REDUCED-IMPACT LAND DISTURBANCE TECHNIQUES FOR NATURAL GAS PRODUCTION[1]

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Abstract: Traditional drill pad construction techniques for natural gas production involve a cut-and-fill procedure that displaces existing plant communities and results in costly soil remediation and revegetation procedures. At the Jonah natural gas field, Sublette County, Wyoming, EnCana Oil and Gas (USA), Inc. is evaluating use of oak mats during drilling and completion activities to minimize disturbances to soil and plant resources. In this study, changes in vegetation and soil attributes were evaluated as a result of oak mat use. Overall, oak mats tended to protect plant resources, minimize weedy forb establishment and maintain the plant community in a condition similar to adjacent rangeland. On average when compared to native range, grass growth improved, forbs remained similar, and shrubs were negatively impacted in oak matted areas. Vegetative results suggest that the success and timeliness of reclamation following the use of oak mat drill pads is superior to that obtained at reclaimed cut and fill locations. Following mat removal, mean soil bulk density values changed -2.9, 2.2 and 3.7 percent for the 0 to 5.1, 0 to 15.3, and 0 to 30.5 cm depth increments. All soil bulk density values remained below recommended thresholds for rangeland environments. A cost-benefit discussion indicates that in this setting, construction costs associated with oak mats are similar to those incurred by traditional cut-and-fill techniques. Drilling procedures using oak mats are more costly due to the need for a closed system for treatment of drill cuttings. However, this expense may be offset by lower reclamation costs associated with oak mat use.

Additional Key Words: natural gas development, drill pad construction, Jonah Field, and land reclamation

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Introduction

Reclamation of disturbed soils associated with oil and gas production continues to be one of the greatest challenges facing the industry, particularly in the driest precipitation regimes of cold desert sagebrush biome.

Conventional natural gas production has experienced a recent growth in the state of Wyoming, particularly within the Jonah Field, located approximately 53 km south of the town of Pinedale in western Wyoming. The Jonah Field is estimated to contain 0.3 trillion cubic meters of natural gas. The field itself is characterized by low, gently rolling hills interspersed with buttes, with a vegetation community dominated by Wyoming big sagebrush (*Artemisia tridentata* var. *wyomingensis*) (USDI 2006).

Drill pad construction in the Jonah Field typically uses a cut-and-fill technique to produce a level drilling surface (McWilliams et al. 2007). During cut-and-fill, native soil and plant communities are removed, requiring costly post-drilling soil reclamation and vegetation reestablishment. Vegetation establishment and growth are at the mercy of drought, harsh soil substrates, and a recovery time of decades. Recovery is particularly challenging during extended seasonal drought in low precipitation zones. Furthermore, previously evaluated site and seedbed preparation techniques for cut-and-fill drill pad reclamation suggest that this technique may produce elevated soil bulk densities that limit plant growth and impede reclamation efforts (McWilliams et al. 2007).

In November 2005, EnCana Oil and Gas (USA), Inc. began a pilot project utilizing oak mats in place of cut-and-fill construction to minimize impacts to soil, plant, wildlife and cultural resources. The goal of using oak mats is to minimize the need for earthen excavation associated with conventional drill pads and roads. Instead of stockpiling the soil resource and leveling the drill pad area with earth moving equipment, which effectively removes existing plant growth, oak mats are placed directly on top of the soil and plant resources to facilitate drilling operations. When the drilling operation is completed, oak mats are removed and reused on the next well location.

Individual oak mat sections used in the Jonah Field are 2.4 meters (m) wide by 3.7 m long. Mats are constructed using 25 cm wide oak mat planks spaced at 2.5 cm intervals. Three layers of planks are arranged perpendicularly, resulting in a mat thickness of 15.2 cm (Fig. 1). This arrangement helps distribute the weight of drilling equipment and increases mat strength. Each oak mat section is connected to a neighboring mat using a tongue-and-groove method (Fig. 1). The anticipated longevity of an oak mat in the Jonah Field is 3 to 5 years of continual use (KC Harvey, Inc. 2007). Approximately 776 mats are required to construct a single drill pad (USDI 2005) (Figure 2).

Figure 1. Side view of oak mat illustrating three-ply construction and plank spacing (left photo), and oak mat tongue-and-groove connectors (right photo).

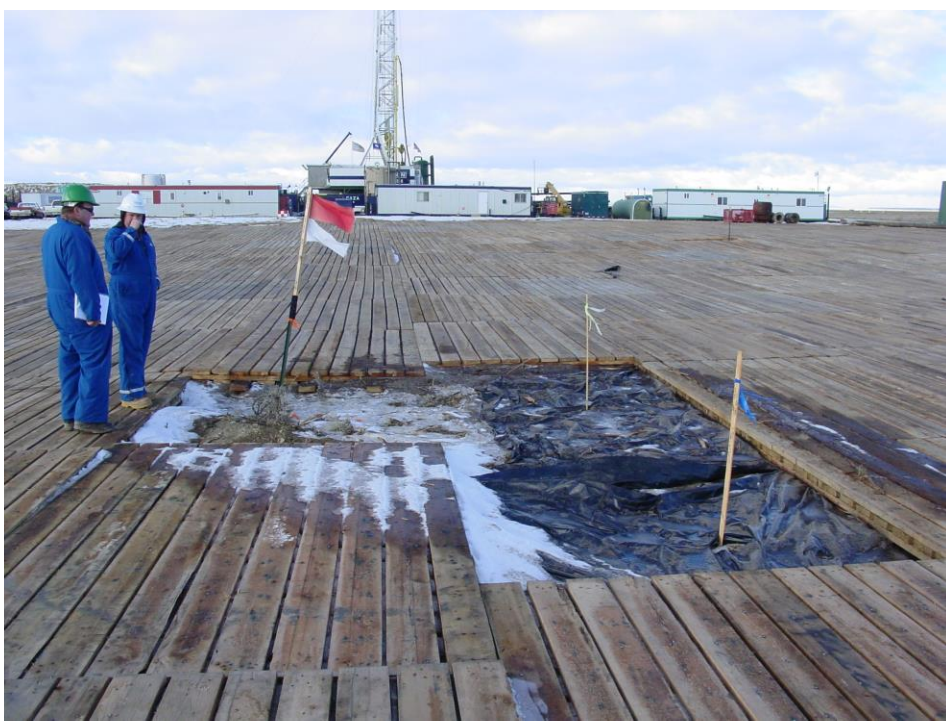

Figure 2. Drill pad constructed with oak mats. Red and white flag denotes drill hole location.

Oak matted drill pads occupy approximately half the area of the cut-and-fill techniques, as they eliminate area requirements for coversoil and fill stockpiles, reserve pit, flare pit, and condensation tanks (KC Harvey, Inc. 2007). Typically, oak mat drill pad areas are spatially arranged in a radial pattern with underground piping transporting drilling fluids and waste products to a centralized reserve pit, flare pit, and condensation tank battery constructed on previously disturbed areas (KC Harvey, Inc. 2007). Mats weigh approximately 1,134 kilograms, which applies an average soil bearing pressure of 128 kg/m^2. Because of the weight of the drill rig and auxiliary equipment, each oak mat transmits an average of 854 kg/m^2 to the soil surface. A maximum of 1,255 kg/m^2 is exerted on the area directly under the sub-structure of the drilling rig (EnCana Oil and Gas Inc. et al. 2006).

The goal of this study was to evaluate practices to minimize disturbance to soil and plant resources associated with natural gas drill pad construction. Specific objectives were as follows:

1) Quantify vegetation recovery following oak mat removal by measuring density and cover of grasses, forbs and shrubs,
2) Determine soil bulk density change after oak mats are removed, and
3) Discuss the cost-benefit of implementation and reclamation costs associated with oak mat construction relative to traditional cut-and-fill techniques.

Materials and Methods

Measurement of Plant Community Traits

During June 2007, vegetation community characteristics were evaluated on 43 Jonah Field oak mat removal sites. Vegetation data collected on oak mat removal areas were statistically compared to data collected on adjacent undisturbed rangeland to evaluate the effectiveness of oak matting as a reclamation tool. On a sub-set of removal sites, changes in vegetation community from the first growing season (2006) to the second (2007) were also evaluated.

The Daubenmire method (BLM 1996) was used to measure vegetation establishment and growth traits on oak matted drill pads. At each drill pad, two 15.2 m transects were randomly located within the disturbance area. Two 15.2 m control transects were also randomly located in the undisturbed range adjacent to each oak mat location to serve as a basis for comparison. One 50 x 50 cm Daubenmire frame was placed every 3.05 m along one side of each transect. Within each frame, plant species were recorded. If plants could not be identified to species (e.g., young forbs), they were grouped by life-form (grass, forb, shrub), designated as weedy or desired species, and given a unique identifier.

Species richness was calculated by summing the number of species within a life-form. Species density was recorded by counting the number of stems present within each frame. Non-rhizomatous plants were counted as one stem. Non-rhizomatous plants with multiple stems radiating from one basal root were counted as one stem (e.g., sagebrush). Grasses and rhizomatous plants were counted by tiller or stem. For shrubs, those in seedling stage were counted separately from mature plants. Finally, percent canopy cover per plant species, rock, bare ground and litter were recorded. Canopy cover is the percentage of the soil covered by the vertical projection of a species regardless of what is below. Rocks less than 0.64 cm in diameter were counted as bare ground.

A paired Student t-test was used to determined whether vegetation growth on 43 oak mat removal areas was statistically different compared to adjacent undisturbed native rangeland, or "reference area" ($\alpha = 0.05$, two-tailed). The same procedure was used to statistically compare vegetation growth between study years. Data sets that did not exhibit a normal distribution were analyzed using the Wilcoxons Signed Rank Test. This analysis was completed for total plant density and canopy cover for the following life forms: grass, forb, shrub, and weedy forb.

Measurement of Soil Dry Bulk Density

A Troxler nuclear density and moisture gauge was used to measure soil dry bulk density (ρ_b) at 38 oak mat drill pads. This instrument has an Am-241/Be radioactive source to facilitate determination of soil moisture content, and a Cs-137 radioactive source to facilitate a wet soil bulk density determination. An internal processor subtracts the water content from the wet bulk density value to yield the dry soil bulk density (g/cm^3). A 2 cm diameter hole was punched into the soil to 30.5 cm depth to facilitate entry of the radioactive probe.

Across each drill pad area ρ_b was measured at six random locations prior to placement of oak mats on the soil surface. At each of the six locations, ρ_b was measured from 0 to 5.1 cm, 0 to15.2 cm, and 0 to 30.5 cm. In addition, ρ_b was measured at one reference site approximately 30.5 meters off each drill pad area in rangeland that would not be disturbed by drilling or matting procedures. This reference location served to evaluate whether the Troxler instrument provided repeatable soil dry bulk density data, or whether instrument variability and environmental factors (e.g., temperature) introduced error.

A survey-grade GPS and labeled surface markers were used to permanently locate each initial measurement location to facilitate subsequent re-measurement following oak mat removal. A compass was used to orient the Troxler instrument north of the probe entry hole to ensure that repeat measurements of ρ_b represent the same volume of soil. Following oak mat removal, measurement locations were re-located using the survey grade GPS and surface markers and ρ_b was measured at the same depth increments. The Troxler gauge reported soil bulk density in pounds per cubic foot (PCF) which was converted to grams per cubic centimeter (g/cm^3) using:

$$\text{pounds/ft}^3\,(0.0160184) = \text{g/cm}^3 \qquad \textbf{(1)}$$

Soil profile bulk density data were analyzed using a two-way analysis of variance (ANOVA) statistical procedure to determine if soil bulk density increased significantly, or not, within the 0 to 5.1, 0 to 15.2, and 0 to 30.5 cm depth increments. This procedure identified if significant differences were present before mat construction versus after mat removal.

Accuracy and Precision of the Troxler Gauge

Accuracy of the Troxler gauge was addressed using two methods. First, annual calibration tests were performed by an independent laboratory. In the Jonah Field, a standard count was made daily to compensate for the decay process of both radioactive sources which enabled the gauge to operate accurately within the range of the factory prescribed calibration.

Second, soil bulk density measured with the Troxler gauge was compared to the soil bulk density determined with soil sampling and laboratory procedures. Following a Troxler gauge soil dry bulk density measurement, a Shelby tube was used to collect a core of the 0 to 5.1, 0 to 15.2, and 0 to 30.5 cm soil increment from the same section of soil. Core samples were dried and weighed in the laboratory. Linear regression was used to compare laboratory determined soil bulk density to Troxler gauge soil bulk density for each depth increment, and correlation coefficients (r) were calculated.

Precision of the Troxler gauge was also evaluated during collection of soil dry bulk density data in the Jonah Field. Dry soil bulk density measurements were repeated for the 0 to 5.1, 0 to 15.2, and 0 to 30.5 cm depth increments at three locations in 2006, and at four locations in 2007. The relative percent difference (RPD) was calculated using:

$$RPD = [(Duplicate\ 1 – Duplicate\ 2)/ ((Duplicate\ 1 + Duplicate\ 2)/2)]\ 100 \qquad \textbf{(2)}$$

Results and Discussion

Plant Community Traits

Grass Growth. Data indicate that the use of oak mats in constructing drill pad areas does not negatively impact either the density or canopy cover of grass species. In fact, oak mat use may actually promote grass density.

Trends observed during the 2007 field investigation indicate that overall grass density was significantly greater on oak mat removal areas than in the reference areas (Table 1). It is possible that the placement of oak mats can facilitate greater grass growth on a site by pressing seeds into the soil and creating favorable micro-sites for germination (Figure 3). Also, competition is decreased when oak mats crush older, more decadent shrubs, thereby creating openings for increased grass growth.

Figure 3. Close-up of ground surface following oak mat removal.

Mean grass canopy cover was statistically similar between oak mat and reference area data (Table 1). The canopy cover contribution by grass stems is usually small, on the order of 1 to 3 percent per Daubenmire frame. Therefore, a significant increase in grass density (stems/m^2) does not always contribute to an increase in canopy cover. Also, the average canopy cover for a grass species when averaged across an entire transect often resulted in fractional percentages, which were rounded to 1 percent for the purposes of comparison. This method of rounding may have resulted in more similarity between the matted and reference areas than would be expected based on the significantly higher grass density overall on oak mat areas.

Forb Growth. Data indicate that the use of oak mats in constructing drill pad areas does not negatively impact either the density or canopy cover of forb species. Mean forb density and cover were statistically similar before and after oak mat construction (Table 1).

It is likely that forbs, which are of low stature (i.e., propagate in near vicinity to the soil surface) in the Jonah Field, were minimally impacted by the weight of the oak mats, making them rebound easily upon removal. It is also possible that the presence of oak mats resulted in increased soil moisture retention, resulting in a healthy population of juvenile forbs.

Table 1. Summary of mean vegetation density and cover values and associated p-values on 43 oak mat removal areas compared to the reference area using a paired student t-test.

Life-form	Parameter	Reference Area	Matted Area	p-value
Grass	Mean Density†	182.5	217.4	0.006§
	Mean Cover‡	3.53	3.67	0.418§
Forb	Mean Density	6.47	6.19	0.427§
	Mean Cover	2.19	2.28	0.684§
Shrub	Mean Density	7.21	3.93	<0.001
	Mean Cover	11.49	3.16	<0.001§
Weedy Forb	Mean Density	0.19	1.63	<0.001§
	Mean Cover	0.14	1.12	<0.001§

† Mean density values are reported as (stems/m^2).
‡ Mean cover values are reported as percent (%).
§ Data exhibiting a non-normal distribution were analyzed using the non-parametric Wilcoxon Signed Rank test.

Shrub Growth. Data indicate that oak mat use may negatively impact both the density and cover of shrub species. Mean shrub density and canopy cover were statistically lower following oak mat removal (Table 1).

Although the use of oak mats may result in reduced shrub density and canopy cover, this may be beneficial to the habitat as a whole by effectively removing old, brittle, more decadent shrubs. Such removal encourages new growth and promotes increased diversity by creating openings for the establishment of new grasses, forbs, and shrubs (Castrale, 1982). Removal of older sagebrush plants may benefit wildlife habit by contributing to a "mosaic" type landscape, which can support a more bio-diverse community (Castrale, 1982). Studies by Summers (2005) and Fairchild (2005) found that mechanical disturbances increased vigor of surviving sagebrush and increased overall shrub production during the years following treatment. Dahlgren (2006) recommends the use of small-scale disturbance to remediate degraded sagebrush habitats and increase use by sage grouse.

<u>Weedy Forb Growth.</u> Mean weedy forb density and cover increased significantly following oak mat removal (Table 1). Moisture retention and microclimates provided by oak mats may create a favorable environment for the establishment of weedy forb seedlings. Weedy forb populations on oak mat areas are currently small, contributing to less than one percent of the canopy cover. Weeds do not appear to be out-competing desirable species, and are likely to be kept under control with best management practices.

When compared to traditional cut-and-fill construction methods, the oak matting procedure appears to reduce weedy forb establishment. EnCana Oil and Gas (USA), Inc. contractors provided reclamation monitoring data for 66 cut-and-fill drill pads reclaimed prior to 2005. Mean weedy forb density and cover were 71.9 stems/m^2 and 2.2 percent, respectively. These data were collected anywhere from 1 to 15+ years post reclamation, and indicate that weedy forb populations on cut-and-fill drill pads are well established, and likely to be a significant vector for weedy forb dispersal in the Jonah Field. In comparison, weedy forb establishment on oak matted drill pads was limited to 0.19 stems/m^2, or 0.14 percent (Table 2).

<u>Comparison of Vegetation Traits in 2006 to 2007.</u> Following mat removal, vegetation data were collected on 16 sites during 2006 and 2007. A paired Student t-test was used to determined whether changes in vegetation traits from 2006 to 2007 were different ($\alpha = 0.05$, two-tailed). Data sets that did not exhibit a normal distribution were analyzed using the Wilcoxons Signed Rank Test. The statistical analysis was completed for plant density, canopy cover and species diversity for grasses, forbs, and shrubs.

Grass canopy cover and density significantly increased in 2007 compared to 2006 (Table 2). Comparison of grass traits on oak mat removal sites to their respective reference areas revealed grass density increased by the use of oak mats (Table 1). 2007 data indicate the increased vigor of grass after oak mat removal continued through a second growing season (Table 2).

Forb canopy cover and density were not significantly different in 2006 compared to 2007 (Table 2). Comparison of forb growth traits on oak mat removal sites to their respective reference areas indicated no significant difference was present (Table 1). These data indicate forb cover and density were stable through the 2006 and 2007 growing season (Table 2). Therefore, the use of oak mats appears to not significantly change the forb cover and density when compared to the references areas.

Shrub canopy cover and density were negatively affected by oak matting (Table 1). However, shrub canopy cover increased from 2006 through 2007 (Table 2). The trend indicates shrub cover is recovering with time following oak matting. Recovery may be attributable to surviving shrubs have little competition from other mature shrubs.

Table 2. Change in vegetation traits on 16 oak mat drill pads from 2006 to 2007.

Life-form	Mean †	2006	2007	% Change
Grass	Canopy Cover (%)	1.3 a	3.2 b ‡	1.9
	Density (stems/m^2)	140.5 a	267.8 b	127.3
	Species Diversity	1.1 a	2.4 b ‡	1.3
Forb	Canopy Cover (%)	1.0 a	1.2 a	0.2
	Density (stems/m^2)	4.5 a	3.9 a	-0.5
	Species Diversity	0.4 a	1.2 b ‡	0.8
Shrub	Canopy Cover (%)	2.0 a	3.3 b	1.3
	Density (stems/m^2)	4.1 a	5.1 a ‡	1
	Species Diversity	0.6 a	2.7 b	2.1

† Means across years followed by a different letter are statistically different ($p<0.05$).
‡ Data were transformed prior to analysis in order to normalize the distribution.

Species diversity of grasses, forbs and shrubs significantly increased in 2007 compared to the diversity in 2006 (Table 2). Since shrub canopy cover and density are negatively affected by oak matting, the reduced competition from shrubs may be enough to attract new native grass, forb and shrub species to colonize the area. While shrub cover and density are reduced by oak matting, the effect on the sagebrush ecosystem as a whole may be positive. Old, decadent shrub communities are replaced with younger and more diverse shrub communities, creating a mosaic of age classes and species in the landscape, which may be beneficial to wildlife (Castrale, 1982; Fairchild, 2005; Summers, 2005; Dahlgren, 2006).

Soil Dry Bulk Density

Accuracy and Precision of the Troxler Gauge. Regressions comparing Troxler gauge and Shelby tube measurements of dry soil bulk density were significant ($p < 0.001$) and had good correlation coefficients (r), 0.90-0.91. To optimize accuracy in this investigation, unique regression equations were applied to each soil increment. Confidence intervals (95 percent) were calculated for each regression line. This analysis indicated that 95 percent of the time the estimated value was within 0.07 g/cm^3, or less, of the true soil bulk density. These data indicate the Troxler gauge produced very accurate measurements of soil dry bulk density.

The RPD used to test precision ranged from 0 to 1.6 percent. These results suggest that as much as 1.6 percent error can be introduced into the dry soil bulk density determination due to imperfection in instrument operation and electronics. This amount of error is very small and will not impair interpretation associated with evaluation of whether oak mats compact soil at drill pad sites.

Change in Soil Bulk Density Following Mat Removal. Across all 38 sites, mean soil bulk density within the 0 to 5.1 cm increment decreased slightly, 2.9 percent, from 1.36 to 1.32 g/cm^3 following oak mat removal (Table 3). On an individual site level, 9 of the 38 sites measured showed significant changes in bulk density, meaning an average decrease of 0.07 g/cm^3 within the 0 to 5.1 cm increment after oak mats were removed. Following mat removal, no soil bulk density values were greater than 1.45 g/cm^3, which was far below the threshold level of 1.65 g/cm^3.

Across all 38 sites, mean soil bulk density within the 0 to 15.3 cm increment increased 2.2 percent from 1.35 to 1.38 g/cm^3 following oak mat removal (Table 3). For individual drill pad sites, only 2 of the 38 sites showed significant changes in bulk density within the 0-6 inch increment after oak mats were removed. Following mat removal, all soil bulk density values were less than the threshold level of 1.65 g/cm^3 established by the USDA (2001) for rangeland environments.

Table 3. Mean soil bulk density before oak mat construction and after removal.

Site ID	---------Soil Bulk Density (g/cm^3)†,‡ ----------					
	0-5.1 cm		0-15.3 cm		0-30.5 cm	
	Before	After	Before	After	Before	After
JF 7-7X	1.42 a	1.32 a	1.47 a	1.42 a	1.5 a	1.45 a
JF 19-7X	1.35 a	1.34 a	1.37 a	1.41 a	1.41 a	1.46 a
JF 27-7X	1.28 a	1.31 a	1.30 a	1.35 a	1.33 a	1.45 a
JF 39-7X	1.36 a	1.22 b	1.39 a	1.38 a	1.41 a	1.43 a
JF 67-7	1.38 a	1.21 a	1.43 a	1.35 a	1.43 a	1.38 a
JF 120-7	1.37 a	1.35 a	1.42 a	1.39 a	1.46 a	1.43 a
SHB 53-20	1.35 a	1.30 a	1.27 a	1.32 a	1.24 a	1.37 b
SHB 54-20	1.40 a	1.38 a	1.34 a	1.42 a	1.31 a	1.43 b
SHB 58-20	1.31 a	1.36 a	1.27 a	1.35 a	1.26 a	1.38 b
SHB 59/113-20	1.37 a	1.45 b	1.34 a	1.47 b	1.29 a	1.48 b
SHB 60/114-20	1.36 a	1.28 b	1.32 a	1.32 a	1.29 a	1.35 a
SHB 69-20	1.38 a	1.33 a	1.34 a	1.33 a	1.25 a	1.32 b
SHB 70-20	1.32 a	1.29 a	1.28 a	1.28 a	1.25 a	1.29 b
SHB 71-20	1.36 a	1.35 a	1.32 a	1.33 a	1.3 a	1.38 b
SHB 75-20	1.33 a	1.30 a	1.31 a	1.31 a	1.26 a	1.33 b
SHB 76-20	1.35 a	1.34 a	1.31 a	1.33 a	1.25 a	1.36 b
SHB 111-20	1.44 a	1.30 b	1.35 a	1.37 a	1.30 a	1.40 b
SHB 112-20	1.39 a	1.35 a	1.38 a	1.40 a	1.32 a	1.41 b
SHB 112X-20	1.36 a	1.37 a	1.30 a	1.42 a	1.26 a	1.42 b
SHB 122-20	1.36 a	1.35 a	1.32 a	1.36 a	1.26 a	1.36 b
SHB 123-20	1.32 a	1.31 a	1.29 a	1.32 a	1.30 a	1.36 a
SHB 124-20	1.37 a	1.37 a	1.31 a	1.37 a	1.32 a	1.37 a
SHB 124X-20	1.33 a	1.34 a	1.31 a	1.32 a	1.33 a	1.31 a
SHB 125-20	1.35 a	1.34 a	1.29 a	1.35 a	1.24 a	1.35 b
SHB 51-28	1.36 a	1.33 a	1.37 a	1.42 a	1.43 a	1.49 b
SHB 52-28	1.47 a	1.39 a	1.56 a	1.54 a	1.56 a	1.57 a
SHB 61-28	1.51 a	1.44 a	1.60 a	1.57 a	1.58 a	1.60 a
SHB 68-28	1.44 a	1.39 a	1.48 a	1.53 a	1.50 a	1.51 a
SHB 19-34	1.27 a	1.24 a	1.25 a	1.36 a	1.33 a	1.33 a
SHB 30-34	1.35 a	1.27 b	1.39 a	1.38 a	1.41 a	1.33 a
SHB 31-34	1.33 a	1.23 b	1.34 a	1.30 a	1.37 a	1.42 b
SHB 42-34	1.34 a	1.20 b	1.31 a	1.27 b	1.35 a	1.38 a
SHB 43-34	1.28 a	1.21 a	1.27 a	1.31 a	1.30 a	1.34 b
SHB 46-34X	1.33 a	1.31 b	1.29 a	1.49 a	1.31 a	1.45 a
SHB 47-34X	1.36 a	1.34 b	1.39 a	1.43 a	1.40 a	1.44 a
SHB 48-34	1.29 a	1.27 a	1.30 a	1.35 a	1.32 a	1.39 a
SHB 96-34	1.28 a	1.24 a	1.36 a	1.32 a	1.39 a	1.41 a
JF 25-4	1.28 a	1.33 a	1.35 a	1.42 a	1.36 a	1.43 a
Total Mean	**1.36 a**	**1.32 b**	**1.35 a**	**1.38 b**	**1.35 a**	**1.41 b**

† Mean value of six measurements per drill pad.

‡ Means within depths followed by a different letter are significantly different ($p<0.05$).

Across all 38 sites, mean soil bulk density within the 0 to 30.5 cm increment increased from 1.35 to 1.40 g/cm^3 following oak mat removal (Table 3). For individual drill pad sites, 17 of the 38 sites showed significant changes in bulk density within the 0 to 30.5 cm increment after oak mats were removed. Although significant increases in bulk density were present increases were small, an average of 0.09 g/cm^3, which is not expected to cause a measurable change in plant growth. Following mat removal the average soil bulk density values for this depth were less than the threshold level of 1.65 g/cm^3.

Cost-Benefit Discussion

Construction Costs

The cost to acquire and to construct an oak matted drill pad is generally less than using conventional cut and fills procedures. A matted drill pad does not have reserve pit, flare pit, and condensation tank features. Instead, underground piping from each matted drill pad transport both drilling fluids and waste products to a centralized reserve pit, flare pit, and condensation tank. Construction of only one flare pit, and one reserve pit, to service 5 to 10 oak mat drill pads represents a cost savings. Access roads are also constructed using oak mats, eliminating costs associated with surfacing, dust control, grading, and reclamation.

Construction costs are a function of the slope gradient where the drill pad is constructed. As the slope gradient increases, cut-and-fill construction costs will increase due to the greater amount of fill that must be moved to construct a near level drill pad. Therefore, as landscape slope gradient increases, the cost of matting a drill pad may be less than the conventional cut-and-fill procedure. However, as landscape slope gradients approach 10 percent, oak mats may have limited feasibility.

Drilling Costs

Drilling costs are generally higher on an oak matted drill pad as compared to conventional cut-and-fill drill pads. Because an oak matted pad does not have a traditional reserve pit, a ‘closed loop’ system must be engineered to treat drill cuttings. At present, the costs of this closed loop system greatly reduce the overall cost-benefit of oak matting. However, the development of lower cost alternatives to this treatment system is imminent.

Reclamation Costs

Reclamation costs are greatly reduced when using the oak matting construction technique and may potentially offset increased drilling cost requirements. Using oak mats, there is no impact to soil structure, no loss of valuable topsoil, and no degradation of the soil resource due to mixing. Plant communities and seed banks remain intact, eliminating the need for seeding. Weed introduction is kept to a minimum, reducing the need for costly weed control and potential re-seeding. Oak mat use also eliminates the need for costly earth moving and site preparation practices such as grading, ripping, and discing. Furthermore, oak mat use can help meet regulatory agency reclamation requirements in an expedited manner.

Summary

Overall, the use of oak mats tended to increase and/or protect grass and forb community. Grass growth, on average, improved when oak mats were used. Forb populations remained similar and shrubs were negatively impacted. As the soil is only minimally disturbed, vegetation re-establishment is easier to achieve, compared to the conventional cut-and-fill procedures for drill pad construction. The soil resource remains intact, as does the seed bank. In addition, the mats may aid in soil moisture retention and create favorable microsites for grass and forb development. Oak mats may also benefit habitat by removing older shrubs, promoting new growth, and contributing to a mosaic-type landscape.

When compared to the traditional cut-and-fill method of site construction, weed presence on reclaimed sites is reduced when oak mats are used. While weeds are commonly found on large portions of reclaimed cut-and-fill sites, weedy forbs contributed to less than one percent of oak mat area canopy cover, and are likely to be kept under control with best management practices.

In summary, for 38 mat removal areas the mean soil bulk density values changed -2.9, 2.2, and 3.7 percent for the 0 to 5.1, 0 to 15.3, and 0 to 30.5 cm depth increments, respectively. Following mat removal, no average soil bulk density values exceeded the 1.65 g/cm^3 threshold established by the USDA (2001) for rangeland environments. These results indicate the oak matting method will not increase mean soil bulk density to levels that would impact plant growth.

Matted drill pads will greatly reduce the environmental impact in landscapes being developed for resource extraction. Acceptance of this matting methodology will be a direct function of cost compared to conventional drill pad construction techniques, and the regulatory demands of state and federal government agencies.

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