Tillage Effects on Bulk Density During Reclamation of Mined Soil

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Currently, about 2,000 acres of land are disturbed by strip-mine activities each year in North Dakota. During the mining process, the soil is generally removed (topsoil and subsoil separately), stockpiled and respread when mining has finished. The majority of mining companies in North Dakota use large scrapers to facilitate removing and respreading the soil materials plus graders to maintain a fairly level surface.

Stripmining and reclamation processes have been shown to change some soil properties. When compared to undisturbed soil, bulk densities are usually higher (Bauer et al., 1976), runoff amounts higher for wet surface conditions for grasslands (Schroeder, 1987), and rates of water infiltration into and water movement within the reclaimed profiles are slower (Gilley, 1981). Some of these differences are directly attributable to changes in total porosity and hydraulic conductivity caused by compaction of the soil materials during reclamation activities (Schroeder, 1987).

Compaction, whether on cultivated cropland or reclaimed land, is generally determined by measuring bulk density (weight per unit volume). However, bulk density values by themselves may be misleading, especially when measured by coring, since some compaction may occur during the coring operation. Measurements of depths of rooting for various crops or grasses may give a better indication of the effect compaction of soil materials will have on grain or biomass production. Restricted root growth decreases the volume of soil a plant is able to use to extract water and nutrients necessary for production of grain or biomass. In a semiarid state like North Dakota where precipitation during the growing season is not always adequate, restricted rooting depths may cause an earlier onset of water stress on the growing plants, reducing potential productivity.

Compaction of reclaimed soil materials which results in higher bulk densities and other property changes is due mainly to the heavy mining equipment used to respread (scrapers) and level (graders) the soil surface. The degree to which this equipment increases the bulk densities of the reclaimed soil also is affected by soil texture and moisture content of the soil during the various operations.

A long-term study was initiated in 1987 to see if some of this compaction through reduction of bulk density values could be accomplished during reclamation rather than waiting for problems to appear many years from now. The main objectives were 1) to determine if various tillage treatments or operations after or during subsoil respreading, respectively, would result in lower bulk densities after topsoil respreading; 2) to determine if tillage operations after topsoil respreading would result in lower bulk densities; and 3) to study the effects of the treatments by depth over time on such factors as bulk density, root penetration and soil water movement. The third objective, which will not be addressed in this article, may allow for determining residual tillage effects on the reclaimed areas that are not distinguishable from bulk density values alone taken immediately following reclamation.

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Methods and Materials

Experimental sites (prior to topsoil and subsoil respreading operations) were located on the Baukol-Noonan, Inc. mine near Center and on the Coteau Properties, North American Coal Corp. mine near Beulah. The area at Center is approximately 2 acres in size while the plot at Coteau is approximately 5 acres.

Subsoil was respread over 80 percent of each plot using normal mine procedures. This consisted of scrapers respreading the materials in 4 to 6 inch thicknesses followed by grading for surface leveling. The remaining 20 percent of each plot was replaced as thick as possible (deep lift) by scrapers utilizing minimum traffic patterns and no grading until enough subsoil material was respread to constitute the depth to be replaced.

Following a final grading operation on the subsoil, the area other than the deep lift area was subdivided into four equal areas for further treatments. These tillage treatments consisted of chiseling, grader ripping, deep ripping (D9 bulldozer at Center, larger chisel-like subsoiler at Coteau) and no tillage.

Topsoil was then respread over the entire plot areas using scrapers and normal spreading procedures. Following a final grading, the plot was subdivided into nine equal areas for the topsoil treatments. Topsoil tillage treatments were applied perpendicular to the subsoil treatments and rotated randomly across the plot such that each tillage treatment was used three times. The tillage treatments used were chiseling, grader ripping and deep ripping using the same equipment used for the subsoil tillage treatments. Each topsoil by subsoil tillage treatment thus had three replicated subplots. Each subplot was 21 by 70 feet at Center and 50 by 100 feet at Coteau.

Following the topsoil tillage treatments at Center, the entire plot area was windrowed to facilitate rock removal. The entire area at Coteau was chiseled to decrease cloddiness.

An access tube was installed to 5 feet in each subplot to facilitate future measurements of soil water and bulk density changes by depth over time. Cores were sectioned into 6-inch segments during removal for bulk density calculations. Additional characteristics of the cores that are now being measured include particle size, wilting point, pH, electrical conductivity and sodium adsorption ratio.

Analysis of variance procedures were used to analyze tillage effects on the bulk density values by depth. A nonrandomized block design was used for the analysis.

Discussion

Table 1 lists some of the measured characteristics of the tillage treatments performed at the two mining sites. The reduced spacings for the grader ripping treatments at Coteau was due to two passes being used rather than only one pass that was used at Center.

All tillage treatments at both sites, except the deep rip at Center, left the topsoil and subsoil surface very rough and cloddy with no evidence of wheel tracks. Wheel tracks were present after the deep rip treatment with the D9 bulldozer at Center. The bulldozer shank "lifted" the soil materials approximately 8-10 inches for a distance of approximately 12 inches on either side of the shank. Some soil lifting was observed farther away from the shank though not to the degree near the shank. This treatment at Center also left shank furrows that did not completely fill in during topsoil respreading or topsoil tillage. These shank furrows will be monitored separately for their subsequent effects on root and water penetration over time.

Mean bulk density values from the access tube core data are listed in Table 2 and 3 for the Center and Coteau sites, respectively. The deep rip topsoil treatment at Center did result in significantly, though inconsistently, lower bulk density values to the depth applied than was found for the chisel and grader rip treatments. Only the 6 to 12-inch depth at Coteau showed significant differences and this was attributed to the higher values for the grader rip treatment. The values at both sites would seem to indicate that the operations conducted on the sites following the topsoil tillage treatments may have caused some additional compaction to have taken place.

No significant tillage effects on the subsoil bulk densities were found for either site. Bulk density values within each site for each depth increment were also relatively uniform. These data indicate that the tilled and deep lift subsoil areas were compacted during the topsoil respreading (approximately 14 and 17 inches at Center and Coteau, respectively) and grading operations. The values were, however, still slightly lower, though not significantly so, than the values found for the no-till subsoil areas of each site.

At Coteau (Table 3), no significant topsoil by subsoil tillage interaction effects were found for bulk density for any depth increment. At Center, remnants of the topsoil tillage still had a significant effect near the surface (Table 2). However, no significant effect, except one depth, was present beneath the surface. A void area was contacted for one sample at the 30 to 36-inch depth at Center which caused the topsoil by subsoil interaction term to be significant for this depth. Deletion of this one value resulted in a lack of significant difference at this depth rather than a presence of significant different. Bulk density values within both sites were relatively uniform for each depth increment.

Summary

Two experimental sites were selected, one each at two mining locations, to study the effect of several various tillage treatments on bulk density during disturbed land reclamation. Tillage treatments imposed on the respread and graded subsoil included deep ripping, grader ripping, chiseling, deep lift (replacement as thick as possible with minimum traffic) and no till. Following topsoil respreading and grading, three additional tillage treatments perpendicular to the subsoil treatments were applied and consisted of chiseling, grader ripping and deep ripping. Soil cores were removed from each topsoil by subsoil tillage subplot (three replications each), sectioned into 6-inch cores and analyzed for bulk density.

Table 1. Tillage characteristics applied to the study sites (fall, 1987).

	Topsoil Treatments			Subsoil Treatments[1]		
Tillage	Average spacing	Depth range	Average depth	Average spacing	Depth range	Average depth
	Inches					
Center						
Chisel	12	5-7	6	12	4-7	6
Deep Rip[2]	50	40-48	45	48	48-53	50
Grader Rip[3]	54	10-14	12	54	8-13	11
Coteau						
Chisel	12	4-7	6	12	4-7	6
Deep Rip[4]	42	19-25	23	42	24-30	25
Grader Rip[3]	27	12-20	17	27	12-14	13

[1]Other treatments were deep lift and no till.
[2]D9 bulldozer with 5-inch thick shank.
[3]Standard grader with 3-inch thick shanks. Two passes were used at Coteau.
[4]Large chisel-like subsoiler with 1.5-inch thick shanks.

Two main conclusions were drawn from the data due to the similarity in results between the two sites. First, no significant subsoil tillage treatment effects were found for any depth increment at either mining site. Traffic by scrapers and graders during the topsoil respreading and grading operations effectively recompacted the tilled soil to negate tillage effects on bulk density values to values not significantly different from those where no tillage occurred. Second, operations on the sites following the topsoil tillage treatments to reduce roughness and cloddiness plus to facilitate rock removal have generally caused the bulk density values between topsoil treatments to be not significantly different. Some effect of the topsoil tillage treatments on bulk density remain in that values near the surface are lower than those at greater depths.

The tillage treatments applied in this experiment were not as effective in reducing compaction (lowering bulk density values) as was expected. Methodologies must be developed, therefore, that will accomplish this after most or all traffic necessary for reclamation (and possibly including seeding) has been completed.

Both sites will be monitored periodically after grass is planted in 1988 to determine residual tillage effects, if any. Parameters to be measured will include changes by depth over time for bulk density, root penetration and soil water. Additionally, biomass production will also be measured. These parameters may allow for distinguishing the effects of tillage during reclamation on the performance of the reclaimed land that could not be determined from measuring only bulk density following reclamation.

Acknowledgment

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Table 2. Mean dry bulk densities (g/cm^3) from access-tube-installation cores for the Center tillage study location (fall, 1987).

Tillage Treatment[1]		Depth (in)									
Topsoil	Subsoil	0-6	6-12	12-18	18-24	24-30	30-36	36-42	42-48	48-54	54-60
						Topsoil Treatments[2]					
CHIS		1.26	1.42	1.58	1.64	1.62	1.52	1.53	1.57	1.70	1.74
DR		1.15	1.36	1.42	1.60	1.60	1.55	1.47	1.55	1.62	1.65
GR		1.30	1.36	1.55	1.65	1.68	1.57	1.59	1.59	1.66	1.72
	LSD (0.10)[3]	0.06	NS	0.06	NS	0.05	NS	0.08	NS	NS	NS
						Subsoil Treatment[2]					
	CHIS	1.22	1.36	1.53	1.61	1.61	1.58	1.53	1.58	1.70	1.69
	DL	1.34	1.40	1.49	1.63	1.65	1.46	1.54	1.57	1.56	1.67
	DR	1.18	1.39	1.51	1.62	1.63	1.57	1.51	1.58	1.66	1.74
	GR	1.17	1.35	1.51	1.62	1.61	1.53	1.48	1.52	1.69	1.76
	NT	1.28	1.39	1.54	1.68	1.67	1.60	1.58	1.58	1.68	1.67
	LSD (0.10)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
						Topsoil × Subsoil Treatments[2]					
CHIS	CHIS	1.18	1.39	1.57	1.59	1.57	1.62	1.60	1.59	1.69	1.68
	DL	1.34	1.43	1.52	1.66	1.60	1.26	1.48	1.56	1.64	1.78
	DR	1.31	1.43	1.56	1.70	1.66	1.59	1.49	1.58	1.67	1.71
	GR	1.26	1.41	1.64	1.61	1.59	1.52	1.48	1.50	1.73	1.80
	NT	1.23	1.43	1.62	1.67	1.70	1.60	1.59	1.61	1.74	1.76
DR	CHIS	1.21	1.35	1.43	1.55	1.56	1.46	1.36	1.49	1.70	1.67
	DL	1.35	1.36	1.39	1.58	1.60	1.60	1.54	1.51	1.44	1.53
	DR	1.00	1.39	1.41	1.60	1.60	1.53	1.46	1.58	1.64	1.80
	GR	1.10	1.34	1.42	1.63	1.59	1.52	1.41	1.53	1.68	1.71
	NT	1.11	1.33	1.46	1.64	1.66	1.64	1.58	1.62	1.63	1.53
GR	CHIS	1.26	1.35	1.59	1.68	1.69	1.65	1.62	1.68	1.71	1.71
	DL	1.34	1.42	1.56	1.65	1.75	1.52	1.62	1.65	1.60	1.69
	DR	1.23	1.34	1.56	1.56	1.63	1.56	1.60	1.58	1.69	1.72
	GR	1.16	1.30	1.47	1.64	1.65	1.56	1.55	1.52	1.66	1.77
	NT	1.49	1.40	1.54	1.72	1.66	1.56	1.59	1.51	1.65	1.71
	LSD (0.10)	0.14	NS	NS	NS	NS	0.16	NS	NS	NS	NS

[1]CHIS - chiseled, DR - deep ripped (D9 bulldozer), GR - grader ripped, DL - deep lift replacement, and NT - no tillage.

[2]15 replications for topsoil, 9 for subsoil, 3 for topsoil × subsoil.

[3]Least significant difference at the 10% level. NS indicates no significant differences between values.

References

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Table 3. Mean dry bulk densities (g/cm^3) from access-tube-installation cores for the Coteau tillage study location (fall, 1987).

Tillage Treatment[1]		Depth (in)									
Topsoil	Subsoil	0-6	6-12	12-18	18-24	24-30	30-36	36-42	42-48	48-54	54-60
		Topsoil Treatments[2]									
CHIS		1.17	1.32	1.47	1.49	1.53	1.49	1.50	1.49	1.54	1.57
DR		1.13	1.31	1.42	1.48	1.51	1.49	1.52	1.49	1.51	1.55
GR		1.25	1.43	1.45	1.51	1.48	1.50	1.48	1.52	1.54	1.56
	LSD (0.10)[3]	NS	0.10	NS	NS	NS	NS	NS	NS	NS	NS
		Subsoil Treatment[2]									
	CHIS	1.19	1.31	1.40	1.45	1.47	1.44	1.47	1.53	1.54	1.59
	DL	1.25	1.38	1.52	1.53	1.47	1.46	1.48	1.47	1.51	1.58
	DR	1.12	1.36	1.45	1.54	1.51	1.48	1.52	1.50	1.56	1.55
	GR	1.13	1.38	1.44	1.46	1.52	1.49	1.47	1.44	1.51	1.55
	NT	1.23	1.36	1.43	1.48	1.56	1.58	1.56	1.55	1.52	1.53
	LSD (0.10)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		Topsoil × Subsoil Treatments[2]									
CHIS	CHIS	1.23	1.36	1.47	1.47	1.51	1.46	1.46	1.52	1.58	1.60
	DL	1.18	1.24	1.52	1.54	1.47	1.46	1.45	1.51	1.49	1.62
	DR	1.19	1.32	1.52	1.53	1.54	1.54	1.52	1.43	1.58	1.53
	GR	1.01	1.31	1.46	1.48	1.55	1.42	1.48	1.43	1.49	1.58
	NT	1.23	1.34	1.39	1.43	1.57	1.55	1.56	1.54	1.55	1.51
DR	CHIS	1.04	1.24	1.34	1.39	1.43	1.44	1.50	1.52	1.47	1.59
	DL	1.30	1.40	1.48	1.48	1.45	1.52	1.48	1.45	1.52	1.52
	DR	1.05	1.31	1.40	1.55	1.56	1.43	1.57	1.48	1.53	1.49
	GR	1.17	1.36	1.41	1.47	1.48	1.50	1.47	1.46	1.54	1.58
	NT	1.10	1.27	1.48	1.52	1.62	1.55	1.60	1.55	1.48	1.55
GR	CHIS	1.28	1.32	1.38	1.49	1.45	1.43	1.46	1.56	1.58	1.58
	DL	1.27	1.49	1.57	1.58	1.51	1.40	1.49	1.45	1.51	1.58
	DR	1.13	1.43	1.42	1.54	1.43	1.50	1.48	1.60	1.58	1.64
	GR	1.20	1.46	1.46	1.45	1.53	1.53	1.47	1.44	1.50	1.48
	NT	1.35	1.46	1.42	1.51	1.50	1.63	1.51	1.57	1.52	1.53
	LSD (0.10)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1]CHIS - chiseled, DR - deep ripped (subsoiler), GR - grader ripped, DL - deep lift replacement, and NT - no tillage.

[2]15 replications for topsoil, 9 for subsoil, 3 for topsoil × subsoil.

[3]Least significant difference at the 10% level. NS indicates no significant differences between values.