Restoration of An Oil Spill Site: Hydroseeding

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

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Abstract

Successful restoration of oil and oil brine spill sites is limited in part by the lack of simple, economical techniques for applying soil amendments and seeds. These techniques need to be applicable to large and small spills, as well as fragile ecosystems. We tested hydroseeding as a potential technique. Hydroseeding is cost effective, can be used over large areas, and does not disturb the site. A field experiment in LaSalle Parish, Louisiana was conducted to test: (1) whether seeds applied to surfaces of brine-contaminated soil using hydroseeding could germinate and survive, and (2) whether the application of organic matter to the soil surface was sufficient to enhance establishment of sown seeds. Forty 29.25 m^2 plots were treated with mulch (recycled newsprint) only, seed only (*Festuca arundinacea*, *Panicum virgatum*, *Cynodon dactylon*, *Lolium perenne*, and *Trifolium repens*), mulch and seed, water only, or no treatment. All plots received fertilizer and lime. After 22 weeks, mean vegetative cover was significantly greater in plots receiving mulch and seed relative to plots with water only or no treatment. Mean number of shoots tended to exhibit a similar pattern of response. Aboveground biomass, however, did not differ between treatments. Thus, the simultaneous application of fertilizer, organic matter, and seeds contributed to vegetative cover of an oil brine spill site. The reestablished vegetation should further ameliorate the soil environment to accelerate successional change, control erosion, and resume ecosystem function.

1.0 Introduction

Restoration of oil and oil brine spill sites can be costly and labor-intensive, involving removal of excess contaminants, soil replacement or cleansing, and reestablishment of ecosystem function. Bioremediation of hydrocarbons and revegetation offers an economical, less invasive alternative to soil replacement and cleansing. Bioremediation is accelerated when soil microbial metabolism is not limited by resource availability. Sufficient quantities of nitrogen, phosphorus, potassium, oxygen, and water are required, relative to the quantity of carbon. Finn (2000) suggested that optimal bioremediation occurs at C:N:P ratios of 100:20:10. Dibble and Bartha (1979) found an optimal degradation rate at a C:N ratio of 60:1.

Revegetation plays a large role in restoration because plants enhance soils and interact with oil-degrading microbes. Vegetation improves soil surficial chemistry, structure, organic content, water capacity, thermal regime, and leaching of salt (Evans and Young 1970; Oke 1978; Hopkins et al. 1987, 1991). An example of improved soil chemistry is the formation of carbonic acid from root-release of carbon dioxide (Raloff 1985). Carbonic acid can release calcium from particular soils. Calcium may, in turn, replace absorbed brine-derived sodium, allowing the sodium to be leached below the rooting zone (Lauchli 1990). Organic matter incorporated in soil from leaf litter improves soil structure and increases the moisture-holding capacity. Leaf litter and shading also reduce evaporation from the soil surface, thereby slowing loss of soil moisture. In addition, plants may lower the water table (e.g. Dacey and Howes 1984). The reduction may be sufficient to halt salt movement to the soil surface by capillary action and allow influx of oxygen. Lastly, plant root action potentially increases salt leaching by enhancing vertical permeability. Therefore, plants contribute significantly to soil reclamation.

Plants also interact with oil-degrading bacteria and fungi by providing resources through sloughed cells, litter, root exudates, diffusion of oxygen through roots and biological fixation (Moser and Haselwandter 1983; Sims 1990; Davis et al. 1993; Shimp et al. 1993). As a result of vegetation effects on soil quality and interaction with microorganisms, oil and oil brine attenuation have been demonstrated to occur more rapidly in the presence of the plants than without vegetation (Keiffer et al. 1997; Banks et al. 2000).

The contaminated soil environment may, however, reduce plant performance. Salt directly impacts plant performance via ion toxicity and osmotic stress. High percent exchangeable sodium affects soil structure (Halverson and Lang 1989; Carty et al. 1997). If excess sodium is not replaced by another cation before leaching, soil aggregates collapse, damaging soil structure (Raloff 1985; Barzegar et al. 1996). Water and gas flux is then limited by the loss of pore space. Hydrophobic soils associated with oil contamination may also reduce water availability to plant roots (Plice 1948; McCown et al 1972; McCauley 1996) and salt leaching. Lastly, salinity slows degradation rates of residual oil. Consequently, plant exposure to oil may persist for longer time periods (e.g. Ward and Brock 1978). Therefore, reestablishing vegetation on a spill site may be difficult.

Plant establishment and productivity in saline, sodic, and saline-sodic soils have been enhanced by plant selection, irrigation, improved drainage, ripping, and soil amendments. Improved salt tolerance from breeding programs has been slow and is usually only associated with agricultural systems. Naturally salt-tolerant plant species (i.e. halophytes) have also been used on saline soils. Their use, however, depends on restoration goals (i.e. whether restoring vegetation is consistent with adjacent, undisturbed plant communities).

Salt leaching *via* irrigation and improved drainage is considered essential to increasing yield in agricultural settings. Irrigation may not be practical at brine spill sites because there is rarely a cost-effective method of irrigation at remote sites. Subsurface drains have successfully improved salt-leaching (Harris and Veenstra 2001). Drainage and soil structure may also be improved by ripping or tilling (Beckmann et al. 2000).

Soil amendments include organic matter, calcium, and inorganic fertilizer. Organic matter is added to soils to restore structure. Mulch (organic matter) helps maintain soil moisture (Cardon and Mortvedt 1994a, b) just as plant litter does. A calcium amendment (e.g. calcium sulfate, calcium nitrate, or calcium chloride) enables plants to maintain potassium transport and potassium/sodium selectivity (Lauchli 1990) and prevents collapse of soil structure upon leaching of sodium (Raloff 1985; Barzegar et al. 1996). Lastly, plants and bacteria may compete for the same limiting resources such as nitrogen and phosphorus. Inorganic fertilizer limits the impact of competition. Thus, in order to enhance degradation of residual petroleum and improve establishment of plants in oil and oil brine contaminated soils, amending soils with organic matter, calcium and inorganic fertilizer is usually necessary.

Restoration efforts have been limited, in part, by a lack of a large-scale, cost-effective treatment application technique that does not further harm the impacted environment. Sensitive ecosystems, in particular, may be further degraded by soil compaction during restoration activity. This project examines hydroseeding as a potential method for dispersing fertilizer, organic matter, and seeds in a single application. The benefits of hydroseeding are clear (Carr and Ballard 1980): the technique is cost effective relative to outplanting nursery stock, large areas can be sprayed rapidly, the technique has a low environmental impact, and the spray mixture can be modified with soil amendments. Hydroseeding has not been employed on brine spill sites. One reason may be that different plant life-history stages may be more sensitive to oil and oil brine contamination than other stages; thus it is not known whether sowing seeds will reestablish vegetation. But hydroseeding is expected to be successful, since previous research has suggested that particular species are capable of germinating on oil- and oil brine-contaminated soil (Vavrek and Campbell 1999). Hydroseeding may improve germination by contributing water and mulch to contaminated soils. The mulch protects the seeds, seals in moisture, and adds organic matter to soils.

This project addresses two specific questions concerning hydroseeding as an application technique:

1) Will seeds applied to the surface of brine-contaminated soil germinate and survive?
2) Is the application of organic matter to the soil surface sufficient to enhance establishment of plants?

2.0 Methods

To assess the effectiveness of hydroseeding for revegetation of an oil brine spill site, a recent spill site in central Louisiana was used. The site, located in LaSalle Parish, represented a typical oil brine spill. A pipeline break (February 2002) caused *ca*. 750 barrels of brine to spill down slope along the pipeline right-of-way and pool at the base of the slope. The spill contaminated *ca*. 0.3 hectares. Mean salinity $\pm$ SE in July 2002 was 22,765 $\pm$ 6,441.4 ppm (n = 8) ranging from 6,568 to 58,754 ppm (Louisiana Soil Testing and Plant Analysis Laboratory). This salinity was greater than levels found in adjacent undisturbed forest soil (398 $\pm$ 63.2 ppm; n = 2). Additionally, soil analysis indicated that oil contamination was low (0.05 $\pm$ 0.013%; mean $\pm$ SE) and similar to adjacent soil (0.02 $\pm$ 0.010%). Soil pH and phosphorus were also low (4.28 $\pm$ 0.18 and 10.8 $\pm$ 1.88 ppm, respectively).

Forty 29.25 m^2 circular plots were delineated at the spill site. Plots were separated by at least one meter to control cross-plot contamination. The circular plot shape reduced the perimeter to area ratio and simplified spray application. One full hydroseed tank mixture was sufficient for two plots. The hydroseeding mixture was applied with a Turbo Turf HS-50 hydroseeding system (Turbo Technologies, Inc.). The basic spray mixture contained 190 L of water, seed of five species (Table 1), tackifier (17.7 g Turbo Tack per 190 L, Turbo Technologies, Inc.), and cellulose mulch. The mulch was made from recycled newsprint (paper mulch, Applegate Environmental) and was added at 3.7 kg per 190 L of water as recommended by the manufacturer. Since the site was relatively remote, a gasoline electric generator and submersible pump were used to fill the hydroseeder from a small creek. An all terrain vehicle (ATV) was used to move the hydroseeder around the site. The first application of the hydroseed mix began on 20 November, 2002. Sheeting erosion from precipitation washed seed and mulch from most plots because soils along the right-of-way were compacted and sloped. A second application was performed on 28 February, 2003. To control erosion after the second application, hay was applied to plots to a depth of 1-2 cm.

Table 2.1. Plant species used in a hydroseed mix applied to an oil brine spill site in central Louisiana. Application rates are standard for surfaces lacking vegetation.

Species	Common name	Application rate
Festuca arundinacea Schreb.	Tall fescue	3.60 kg ha^{-1}
Panicum virgatum L.	Switchgrass	1.26 kg ha^{-1}
Cynodon dactylon (L.) Pers.	Common bermuda	0.72 kg ha^{-1}
Lolium perenne L.	Ryegrass	4.32 kg ha^{-1}
Trifolium repens L.	White clover	0.72 kg ha^{-1}

Plant species were selected based on their tolerance to oil and salt exposure, and their presence in Louisiana. The species mix included a warm and cool season grass species, which expanded the period of productivity for regenerating vegetation. Planting a mix of species also improves vegetative structure and persistence.

To separate and understand the benefits of mulch and seeds, treatments encompassed plots (n = 8) receiving mulch and no seed, seed with no mulch, and mulch with seed (Table 2). Eight plots were also established as controls receiving fertilizer only; eight plots received water as well as fertilizer. Because research has demonstrated both the benefits of fertilizing and the poor nutrient quality of central Louisiana soils, all plots were fertilized. Granular fertilizer (Green Country fertilizer, Shell Beach, Inc.; 17-17-17) was added at the rate of 26.5 kg ha^{-1}. Water was applied to all treatments, with the exception of controls, to exclude water as a confounding factor in the hydroseeding assessment. Lime was also applied to all plots (450 kg ha^{-1}) to provide calcium and to decrease soil acidity. No additional irrigation was provided to plots. A completely random design was employed.

Table 2.2 Treatments applied to a central Louisiana oil brine spill site to test the efficacy of hydroseeding for restoration.

Treatment	Fertilizer	Water	Mulch	Seeds
Water only	Yes	Yes	No	No
Mulch	Yes	Yes	Yes	No
Seed	Yes	Yes	No	Yes
Mulch and seed	Yes	Yes	Yes	Yes
Control	Yes	No	No	No

To appraise the potential use of hydroseeding, plant performance was compared between treatments. Subsampling (with 1-m^2 quadrats) was used to quantify cover. Cover was quantified *ca*. 10, 12, 17.7, and 22.5 weeks after the initial application. Because of the two separate applications of spray, the mean cover across the sampling dates was used in the analysis. Also after 22.5 weeks, circular quadrats (0.056 m^2; 4 randomly placed per plot) were used to estimate the number of stems and aboveground biomass. Analysis of variance was used with Tukey's HSD multiple comparison method to examine the treatment effects on vegetative cover (JMP, v. 4, SAS Institute). Treatments were considered fixed-effects. In the analyses for number of shoots and biomass, plot was added as a random effect in the model. Biomass values were transformed to improve normality (assessed with a normal quantile plot). Man-hours were also tabulated.

3.0 Results

Seeds applied to the surface of brine-contaminated soils germinated and survived. Mean percent vegetative cover ($\pm$ SE) in plots that received surface-applied seed was 38.8 $\pm$ 6.8 across 22 weeks. Cover in these plots ranged from a minimum of 8.8% to a maximum of 81.2%. Establishment of seedlings was also apparent by the mean number of shoots m^{-2} ($\pm$ SE) of 773 $\pm$ 101.8. The number of shoots varied from 250 to 1509 per m^2.

Organic matter applied to the surface via hydroseeding improved establishment of seeds sown. Mean percent vegetative cover differed as a function of treatment ($p = 0.0032$). Plots receiving mulch and seeds exhibited greater cover than control plots or plots receiving water only ($p < 0.05$; Fig. 1). Similarly, the mean number of shoots tended to differ between treatments ($p = 0.0951$; Fig. 2). Aboveground biomass reflected the same pattern, but the differences were not significant since variances were relatively large ($p > 0.05$; Fig. 3).

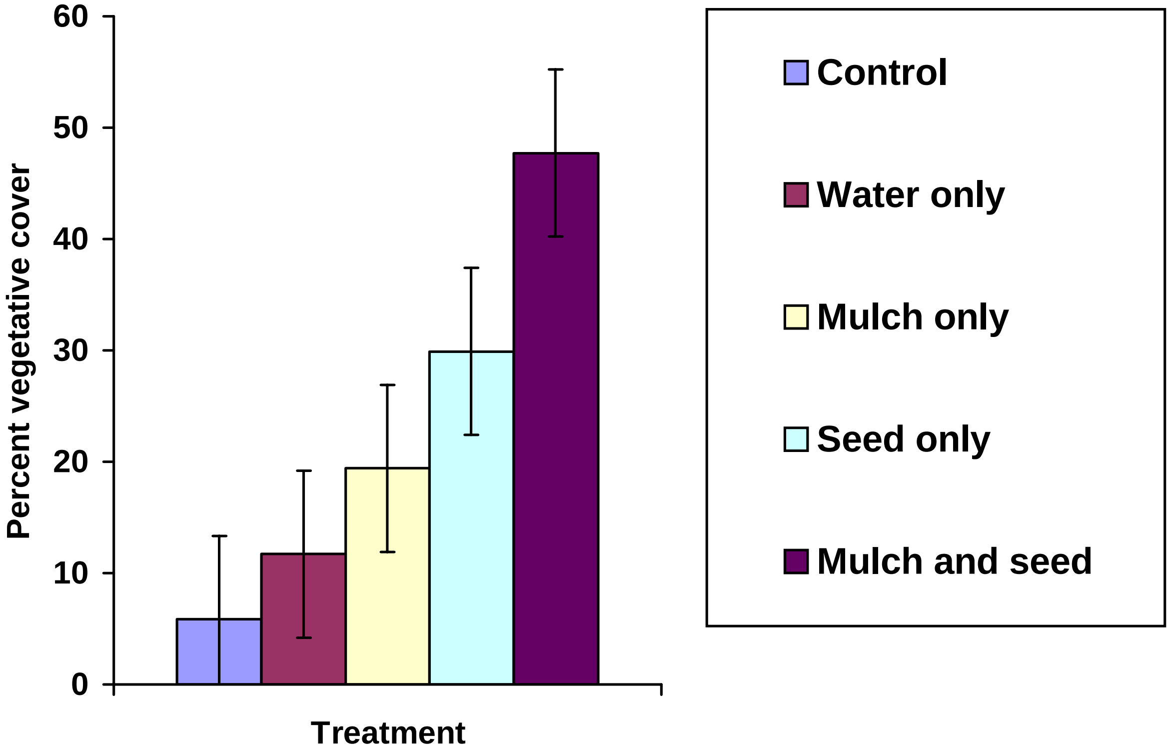

Figure 3.1. The effects of water, mulch, and seeds applied with a hydroseeder on mean vegetative cover of an oil brine spill site. Bars represent ± SE.

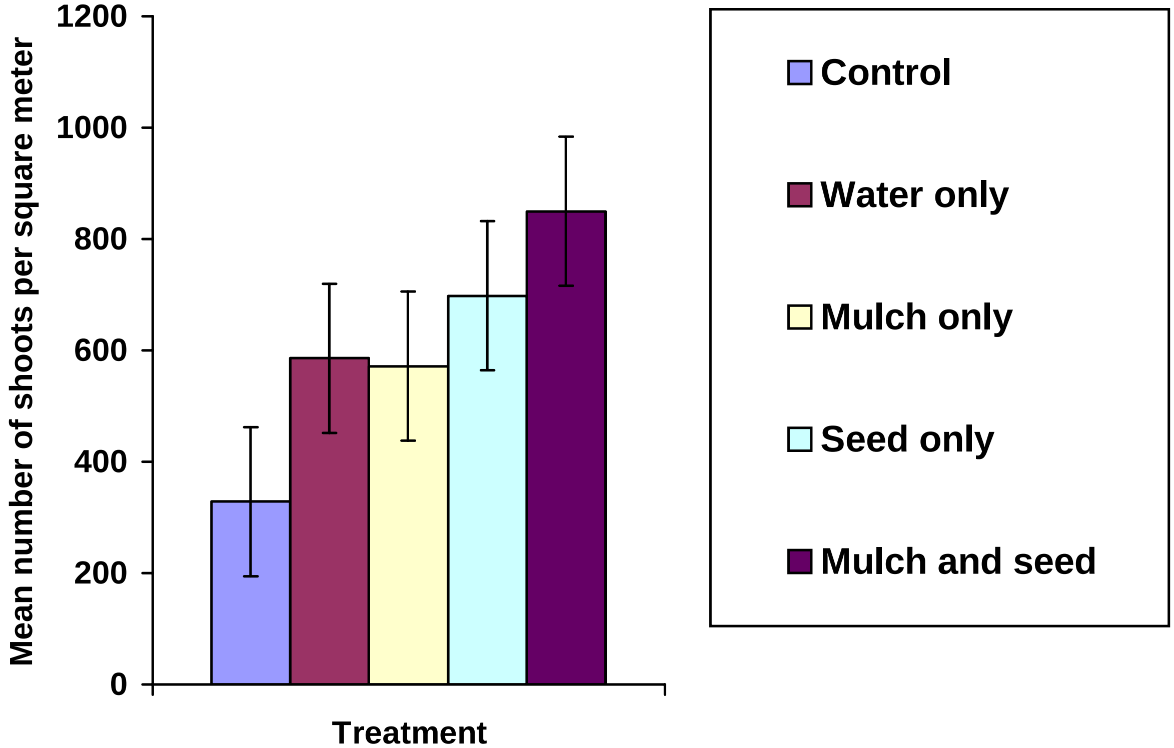

Figure 3.2. The effects of water, mulch and seeds on mean number of shoots on an oil brine spill site. Bars represent ± SE.

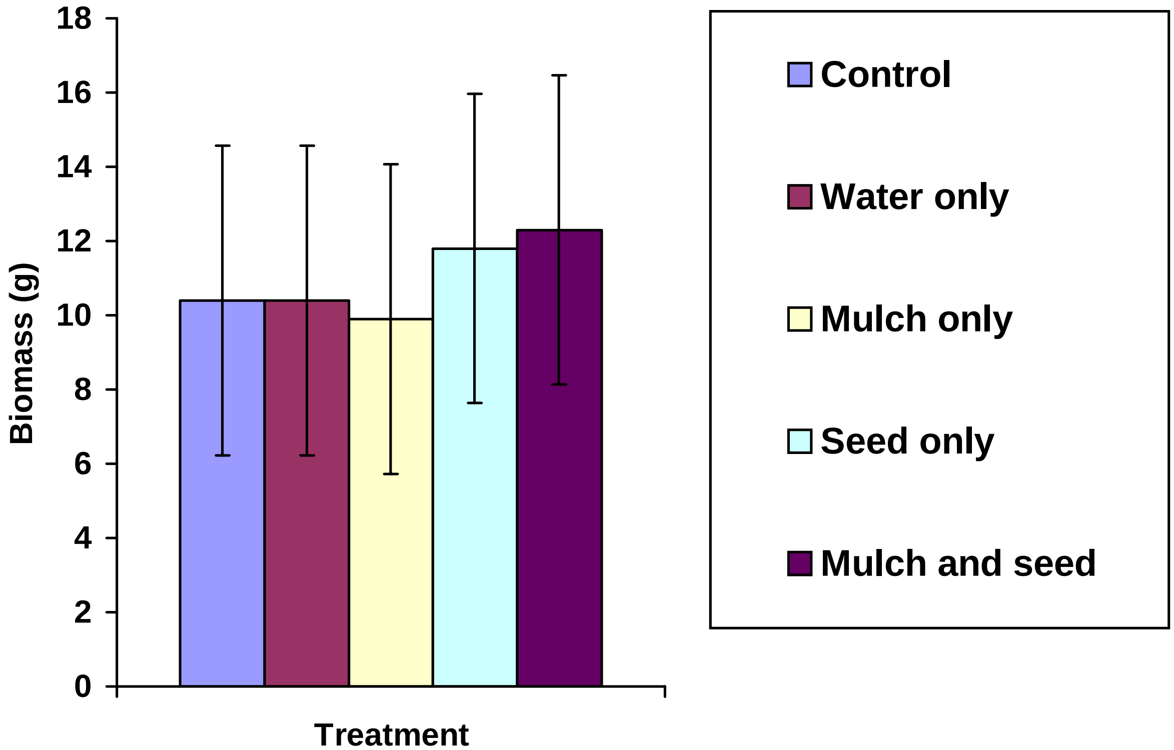

Figure 3.3. The effects of water, mulch, and seeds on mean (not transformed) aboveground plant biomass (dry weight) of an oil brine spill site. Bars represent ± SE.

Differences between plots were significant in all analyses ($p < 0.05$), which most likely indicated variability in plant establishment as a result of natural environmental heterogeneity, erosion, and salt concentration. Application of the hydroseed mix was relatively rapid (three men working approximately 13 hours) considering lack of experience, the need to carefully spray within plots, site characteristics, and the need to pump water from the creek. An application of a single hydroseed mix across an open spill site would have been more rapid.

4.0 Discussion

For *in situ* restoration of oil and oil brine spill sites to be a successful alternative to soil replacement, rapid and economical return of ecosystem function is necessary. Return of function is dependent upon reclamation of soil structure, the presence of bacteria, fungi and plants, and reduction in contaminants. To achieve these characteristics, spill sites generally require fertilizer to accelerate degradation of residual hydrocarbons. Soil structure is improved by amending soils with organic matter and calcium. Lastly, sowing seeds or outplanting nursery stock is used to reestablish vegetation.

The results of this study support the use of hydroseeding as a treatment application technique for restoration of oil brine spills. Organic matter (recycled newsprint) and seeds sprayed on the soil surface significantly improved vegetative cover after 22 weeks. The water and mulch appear to ameliorate the soil environment sufficiently to support germination and plant establishment. Unlike plant cover, differences in aboveground biomass were not detected between treatments. Large variances associated with biomass contributed to the lack of detection. Natural plant establishment occurred sporadically, inflating variances in biomass. Several large individuals of *Eupatorium capillifolium* became established for example, increasing biomass values for particular plots, but providing little influence on cover. Erosion was controlled in part by the application of hay to the soil surface after hydroseeding. Soil ripping and ditching may also have improved vegetative cover and reduced variability as soils on the right-of-way were compacted. Vegetation will, with time, contribute additional organic matter, open channels in the soil, and improve the soil chemistry. These changes will support establishment of additional plants and accelerate successional change. Further, vegetation will reduce nutrient loss and erosion, and support vertebrates and invertebrates.

Hydroseeding costs less and requires fewer man-hours compared to outplanting. In addition, hydroseeding does not compact the soil as does large equipment. The small hydroseeder used is capable of reaching 48 m with a combination of hoses and an area/volume kit (specifications, Turbo Technology, Inc.). Large hydroseeders will propel the hydroseed mix to greater distances.

Hydroseeding may also provide additional amendments to contaminated soils, such as calcium and fungal inoculum. The importance of symbiotic fungi is not fully appreciated, although researchers are increasingly becoming aware of the role of fungi in restoration of oil and brine spills. Mycorrhizal fungi support plant and bacterial performance and improve soil structure (e.g., Heinonsalo et al. 2000; Meharg and Cairney 2000). Future research will test whether establishment of vegetation can be improved by adding inoculum of symbiotic fungi to a hydroseed mix.

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