INFLUENCE OF RECLAMATION MANAGEMENT PRACTICES ON SOIL BULK DENSITY AND INFILTRATION RATES ON SURFACE COAL MINE LANDS IN WYOMING[1]

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Abstract. A study was conducted to examine the impacts of land reclamation and management practices on the saturated infiltration rates (K_s) and bulk densities (BD) of soils in reclaimed surface coal mines of Wyoming. The use of direct-hauled topsoil vs. stockpiled topsoil, hay mulch vs. stubble mulch, grazing vs. no-grazing, and standard seed mixes (grass seeding) vs. shrub mosaic seed mixes as surface coal mineland reclamation practices were studied in five coal mines of the Powder River Basin, the Green River Coal Region and the Hanna Coal Field in Wyoming. Results from the reclaimed sites with the above listed management practices were compared to each other and with representative soils from adjacent native undisturbed sites. In all the study sites, native undisturbed soils had the lowest BD and the highest K_s compared to reclaimed soils. At Jim Bridger mine, results indicated no differences in BD and K_s between stockpiled and directly hauled soils. At the Belle Ayre mine, there was no significant difference in K_s between reclaimed soils and native undisturbed soil. At Seminoe mine, reclaimed stubble mulched soil had greater K_s (9.208 mm/min) than native undisturbed soil K_s (6.042 mm/min). At Jacob's Ranch, ungrazed soils had greater K_s (6.958 mm/min) than grazed soils K_s (3.350 mm/min) and native undisturbed soils (3.833 mm/min). BD at 0-5 cm for grazed soils was also greater (1.462 g/cm^3) than for ungrazed soils (1.255 g/cm^3) . Native undisturbed soils had the lowest BD (1.116 g/cm^3) averaged over all depths. Although native undisturbed BDs were generally lower, their K_s were not always greater. These results suggest that removal and manipulation of soil during mining accompanied by heavy machinery traffic over reapplied topsoil during reclamation may cause some degree of soil compaction relative to undisturbed sites. However, it can be concluded that land reclamation and management measures taken during and after mining may help to improve infiltration rates.

Additional Key Words: mine land reclamation, compaction, saturated infiltration

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Introduction

The ultimate goal of surface mineland reclamation is the re-establishment of a productive, healthy and sustainable ecosystem suitable for post-mining land use. The reclaimed ecosystem has to be able to support a range of natural processes in a way similar to the pre-mining state. Surface mining may alter several hydrologic processes like infiltration, overland flow, groundwater storage, vadoze zone flow and evapotranspiration (National Academy of Sciences, 1990). In this context, this paper discusses the effect of surface coal mining and reclamation or management practices on two physical characteristics of soil: bulk density and infiltration.

Bulk density is often used to measure compaction in soils. Compaction is described as being the result of increase in bulk density or a decrease in void ratio or porosity. It needs to be prevented or reduced in order to maintain adequate soil porosity to allow for soil biochemical activities, air movement and plant root development and establishment. It usually forms layers of high bulk density rather than a uniformly compacted soil mass (Warkentin, 1971). These layers may be formed below the surface due to rolling loads or on the surface due to raindrop action. The compact layers affect infiltration, water retention and transmission. Compaction has also been defined as the change in volume caused by forces that may originate either from mechanical sources such as machines, or from natural sources such as drying and wetting (Harris, 1971). In the case of surface coal mining and reclamation, compaction may result from salvaging and handling topsoil when wet (McSweeney and Jansen, 1984). Frequent and heavy vehicular traffic during spreading and leveling operations causes compaction that forms an abundance of fine-sized inter-aggregate pores in the soil (Sharma and Carter, 1996). Vehicular compaction decreases water permeability as well as root penetrability (Munshower, 1994). Such compaction is usually limited to the areas beneath the wheels (Hillel, 2000). Compaction may also occur as a result of long-term storage of topsoil in stockpiles.

Infiltration rate relative to the rate of water supply, determines the amount of water entering the root zone and the amount of water lost as runoff (Hillel, 1998). When infiltration rates decrease, plants may be denied sufficient moisture and erosion rates may increase (Hillel, 1982). Thus, it a very significant factor should be considered for the success of any restoration and reclamation effort.

For restabilization of soil a variety of land management practices are employed. Surface mulching is one of them. It helps to control erosion and acts as an organic amendment with pronounced impacts on soil infiltration, soil structure and total organic matter (Munshower, 1994). Native hay, stubble mulch and sawdust have often been used during the mine reclamation processes to enhance the physico-chemical structure and properties of the soil and to promote vegetation growth.

Grazing management of reclaimed surface coal mine land is the dominant post-mining land use in Wyoming. It has been recommended by Wyoming DEQ as a post-reclamation land use (WYDEQ, 1991). According to Steward (1996), its two major purposes are husbandry and landscape enhancement (stimulation of root growth, maintenance of optimum litter level, removal of excess biomass and creation of surface microsites). It can help to manipulate the shrub component of the reclaimed community (Steward and Shin, 1996a). Sagebrush growth can be encouraged by reducing competition from grasses with grazing (Steward and Shin, 1996b). Grazing increases the diversity of palatable species for grazers, provides shelter for animals and traps snow in the winter, increasing soil moisture (Steward and Shin, 1996c). It is important for grass growth too as without it, grasses may not be stimulated to produce multiple stems (Steward and Shin, 1996b). However, in addition to positive impacts, grazing, if not well-managed, may have some negative impacts on the soil, such as increasing soil compaction. Martinez and Zinck (2004) studied effects of grazing on pastures in the Amazon Basin and found evidence of increased bulk density, and decreased porosity after a decade of cattle trampling. This resulted in reduction of saturated infiltration rate in both fine and coarse textured soils. Alegre and Cassel (1996) found increased bulk density and decreased infiltration from overgrazing after land clearing and management through slash and burn agriculture. Such impacts may be insignificant if the grazing program is well managed and constantly monitored with respect to ecosystem recovery. For instance, Beuckes and Cowling (2003) found that low frequency, short-duration and non-selective but intensive livestock herbivory led to greater soil stability and infiltration in South Africa.

At the beginning of the surface coal mining process, soil is removed and stockpiled to protect it from damage due to mining operations, contamination from foreign materials or compaction from heavy machinery (Stahl et al., 2002). This requires removal of the A-horizon (the humus rich, dark topsoil) and the layer below it (the B-horizon or the root medium). During stockpiling, the soil is stored separately and undisturbed for a while throughout the duration of the mining activity in one area. As an alternative to stockpiling, topsoil can be directly hauled too, i.e. stripped and reapplied to a subsoil or spoil in one operation without storage time. According to Munshower (1994), topsoil management and application practices may damage the soil structure, complex nutrient cycles, mycorrhizal associations, surface litter distribution, absorption of solar radiation and surface microtopography. These disruptions may prohibit the development of later seral species. A study conducted by Ghose and Kundu (2004) in an open cast coal project in India revealed negative effects on the microbiological, chemical and physical properties of topsoil stored for a long time. Stahl et al. (2002) compared Wyoming uranium mine soils that were stockpiled and those that were left in-situ during the mining process. They found a greater relative degree of soil degradation like loss of organic matter in the stockpiled soil. However, though direct hauling of soil during mining would be preferred to minimize the loss of soil aggregation and organic matter, it is not always a feasible or viable option.

One of the final and most prominent phases of mineland reclamation is revegetation, which is a difficult process prone to failure if not properly implemented and monitored. Shrub seeding and grass seeding is done in Wyoming. The Wyoming DEQ standard (WYDEQ, 1996) for wildlife habitat as post-mining land use is one shrub per m^2 in 20% of the land area. A major concern of shrub restoration on restored mine spoils is the effect of soil compaction from heavy machinery traffic during soil replacement and grading (Ashby, 1997). Grass seeding may be done so that the reclaimed vegetation can be as close to its original native state and functions in species composition. In this case, the main function would be grazing.

The objectives of the study were as follows:

i. To examine the effects of direct-hauling topsoil vs. stockpiling topsoil, hay mulching vs. stubble mulching, grazing vs. no-grazing, and standard seed mix use (grass seeding) vs. shrub mosaic seed mix use on soil bulk density and infiltration rate

ii. To compare the effects of related reclamation and management practices, i.e., direct-hauling topsoil vs. stockpiling topsoil, hay mulching vs. stubble mulching, grazing vs. grazing exclusion, and grass seeding vs. shrub seeding

iii. To compare bulk density and infiltration results from the above practices in reclaimed sites with adjacent undisturbed (or native) sites.

Materials and Methods

Study Sites

During the summer of 2003, sampling was conducted in reclaimed areas of five surface coal mine sites in three regions of Wyoming as shown in Table 1. Three mines are located in northeastern Wyoming's Powder River Basin. This area has an average altitude of approximately 900 m, receives 250 mm – 380 mm of annual precipitation and is mainly composed of rolling hills (SMTC, 2002). The other two mine sites are in the Green River Basin and the Hanna Basin respectively, both receiving lower than 250 mm of annual precipitation. The former is at an altitude of approximately 1200 m. while Hanna Basin is above 1800 m.

Table 1. Mineland reclamation sites studied

Study Sites[1]	County	Basin
Belle Ayr (BA)	Campbell	Powder River
Jacob's Ranch (JR)	Campbell	Powder River
Dave Johnson (DJ)	Converse	Powder River
Jim Bridger (JB)	Sweetwater	Green River
Seminoe (Sem)	Carbon	Hanna

[1]Abbreviations are given within brackets

Pre-mining phase soils at Belle Ayr, Jacob's Ranch, Dave Johnston and Seminoe mines were classified as fine-loamy, mixed, mesic, ustic Haplargids (Westerman and Prink, 2004; Munn and Arneson, 1999) while the soils at Jim Bridger mine were classified as coarse loamy mixed, ustic haplargids (Munn and Arneson, 1999). The vegetation type at the Dave Johnston, Jim Briger and Seminoe mines is designated as shortgrass sagebrush steppe while that in Jacob's Ranch and Belle Ayre has northern mixed grass prairie type vegetation. Post-mining and reclamation phase vegetation in these mines includes native grasses, forbs and shrubs, a product of revegetation and seeding with native species, as required by WYDEQ (1996). During field sampling, the dominant common shrub in both undisturbed and reclaimed areas of all mines except Jacob's Ranch was Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* Beetle & Young). In Jacob's Ranch, four-wing saltbush (*Artriplex canescens*) was the dominant shrub.

The different land reclamation and management practices employed in the studied mines are shown in Table 2. The reclamation ages vary according to the mines and the practices employed. They have also been shown along with the applied topsoil depths in Table 2.

Table 2. Approximate age or duration of reclamation and management practices in the study sites (by time of sample collection in 2003).

Study sites	Reclamation or management practices[1]		Reapplied topsoil depth	Reclamation age
			cm	years
BA	shrub mosaic seeding	standard seed mix (grass) seeding	55	11
JR	grazing (5 years, high stocking rates, short duration)	grazing exclusion	55	11
DJ	grazing (6 years, low to moderate stocking rates, long duration)	grazing exclusion	30	26
	shrub mosaic seeding	standard seed mix (grass) seeding	45	11
	stockpiled topsoil (3 years)	directly-hauled topsoil	45	11
JB	stockpiled topsoil (5 years)	directly-hauled topsoil	35	19
Sem	hay mulching	stubble mulching	60	14

[1] Durations and/or types are given within brackets.

Treatments

Table 3 shows different management practices (treatments) used for analyses and comparisons in this study. Four pairs of land reclamation and management practices that had been employed during the mining and post-mining phases were grouped into four treatment groups and compared to each other as treatments within each mine. These treatments were then compared with adjacent undisturbed (non-mined, non-reclaimed) sites, which are referred to as 'native' or 'native undisturbed' sites in this paper. Different comparisons were made at different mines. All treatments within each mine, including the native undisturbed sites, were similar to each other with respect to vegetation types, soil texture, aspect and slope. The aspects were all south facing.

Table 3. Treatments compared in the study. Mines where those treatments were studied are listed within brackets.

Treatment groups	Treatment comparisons
topsoil management (DJ, JB)	stockpiling vs. direct hauling vs. undisturbed native
seeding (DJ, BA)	shrub mosaic vs. grass vs. undisturbed native
mulching (Sem)	hay vs. stubble vs. undisturbed native
grazing (JR, DJ)	grazing vs. no grazing vs. undisturbed native

Soil texture in the reclaimed and undisturbed native sites was similar in most cases. Dave Johnston mine had sandy clay loam soils in all the treatments except ungrazed treatments, which had sandy loam soils. Jacob's Ranch mine had sandy clay loam soil in all treatments. Belle Ayre had sandy clay loam soil texture in the undisturbed native site and clayey soils in the shrub and grass site. Jim Bridger mine had sandy loam soil in the undisturbed and direct-haul treatment sites and loamy soil in the stockpiled treatment. Seminoe mine had sandy loam soil texture in all its treatments.

Field sampling

Soil sampling for bulk density was conducted at two replicate points at intervals of 40 m, along three randomly laid 100 m transects for each treatment site at each mine. Infiltration was measured within a distance of 1 m from the replicate points using a single ring infiltrometer of 10 cm radius based on the method described by Bouwer (1986). The water level drop from 10 cm was observed and noted every 2 minutes until a constant (saturated infiltration rate) or approximately constant value was observed consecutively 3 times. Initial sampling at one mine used 5 minutes intervals for the first two readings. This method was standardized and readings in subsequent mines were taken every 2 minutes as described above. Six sets of infiltration rates were sampled from each treatment site (2 replicates x 3 transects). For bulk density, a hammer driven double cylinder core sampler (Ben Meadows Company, USA) with an inner core radius of 2.54 cm and a cylinder length of 15.24 cm was used. The method described by Blake and Hartge (1986) was employed. Intact samples were collected from the inner core. Soil samples as columns from 0-5 cm, 5-15 cm and 15-30 cm depths were collected with as little disturbance to the columns and as little intermixing of soil from surrounding layers as possible. They were placed separately inside zip-lock bags and carried to a storage facility. Eighteen samples were collected from each treatment (3 depths x 2 replicate points x 3 transects) in each mine.

Analysis

Bulk density (BD) values were obtained using gravimetric method (Blake and Hartge 1986) in gcm^{-3}. Volume (V) of the inner cylinder of the soil corer was calculated for each of the depths sampled (0-5 cm, 5-15 cm and 15-30 cm) by using the formula $V = \pi r^2 * d$, where $\pi= 3.14$, r is the radius of the core sampler's inner cylinder and d is the soil depth. Soil samples were oven dried at 65ºC for 24-48 hours. This lower temperature, instead of the usual 105 ºC was used so that the samples could be used later for other chemical analyses in the lab. Bulk density was calculated by dividing the dry mass M of each sample by the calculated V for the depth from where they were collected. Rocks, when present, were removed by passing the soil through a 2 mm sieve. The rocks were weighed and their volumes were calculated using the common rock density of 2.6 g cm^{-3}. Rock mass and volume were subtracted from initial soil BDs. The rock masses as a percent of total dry soil mass for rock corrected soil samples have been shown in Table 4. Soil samples from DJ and BA mines did not contain rock fragments.

For analyses of infiltration data, the level of water drop per minute was calculated from field data by using the formula I = {(initial water level – final water level)/time} where I is the infiltration rate, the water levels are in mm and the time is in minutes. Average of the constant two final infiltration rates was used to calculate the saturated infiltration rates (K_s) in mm min^{-1}.

Minitab (MINITAB Release 13.1, 2000) was used for statistical analyses. General Linear Model (GLM) was employed. Tuckey's post-hoc analysis was used for significant interactions and for significant factor comparisons. Statistical comparisons of data were done for treatments only within the same mine. The response variables analyzed were bulk density and infiltration. For infiltration, the factor was treatment. For bulk density, the factors were treatment and depth.

Results

Bulk density

At JB, DJ and Sem mines, there were significant differences in soil BD among treatments ($P = 0.017$, < 0.001 and 0.021 respectively). Results of soil BD comparisons in these mines are given in Fig 1, showing results averaged across all three depths and compared only according to treatments as the significant difference was due to treatment only and no significant interaction was observed. At DJ mine, grazed soils and shrub-seeded soils had significantly greater BD than native undisturbed soils ($P = 0.0018$ and < 0.001 respectively). Grass seeded soil, had greater BD than native soils ($P = 0.0539$). At the JB mine, both directly hauled soils and stockpiled soils had greater BDs than native soils ($P = 0.0485$ and 0.0256 respectively). No other significant differences were found there. At Sem mine, hay mulched soils had greater BD than native undisturbed soils ($P = 0.0221$). At BA mine, no treatments studied (grass, shrub, native) were significantly different from each other. These results are also shown in Fig. 1.

Table 4. Rock mass percentages in rock corrected samples in DJ, JB and Sem mines.

Mine	Treatment	Depth	No. of samples with rocks[1]	Rock mass ± SD[2]
		cm		% of dry soil weight
DJ	Grazed	0-5	1	19.07
		5-15	3	23.70 ± 4.27
		15-30	4	15.57 ± 8.56
	Ungrazed	0-5	1	15.20
		5-15	3	10.22 ± 5.78
		15-30	6	11.12 ± 5.99
JB	Direct-haul	0-5	0	0.00
		5-15	2	5.50 ± 3.07
		15-30	3	8.90 ± 2.02
	Stockpiled	0-5	0	0.00
		5-15	4	8.24 ± 5.58
		15-30	6	13.13 ± 8.98
	Native	0-5	0	0.00
		5-15	1	7.07
		15-30	3	10.74 ± 7.42
Sem	Native	0-5	0	0.00
		5-15	0	0.00
		15-30	2	20.57 ± 12.06
	Hay-mulch	0-5	0	0.00
		5-15	0	0.00
		15-30	3	3.65 ± 2.22
	Stubble-mulch	0-5	0	0.00
		5-15	1	0.42
		15-30	4	11.99 ± 12.01

[1] 18 soil samples (6 samples from each depth) were collected from each treatment site.

[2] Standard deviations

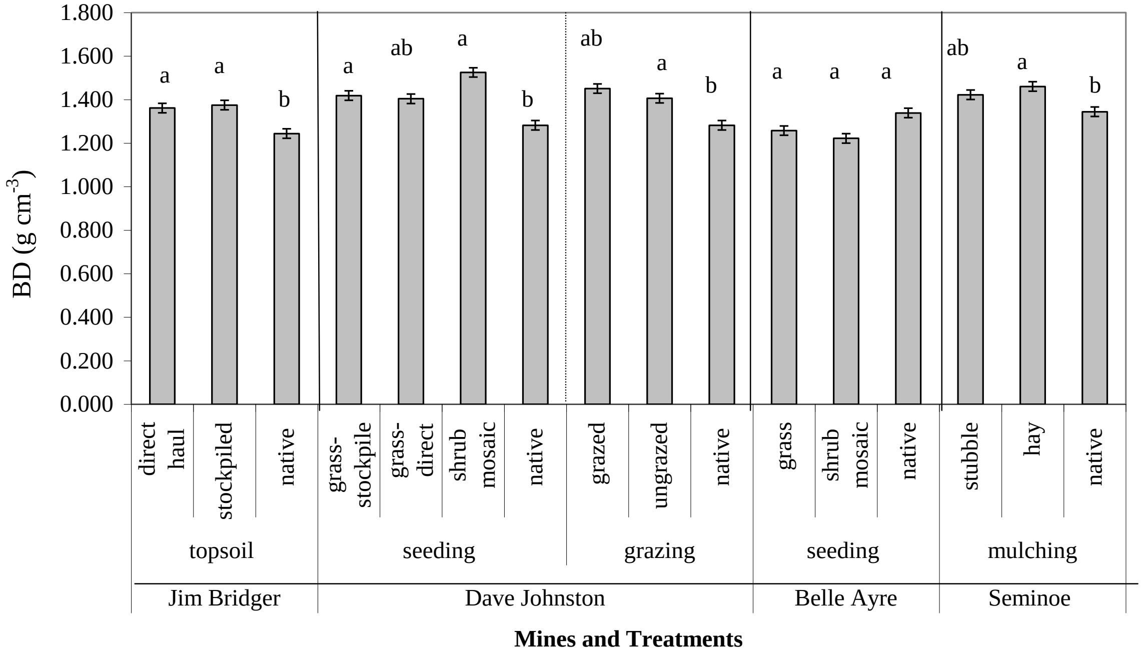

Figure 1. Bulk density results averaged together across all three depths at the JB, DJ, BA and Sem mines, separated according to treatments and treatment groups: different lower case letters within treatment groups denote significant differences within that group. Bars denote standard errors.

At the JR mine, there was a significant interaction between depth and treatment (P = 0.011). The results are shown in Fig. 2, with BDs in all three treatments varying according to depth. At 0-5 cm, grazed soil BD was significantly greater than non-grazed soils (P = 0.0358). Grazed soil at 0-5 cm, 5-15 cm and 15-30 cm had significantly greater BD than native soils at 0-5 cm (P = 0.000, 0.000 and 0.003 respectively). Native soil at 0-5 cm had lower BD than native soils at 5-15 cm and 15-30 cm as well as non-grazed soils at 5-15 cm and 15-30 cm (P = 0.0334, 0.0050, 0.0000 and 0.0001 respectively).

Saturated infiltration rate

All the studied mines, except one, there were significant differences between reclaimed and undisturbed native soils but not always between two compared management practices. At DJ mine, shrub-seeded soils had greater K_s than grass-seeded soils (P = 0.0191), both having been reclaimed with stockpiled soil. Native undisturbed soils had lower K_s than shrub soils (P = 0.0004). Native undisturbed sites had the lowest K_s compared to the rest of the treatments in this mine. At JR mine, ungrazed soils had greater K_s than grazed soils (P = 0.0246). Native undisturbed soils had higher K_s than grazed soils and less K_s than the ungrazed soils but the differences were not significant. At JB mine, native undisturbed soils had significantly greater K_s than directly hauled soils (P = 0.0223). Native undisturbed soil K_s was greater than stockpiled soil too, but the difference was not significant. At Sem mine, stubble mulched soils had greater K_s than native undisturbed soils (P = 0.0592). Mean K_s for stubble mulched soils was higher than for hay mulched soils but the difference was not significant. At BA mine, there was no significant difference in K_s among the three treatments, i.e. shrub, grass and native undisturbed (P = 0.840). These results have been illustrated in Figure 3.

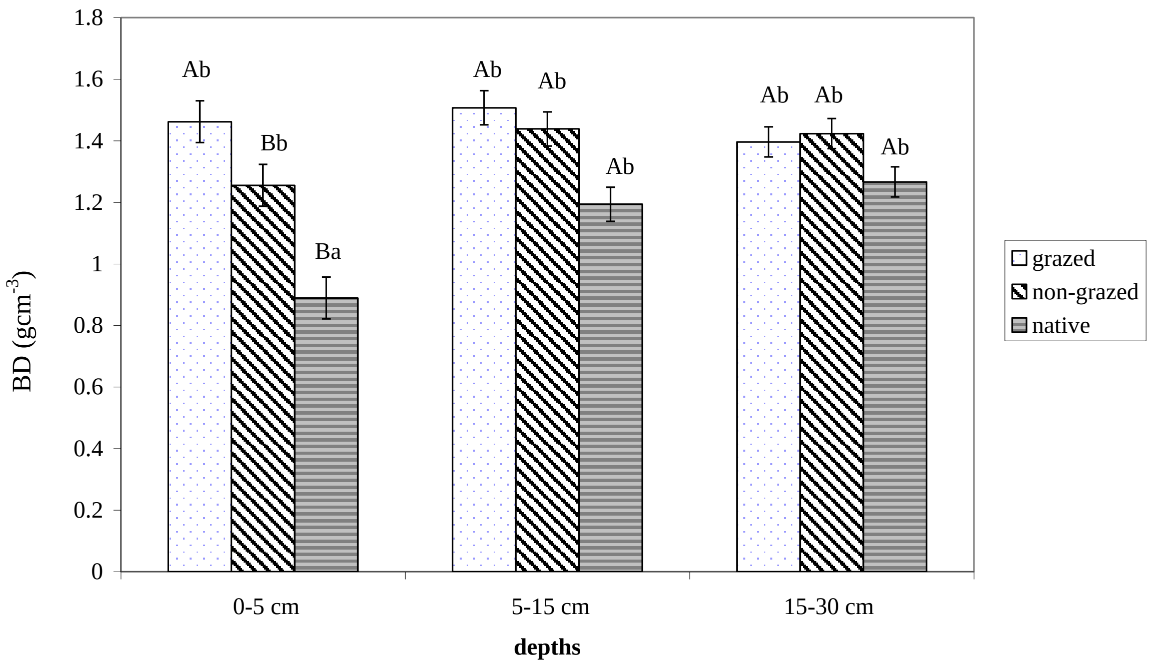

Figure 2. Bulk density results at JR mine showing the interactions between depth and treatment: significant differences between treatments but within same depths are shown by different upper case letters; significant differences of treatments between depths are shown by different lower case letters.

Discussion

Bulk densities were not very high for both reclaimed and native undisturbed sites, implying that the level of compaction resulting from soil salvage, storage, replacement and revegetation in the mines was very low. Generally, in our study sites, greater BD was associated with lower K_s and vice versa. However, native undisturbed soils had lower BD compared to reclaimed soils but not always greater K_s.

Bulk densities for all treatments in the mines were below the minimum level at which root-restricting conditions would occur. These minimum values are approximately 1.40 g/cm^3 for clayey soils, 1.70 g/cm^3 for loamy and sandy clay loam soils and 1.75 g/cm^3 for sandy loam soils (USDA-NRCS, 1996) while the observed bulk densities in all the mines for all treatments ranged between 0.9 and 1.5 g/cm^3. The textures of these soils were sandy loam, sandy clay loam and clay. The clay soils (under grass and shrub in BA mine) had BD less than 1.4 g/cm^3. Reclamation practices in all the study sites had exerted a positive effect on BD of the soil.

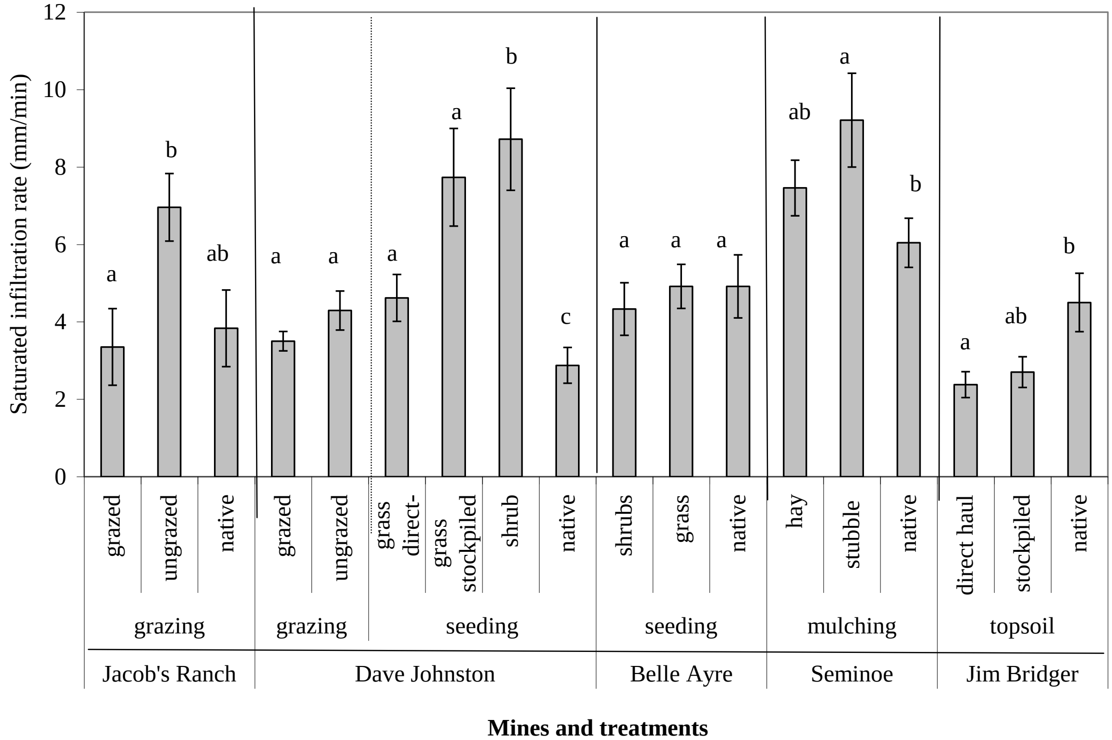

Figure 3. Saturated hydraulic conductivities for different treatments in the mines: significant difference within treatment groups and mines are shown by different lower case letters. Bars denote standard errors.

Native undisturbed soils in the studied mines had lower infiltration rates despite having lower bulk densities. Previous studies can help to understand these results. According to Hallett et al (2003), root exudates may become hydrophobic when stuck to soil particles or they may clog soil pores. This may reduce the infiltration rates in soils in spite of high porosity. Lipiec and Hatano (2004) found that macroporosity, which is inversely proportional to soil compaction, had a significant effect on root growth, water flow and solute flow. Sharma and Carter (1996) found that compaction of soils in mines of North Dakota decreased the total pore volume at the cost of the inter-aggregate effective pores while increasing the volume of intra-aggregate residual pores. At high porosity, the inter-aggregate pores, which are larger and allow faster infiltration, dominate in the infiltration process while at higher bulk density or compaction beyond a certain density, intra-aggregate pores, which are smaller and show less infiltration, start to dominate this process (Scurati et al. 2000).

Relatively higher infiltration rates compared to other soils of similar types were observed in soils of our study sites. Manipulation of the soil during and after mining may have caused this effect. Land use practices have been found to have greater effects than the soil types on water movement in the soil (Schwartz et al. 2000). The soil textures in our study sites varied from sandy loam to sandy clay loams for most treatments as mentioned earlier the text. The rock and coal fragments in the soil could have caused higher infiltration rates in these soils. As mentioned by Azooz and Arshad (1996), the structural stability of soil pores and moisture condition of soil at the time of measurement affects the ability of soil to absorb and transmit water. The pore networks can also vary with time due to surface seal formation after precipitation, soil cracking under drying conditions, breakdown of aggregates and air-entrapment under wet conditions (Azooz and Arshad, 1996). Large soil macropores, deep ripping of the restored soil before revegetation and high porosity in some post-mined soils may cause water to move rapidly through the profile (National Academy of Sciences, 1990). The size, arrangement and distribution of pore spaces, instead of total porosity, may also act as significant factors for increased saturated hydraulic conductivities (Schwartz et al. 2000).

Mulching was seen to improve bulk density and infiltration rates in reclaimed soils of Wyoming. In agreement with these findings, Barton et al. (2004) found that straw mulching maintained the topsoil structure and improved infiltration in China. This decreased runoff and erosion rates. Rasse et al. (2000) found that Alfalfa root mulching caused an increase in saturated hydraulic conductivities, water recharge rates, total and macroporosity in the A_p horizon.

Grazing did not cause any significant change in the bulk density of the soil compared to ungrazed soils at DJ mine. At JR mine, it was observed that soils at 0-5 cm depth in grazed sites had higher bulk density compared to soils from the same depth at ungrazed sites. Saturated infiltration rates increased in absence of grazing in the same mine. These results agree with previous research done by Pietota et al. (2004) who found that that even low intensity of grazing caused a decline in infiltration rates in sandy loam and heavy clay soil. They observed a fall in pore volume below the topsoil.

There was no significant difference in BD between directly hauled soils and stockpiled soils. However, directly hauled soils appeared to have significantly lower K_s compared to native undisturbed soils. The disruption of soil pore networks during manipulation of the soil could have be the reason behind this effect.

Conclusion

These results show that different reclamation practices have varied impacts on soil physical properties. Overall, reclamation efforts had positive effects on soil bulk density and infiltration. The results also suggest that removal, storage and manipulation of soil during mining, accompanied by movement of heavy machinery over the reapplied soil during reclamation, may increase soil bulk density relative to undisturbed native sites. However, higher bulk densities associated with some post-mining activities were below the minimum level at which root restriction occurs. The effect of mining and reclamation on bulk density, depending on the reclamation measures employed, did not seem to hamper the infiltration rates significantly in reclaimed areas. Infiltration rates were seen to improve with management practices like stubble mulching, grass seeding and shrub seeding. Further studies in these sites should be done to examine the pore distribution in detail, including studies on inter- and intra-aggregate pores.

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