattered small trees, but wetland and limestone species are also found there (Raulerson, 1979). It comprises four subtypes (Stone, 1970): (a) the *Miscanthus* community, sometimes pure stands of Swordgrass (*M.*

floridulus, swordgrass; *).* (b) The *Dimeria chloridiformis* community; (c) the erosion-scar community, including pioneer species such as *Dicranopteris linearis*, *Myrtella bennigseniana, Wikstromia elliptica, Decaspermum fruticosum, Blechnum orientale, Xylosma nelsonii, Cheilanthes tenuifolia, Alyxia torresiana* (very local), *Melastoma malabathricum* var*. mariannum, Geniostoma micranthum, Pandanus tectorius* forma *fragrans, Hedyotis megalantha, Timonius nitidus, Utricularia* spp., *Schizachyrium,* and *Casuarina equisetifolia;* (d) *Phragmites karka* valleys.

Sedges (Cyperaceae, in particular *Fimbristylis tristachya*) and grasses (Poaceae, *Dichanthium bladhii, Sporobolus fertilis,* and others) dominated the study site, but a few forbs species were also present. Although the grass *Dimeria chloridiformis* was not abundant at the study site but is believed (Fosberg, as cited by Raulerson, 1979) to have dominated the mixed community that was typical of the original savanna on Guam.

Four treatments were included in the experiments: 1) Natural vegetation (the vegetation already present on the site was left undisturbed), 2) Vetiver technology (Vetiver was planted, in December 2003, as it would be for restoration), 3) Controlled burn (the vegetation on the plots was burned before the experiment began), 4) No-cover (the soil was tilled and left exposed).

These four treatments represent a wide range of conditions that are present in a typical watershed of southern Guam. The natural-vegetation condition serves as the control. The " Vetiver-technology is the treatment of interest. The Vetiver grass was planted in hedgerows 13 ft apart, and sunnhemp was planted between the hedgerows as a green manure intended to provide the initial nitrogen requirement for the grass, before its mycorhiza became established. The controlled-burn treatment was intended to reveal the effect of new vegetation growth on soil erosion and sedimentation and also represents the erosion from land denuded of vegetation by intentionally set savanna wildfires on southern Guam. For the bare-surface treatment, the plot was tilled, and the soil surface was left without cover and exposed to raindrop impact at all times, to represent the degraded bare soils of southern Guam, known as badlands.

The catchment's tanks were placed beneath the collector troughs to collect the runoff from each plot and runoff is measured before tanks are drained for the subsequent events. In addition to the samples from the sediment samplers, sub-samples from the runoff water in the tank were taken for turbidity analysis and sediment quantification after stirring the runoff water in the tanks during each sampling event.

Sampling was conducted twice a week during the wet season (July–December) and once a week during the dry season (January -June). Sampling began in early February of 2004. At each sampling event, the total volume of runoff from each plot was determined. In addition to the samples from the sediment samplers, sub samples were collected from each tank for turbidity analysis and sediment quantification. The tanks were then drained and emptied of water to await the subsequent sampling event.

Samples were brought to the lab and allowed to sit for 72 hours. When the sediments had settled, the extra water was drained off, and the samples were transferred into beakers and dried at 75°C for 48 hours. The weights of sediment remaining represented the amount of sediment eroded from the various plots. Turbidities were measured from sub-samples with a Hatch 2100 turbidity meter.

RESULTS

As shown in Figure 1, during the dry season (January–June) almost all the treatments behaved similarly, and the amount of sedimentation was minimal. The small amount of sediment eroded from the Vetiver-technology plot resulted mainly from the tilling before the grass was planted; the Vetiver did not become fully established until late April 2004. In general, not much sediment was produced from any of the treatment plots from February 2004 to June 2004, mainly due to low rainfall through out this dry season. During the rainy season, however, the Vetiver-technology plot showed much less erosion than the others—less than one-third that from the natural-vegetation plot and less than 1% of that from the bare-surface plot (Table 2). Soil erosion, and the differential between the Vetiver-technology plots and the bare-surface plots, was greatest after major storm events (Fig. 1). The same trend is visible in Figure 2; the amount of sedimentation was the lowest in runoff water from the Vetiver-technology plots and highest in the "bare-surface plots. Although the average rainfall was about the same during the months of June and August, the sedimentation from the bare-surface plot was considerably higher in August because of the higher intensity of a major storm event that occurred in this month. Again it was shown (Fig. 1) that the “Vetiver grass” treatment was the most effective in sediment trapping as an erosion control during a major storm event.

The Vetiver-technology plots also produced the lowest turbidity measurements (Fig. 3). Figure 4, depicting samples collected after a major storm event, shows the difference dramatically.

At the end of the study the organic-matter content of the soil was higher than at the beginning on both Vetiver-technology plots and the Controlled-burn plots; it was lower on the other two treatments (Table 1).

DISCUSSION

Our results show that Vetiver technology can effectively reduce soil erosion, particularly as compared to areas of bare soil. Vetiver grass is not only effective for erosion control but also improves the quality of runoff water (Fig. 4) downstream, reducing sedimentation in near-shore waters and protecting coral reefs from the detrimental effects of storm runoff. Vetiver also increased organic-matter content of the soil. Controlled burning increased it almost as much, because the ash from the burned plants was left on the soil as organic carbon. In addition, the runoff was high on the ‘controlled burned’ plot because initially the soil surface becomes hydrophobic and repels the water causing it to run off. However, following the subsequent burning and as the result of the added ash, the soil organic matter increases and hence improves the aggregate stability increasing the soil less susceptible to water erosion. The other more important factor is that as the roots from previous plants decay as their above ground parts are burned, the decay roots (just like decay roots in No-tillage system) create long and extended macropores causing the infiltration to increase hence producing less runoff. However, if burning continues, the ecosystem conditions of the environment will change, large trees will not be able to re-grow, soil microorganism will decrease leading to eventual poor soil quality and consequently increases soil erosion causing a condition for an eventual land degradation of the area. In short, intentional burnings of the vegetation in these areas had lead land degradation creating badlands in southern Guam.

Finally, as stated by Xia and Shu (2003), we concluded that Vetiver grass, because of its unique characteristics—high biomass, fast growth, and strong root system can play an important role in reducing soil erosion as well as in reclamation of degraded land for sustainable development and environmental integrity.

CONCLUDING REMARKS

Restoration of natural resources in Guam and environmental protection on the island are achievable if the techniques described are implemented properly.

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Initial soil characteristics				Management Practices	Soil characteristics as affected by study treatments			
Avg. % O.M.	Avg. % Soil Texture				Avg. % Soil Texture			Avg. % O.M.
	Clay	Sand	Silt		Clay	Sand	Silt	
3.9	**54.4**	**24.9**	**20.7**	**Burn**	**57.2**	**20.5**	**22.3**	**5.1**
3.9	**54.4**	**24.9**	**20.7**	**Vetiver**	**51.8**	**28.2**	**20.0**	**5.4**
3.9	**54.4**	**24.9**	**20.7**	**Till**	**54.8**	**26.1**	**19.1**	**3.0**
3.9	**54.4**	**24.9**	**20.7**	**Natural**	**56.8**	**25.7**	**17.5**	**3.8**

Table 1.: Characterization of the soil before and after the experimental treatments.

Size and slope of the study plots			Management practices (Soil surface conditions)	Soil loss (tons/ha/yr)
Area ha	Length m	Slope %		
0.0037	**21.95**	**12**	**Burn**	**14.13**
0.0037	**21.95**	**12**	**Vetiver**	**1.47**
0.0037	**21.95**	**12**	**Till**	**104.75**
0.0037	**21.95**	**12**	**Natural**	**5.22**

Table 2: Annual Soil loss from each plot with different treatments.

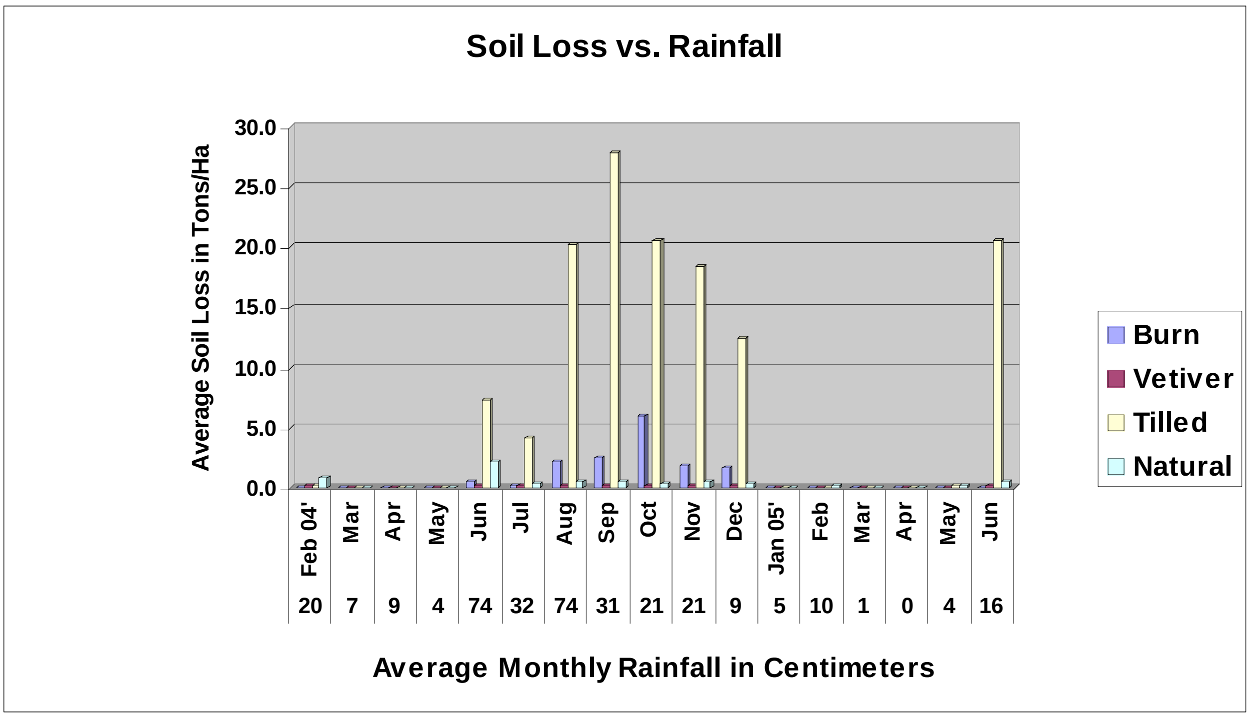

Fig. 1: Soil loss from experimental treatments as a function of average monthly rainfall, showing that runoff was greatest from bare-soil treatments and least from plots planted with Vetiver grass.

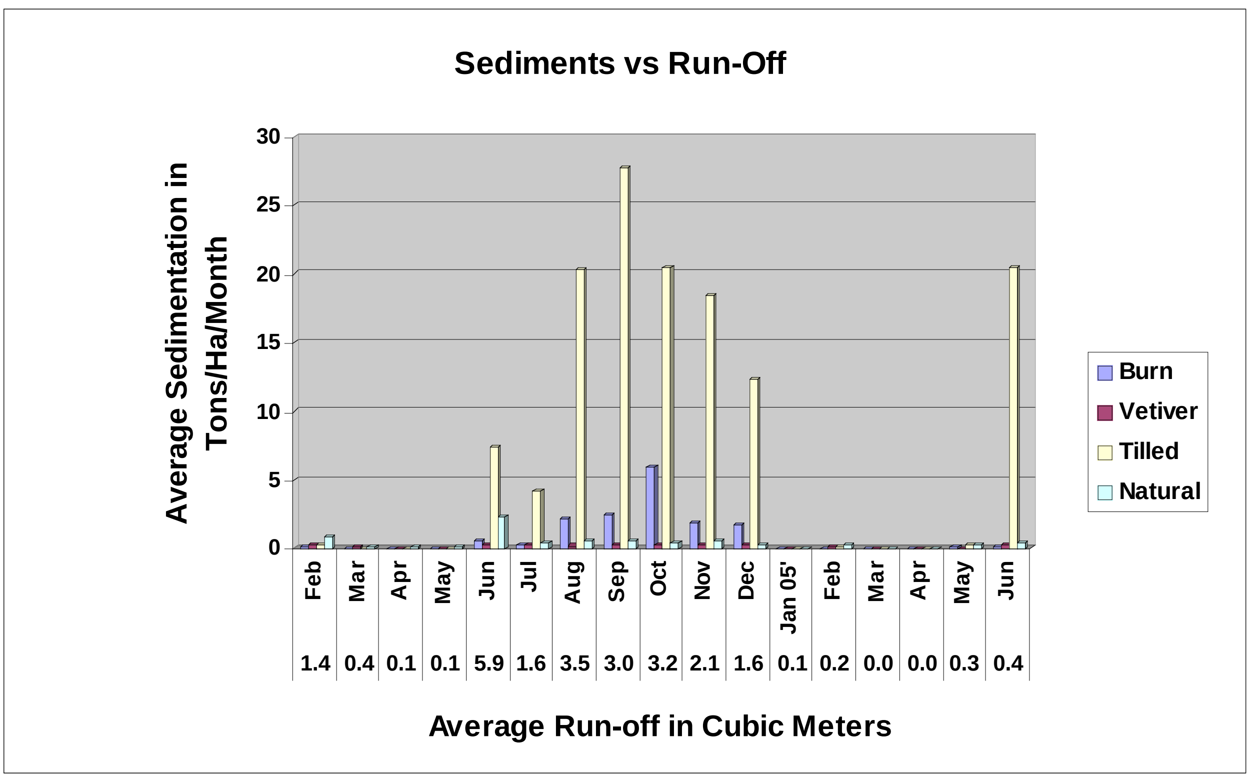

Fig. 2: Average runoff and corresponding soil loss per plot in different treatments, showing that the increase in sedimentation with increased runoff was greatest on bare-soil plots and least on plots planted with Vetiver grass.

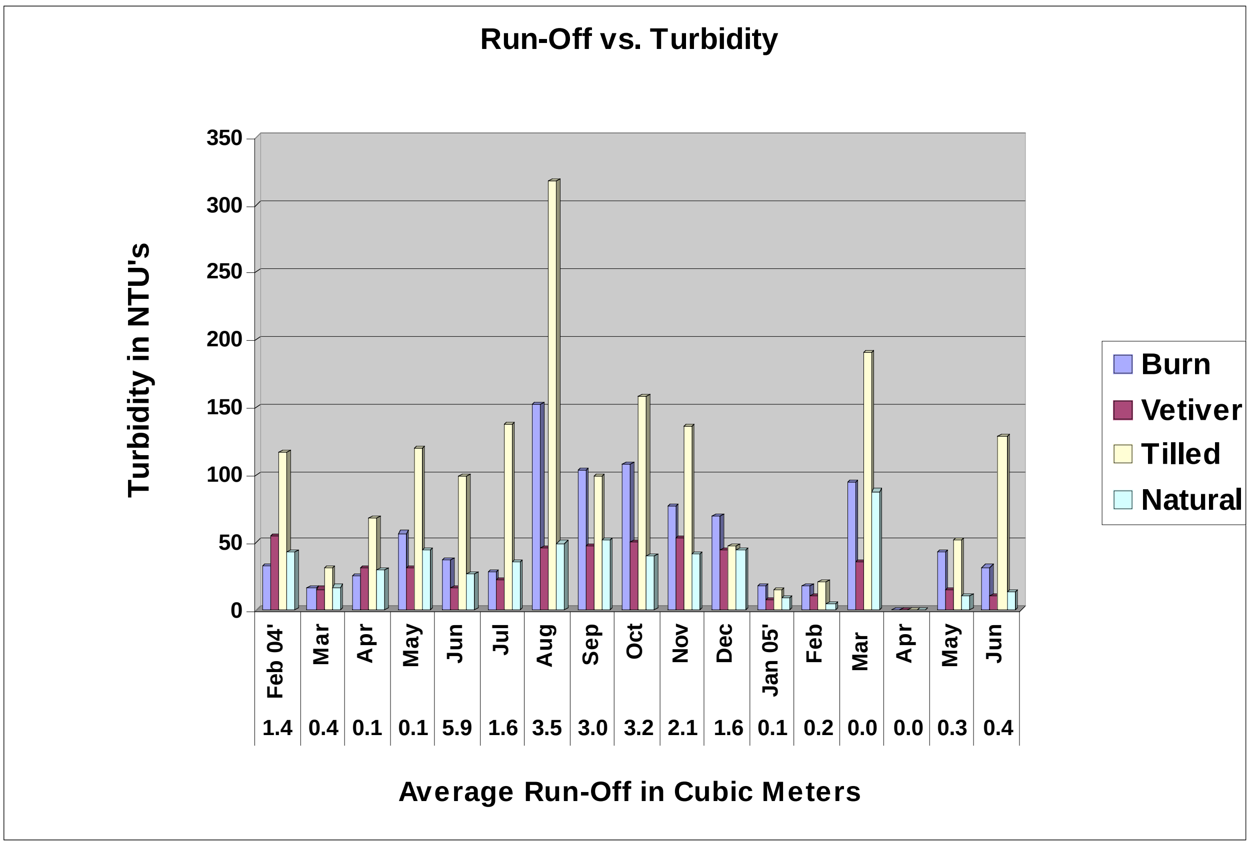

Fig. 3: Turbidity measured from the runoff water following each sampling event from the study plots.

Fig. 4: Runoff samples illustrating the differences in water quality leaving the different experimental plots after a major storm event.