IMPACT OF SOIL RECONSTRUCTION METHOD ON YIELD, NUTRITIVE VALUE AND BOTANICAL COMPOSITION OF A MIXED GRASS-LEGUME STAND[1]

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Abstract: Mineral sands mining has disturbed over 400 ha of prime farmland in Dinwiddie County, VA. This land is being reclaimed to a hay and pasture post mining land use. In 2005, an experiment was initiated that compared three soil construction methods. The treatments were 1) Control: rip, lime, P, and routine fertilization per crop management protocols, 2) Biosolids: rip, lime stabilized biosolids at 78 dry Mg per ha, and routine fertilization per crop management protocols, and 3) Topsoil: rip, lime, P to subsoil, 15 cm of topsoil return, and routine fertilization per crop management protocols. The objective of this experiment was to compare the effect of soil reconstruction treatment on the yield, nutritive value and botanical composition of mixed cool-season grass-legume sward. Total seasonal dry matter (DM) yield ranged from 8,500 to 9,500 kg DM per ha and 4,200 to 5,800 kg DM per ha for 2006 and 2007, respectively and was not affected by soil reconstruction treatment or N fertilization in either year ($P > 0.05$). Crude protein (CP) concentration in the forage tissue was higher for the biosolids treatment for the first and second harvest in 2006, but did not differ in 2007. Crude protein was high enough to meet the requirements of a brood cow at all stages of the production cycle. In 2007, total digestible nutrients (TDN) were higher for the biosolids treatment for the first harvest only. In 2007, TDN was greater for the control and topsoil treatments and was likely influenced by greater quantities of legumes found in these treatments. Depending on year and harvest, legumes contributed between 20 and 35% to the total dry matter for the topsoil and control treatments and were not detectable in the biosolid treatment. Initial results indicate that properly amended mine soils generated from the mineral sands mining and reclamation process can support the production of high quality forage crops.

Additional Key Words: biosolids, mineral sands, reclamation, forages

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Introduction

Significant areas of prime farmland in the upper Coastal Plain of Virginia have been disturbed by heavy mineral sands (Ti/Zr-bearing ilmenite, rutile, zircon) mining over the past 10 years. The new mine soils consist of variably mixed and segregated tailings and slimes which have been dewatered and graded. These soils exhibit physical and chemical properties that limit agricultural use due to the inherent infertility of the processed subsoils, the abrupt layering of slimes and tails that often occurs during re-deposition, and heavy compaction from grading (Meredith, 2007). In the fall of 2004 the Carraway-Winn Reclamation Research Farm was developed at Iluka Resources Inc., to enable comparison of different soil reconstruction strategies for the return of mined lands to agricultural production.

Past research has demonstrated that amending drastically disturbed soils with organic materials improves overall reclamation success (Haering et al., 2000). The most common organic amendment used in mined land reclamation is biosolids. The application of biosolids has been shown to increase soil organic matter, cation exchange capacity, soil nutrient levels, water holding capacity, and soil aggregate stability. In addition to the positive impact of biosolids on chemical and physical soil characteristics, they have also been shown to increase forage yields, improve nutritive value, and enhance persistence of newly established stands when compared to using conventional fertilizer.

In the past, Kentucky-31 tall fescue infected with the toxic endophyte has been the standard in reclamation mixtures utilized in the humid southeastern United States. This cultivar has excellent tolerance to both biotic and abiotic stresses (Ditsch and Collins, 2000). However, animal performance is poor due to the presence of the toxic endophyte (Oliver and Fletcher, 2005). When the toxic endophyte is removed from tall fescue animal performance improves, but persistence decreases. Jesup with the Max-Q endophyte, represents the most recent advances in tall fescue breeding. This cultivar is infected with a novel endophyte offers the persistence of Kentuckty-31 infected with the toxic endopyhte and the improved animal performance of endophyte free tall fescue.

In reclamation situations where the designated end land use is hay and pasture, use of novel endophyte tall fescue would be highly desirable. However, high seed cost may limit use. At the present time novel endophyte tall fescue costs approximately four times more that Kentucky-31.

Even at this elevated cost, increases in animal performance would likely justify use (Hoveland, 2005).

Hay and pastureland is a common post mining land use (Ditsch and Collins, 2000) and is the primary land use designated for the mineral sands mine located in Dinwiddie County, VA. Thre has been little research that has evaluated the potential of soils reconstructed after heavy mineral mining to support forage production for livestock systems in the southeastern United States. The objective of this experiment was to compare the effect of soil reconstruction treatments on the yield, nutritive value, and botanical composition of mixed cool-season grass-legume sward.

Methods

The experimental design was a complete block design with a strip-plot treatment arrangement (Gomez and Gomez, 1984) and four replications. Vertical strips consisted of three soil reconstruction treatments and horizontal strips consisted of two nitrogen (N) rates. Plot size was 15 x 84 m. Soil reconstruction treatments were:

1) Control: ripping, 9 Mg lime and 674 kg P_2O_5 per ha, and N-P-K fertilization per crop management protocols;
2) Biosolids: ripping, lime-stabilized biosolids at 78 Mg per ha and N-P-K fertilization per crop management protocols;
3) Topsoil: ripping, 9 Mg lime and 674 kg P_2O_5 per ha applied prior to topsoil return, 15 cm of topsoil return from a near by wooded area, and N-P-K fertilization per crop management protocols.

Prior to soil reconstruction, all plots were deep ripped in two perpendicular directions with a multi-shank (3) ripper attachment mounted on a Caterpillar D-8 bulldozer to 90 cm, and one subsequent pass with a chisel plow (15 to 20-cm) was made over all the plots. The N treatments were no nitrogen and 252 kg N per ha (84 kg per ha in March, 84 kg per ha after the first cutting and 84 kg per ha in late August). These treatments were imposed in the spring of 2006 after the first cutting was completed.

Nitrogen, P, K, and lime were applied in the fall of 2005 according to soil test recommendations and plots were seeded in early October. The seeding mixture consisted of 56 kg per ha of ‘Jesup’ tall fescue [*Schedonorus phoenix* (Scop.) Holub] infected with the Max-Q endophyte (Pennington Seed Company, Madison, GA), 28 kg per ha of ‘WP-300’ orchardgrass (*Dactylis glomerata* L.) (Evergreen Seed Company, Rice, VA), 11 kg per acre of 'Tryant' red clover (*Trifolium pratense* L.) (Evergreen Seed Company, Rice, VA) and 'Magnagraze' alfalfa (*Medicago sativa* L.) (Dairyland Seed Company, WI), and 4 kg per ha of 'Pinnacle' ladino clover (*Trifolium repens* L.) (Evergreen Seed Company, Rice, VA). In January 2006 two plots (topsoil and control) on the south side of the experimental area were destroyed when an adjacent area was remined. The control was relocated to the north side of the third replication. The topsoil treatment from the second replication is considered a missing plot.

Plots were harvested twice in the year following establishment (22 May 2006 and 07 Aug 2006) and once in 2007 (23 May 2007). Yield was determined by clipping a 1.2 x 31 m strip through the center of each plot using a self-propelled sickle-bar type forage harvester (Swift Machine Company, Swift Current, SK) ('t Mannetje and Jones, 2000). A subsample of the clipped forage was collected from each plot for determination of dry matter, nutritive value, and botanical composition. The sample was weighed, hand separated into grass, legume, weed, and other, and dried at 60^0 C for 3 to 5 days. Each component was then weighed and its contribution to the total dry weight was determined. The individual components from each plot were recombined and ground to pass through a 2 mm and 1mm screen using Wiley (Thomas Scientific, Swedesboro, NJ) and Cyclone (Udy Corporation, Fort Collins, CO) sample mills, respectively. Neutral detergent fiber (NDF), acid detergent fiber (ADF), and crude protein (CP) were predicted using near infrared spectroscopy (Foss North America, Eden Prairie, MN). Total digestible nutrients (TDN), an estimation of available energy in forages (Undersander et al., 1993), were calculated using the following equation $TDN = 100.32 - 1.118 \times ADF$, which was developed and validated at Virginia Tech's Forage Testing Laboratory.

Data were analyzed using the general linear model procedure from SAS version 9.1 (SAS Institute Inc., Cary, NC). Main effects and interactions included in the model were soil reconstruction, N rate, and soil reconstruction x N rate. Means were separated using Fisher's protected least significant difference ($P \leq 0.05$).

Results and Discussion

In 2006, annual rainfall was above normal, but the distribution was skewed toward summer and fall (Fig. 1). Rainfall early in the 2006 growing season (March to May) was only 44% of normal. In 2007, total annual rainfall was more than 100 mm below normal. For the period from June to November 2007 rainfall was 24% below normal. Proper seed placement and favorable weather conditions resulted in excellent stands in the fall of 2005.

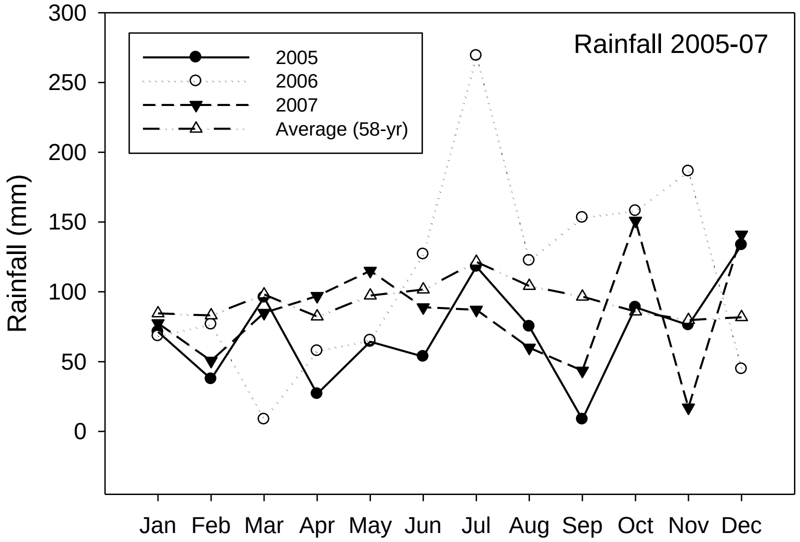

Figure 1. Rainfall data for the 2005, 2006, and 2007 growing seasons. Data was collected at the Southern Piedmont AREC, Blackstone, VA.

Herbage Yield

There was no soil reconstruction x N rate interaction for the first harvest, second harvest, and the total seasonal yield in 2006 and in the first and only harvest in 2007 (P> 0.05). Therefore, the main effects of soil reconstruction and N rate will be presented.

In 2006, first harvest yields ranged from 5,600 to 5,800 kg dry matter (DM) per ha and were not affected by soil reconstruction treatment (Fig. 2). Averaged over N rate, second harvest yields were 2,900, 3,100, and 3,700 kg DM per ha for the control, topsoil, and biosolid treatments, respectively and were not significantly different (Fig. 2). Similarly, N fertilization had no effect on first or second harvest yields in 2006 (Fig. 3). Total seasonal DM yield for the 2006 growing season ranged from 8,500 to 9,500 kg DM per acre and was not affected by soil reconstruction treatment or N fertilization (Figs. 2 and 3).

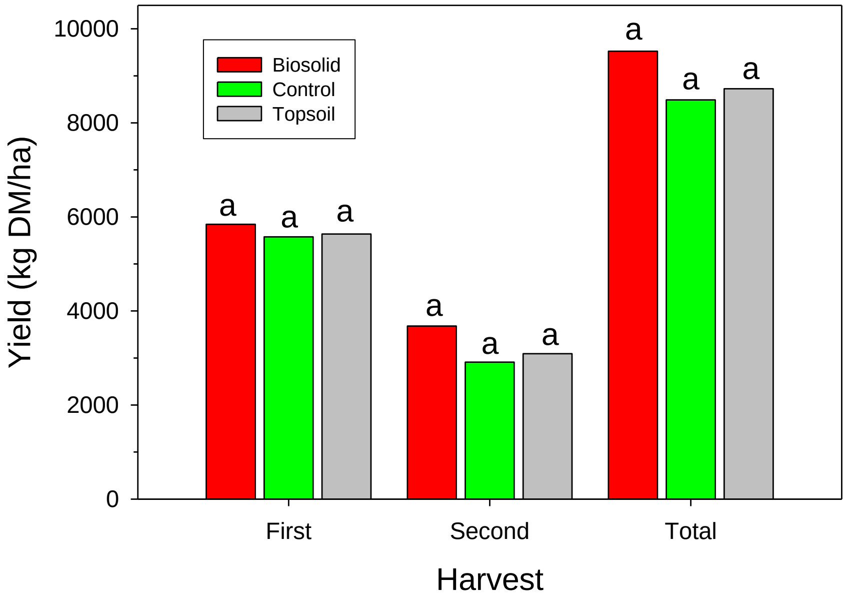

Figure 2. Dry matter yield averaged over N fertilization as impacted by soil reconstruction treatment for the first and second harvest and total seasonal production in 2006. Bars with the same letter within a harvest date are not significantly different according to Fisher's protected least significant difference ($P \leq 0.05$).

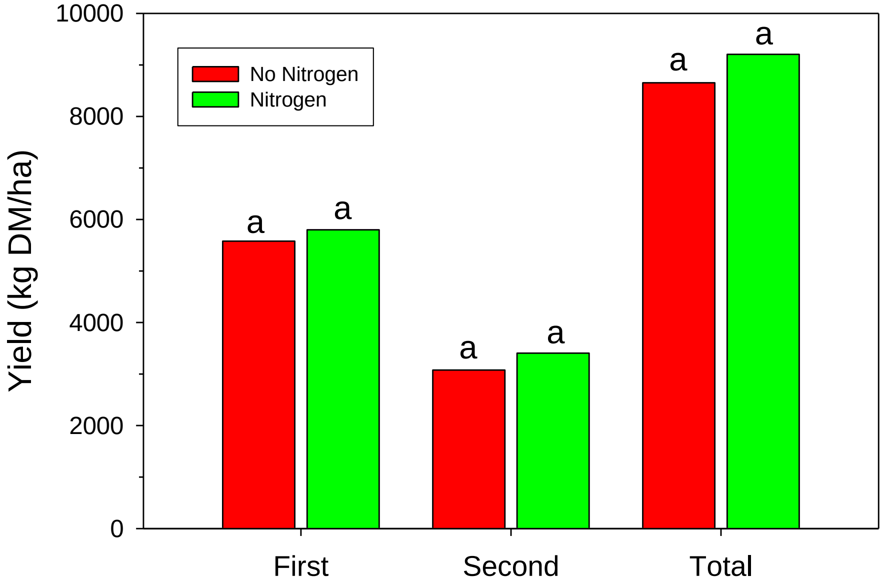

Figure 3. Dry matter yield averaged over soil reconstruction treatments as impacted by N fertilization for the first and second harvest and total seasonal production in 2006. Bars with the same letter within a harvest date are not significantly different according to Fisher's protected least significant difference ($P \leq 0.05$).

In 2007, yields were 4,200, 5,200, and 5,800 kg DM per ha for the control, topsoil, and biosolid treatments, respectively and were not significantly different (Fig. 4). Averaged over soil reconstruction treatments, yields were 4,200 and 5,700 kg DM per ha for the no N control and N treatments, respectively and were not different (Fig. 5).

It was somewhat unexpected that yield differences between the control and biosolid treatments could not be detected. These differences may have been masked by the high heterogeneity of the mine spoil. These new mine soils consist of variably mixed and segregated tailings and slimes which result in areas of high clay and sand content. In addition to the heterogeneity of the reclaimed soils, differences in the legume content of the stands in this study may have equalized yields by supplying N via symbiotic N fixation to the control and topsoil treatments (Ditsch and Collins, 2000).

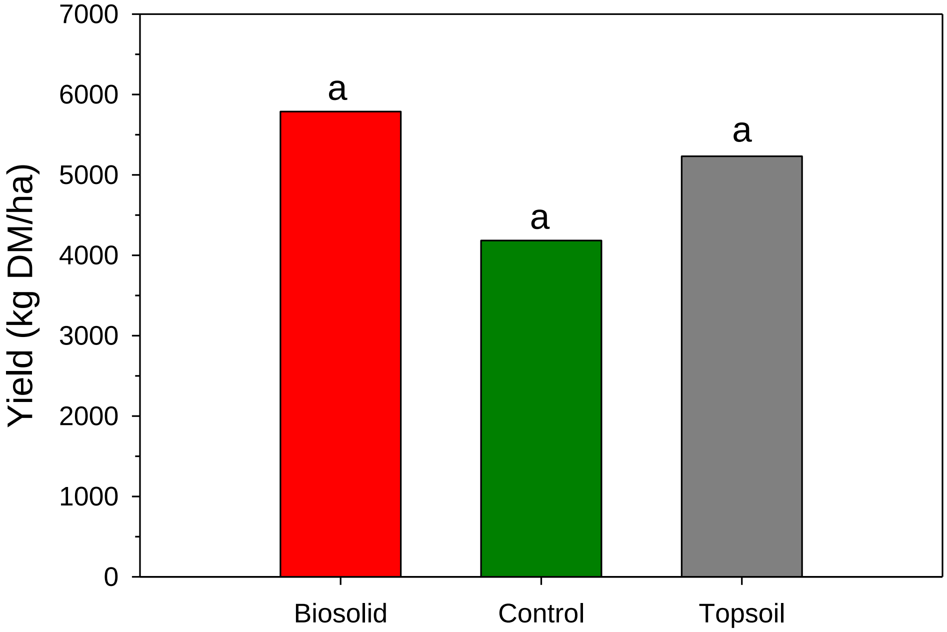

Figure 4. Dry matter yield averaged over N fertilization as impacted by soil reconstruction treatment for the 2007 growing season. Bars with the same letter are not significantly different according to Fisher's protected least significant difference ($P \leq 0.05$).

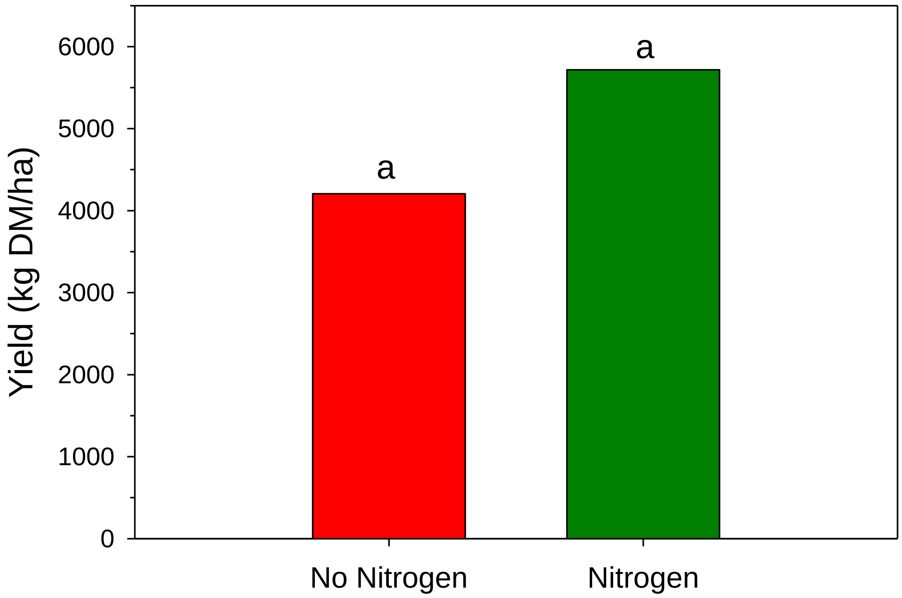

Figure 5. Dry matter yield averaged over soil reconstruction treatments as impacted by N fertilization for the 2007 growing season. Bars with the same letter are not significantly different according to Fisher's protected least significant difference ($P \leq 0.05$).

Botanical Composition

Stands in this study were dominated by grasses and legumes. Weeds and other material made up small portion of the total yield (data not shown). At the first harvest in 2006, legumes contributed approximately 20% to the total dry matter for the topsoil and control treatments and were not present in the biosolid treatment (Fig. 6). The biosolid treatment contained more grass at the first harvest than either the control or topsoil treatment (Fig. 7). By the second harvest legumes made up more than one-third of the sward for the control and topsoil treatments compared to only 5% for the biosolid treatment (Fig. 6). The biosolid treatment still contained more grass than the control or topsoil treatments at the second harvest (Fig. 7).

Figure 6. Legumes in the sward averaged over N fertilization as impacted by soil reconstruction treatment for the first and second harvest in 2006. Bars within a harvest date with the same letter are not significantly different according to Fisher's protected least significant difference ($P \leq 0.05$).

Figure 7. Grass in the sward averaged over N fertilization as impacted by soil reconstruction treatment for the first and second harvest in 2006. Bars within a harvest date with the same letter are not significantly different according to Fisher's protected least significant difference ($P \leq 0.05$).

In 2007, the botanical composition for the first harvest was still dominated by grasses and legumes. Weeds and other material did not occur in the biosolids or control treatments (data not shown). In the topsoil treatment weeds made up 10% of the stand (data not shown). The topsoil used in this reconstruction treatment likely contained weed seed that has germinated and is now significantly contributing to the observed differences in the botanical composition (Renne and Tracy, 2007). At the first harvest, legumes contributed 22 and 30% to the total dry matter for the topsoil and control treatments, respectively and were not present in the biosolid treatment (Fig. 8). The biosolid treatment contained more grass at the first harvest than either the control or topsoil treatment (Fig. 9). Differences in the botanical composition due to N fertilization could not be detected (data not shown).

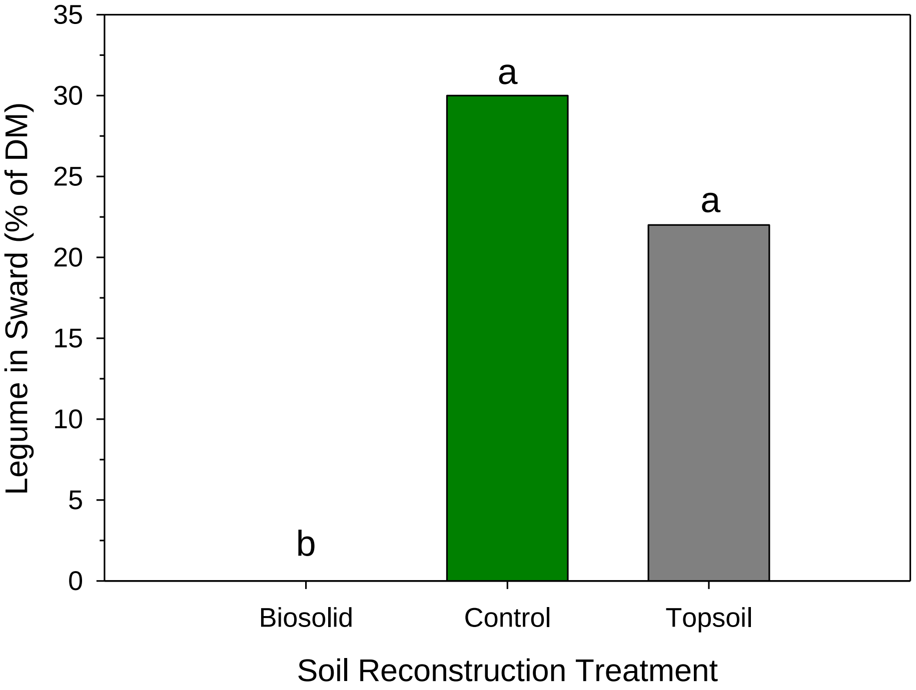

Figure 8. Legumes in the sward averaged over N fertilization as impacted by soil reconstruction treatment for the first and only harvest in 2007. Bars with the same letter are not significantly different according to Fisher's protected least significant difference ($P \leq 0.05$).

A common feature to mine spoils in the humid southeastern U.S. is low plant available nitrogen (PAN) (Vogel, 1981; Mays and Bengston, 1978). Nitrogen fertilization increases yields initially, but this effect is short-lived due to N losses via plant use, denitrification, and leaching below the root zone (Whitehead, 2000). Therefore, the establishment and maintenance of legumes in the sward is essential for the long-term stability and productivity of plant communities on reclaimed landscapes and the establishment of a functional N cycle (Ditsch and Collins, 2000). In this study, two years of data indicates that the use of biosolids limited the establishment of legumes, leading to a sward that was dominated by grasses. The long-term impact of biosolid usage on the botanical composition and productivity of plant communities in this study will be closely monitored. It is important to note that the use of biosolids has many other beneficial effects on the physical and chemical characteristics of spoil materials (Haering and Daniels, 2000) and these effects may outweigh the initial negative impact on plant diversity.

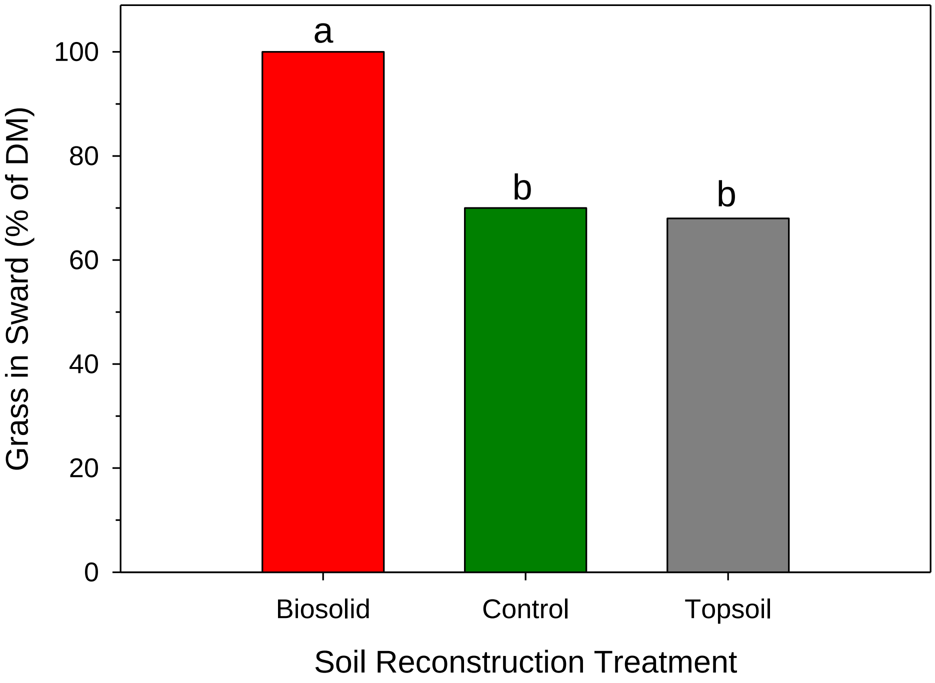

Figure 9. Grass in the sward averaged over N fertilization as impacted by soil reconstruction treatment for the first and only harvest in 2007. Bars with the same letter are not significantly different according to Fisher's protected least significant difference (P = 0.05).

Nutritive Value

In 2006, N rate did not affect the nutritive value of forage for either the first or second harvest (Table 1). In contrast, soil reconstruction method impacted the CP for both the first and second harvests (Table 2). Crude protein content of the forage was higher for the biosolid treatment at both the first and second harvests (Table 2). This is not unexpected since CP concentration in forages is closely related to N fertilization (Fribourg, 1974) and the addition of biosolids likely resulted in higher levels of PAN for this treatment, which in turn increased CP.

Table 1. Crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), and total digestible nutrients (TDN) averaged over soil reconstruction treatments as impacted by N fertilization for the first and second harvest in 2006 and the first and only harvest in 2007.

Harvest-Year	**CP**	**ADF**	**NDF**	**TDN**
		%		
First Harvest, 2006				
No Nitrogen	16.3	36	54	61
Nitrogen	16.4	36	57	60
LSD (0.05)	**ns**	**ns**	**ns**	**ns**
Second Harvest, 2006				
No Nitrogen	14.6	30	51	67
Nitrogen	14.9	30	52	66
LSD (0.05)	**ns**	**ns**	**ns**	**ns**
First Harvest, 2007				
No Nitrogen	14.4	36	56	61
Nitrogen	13.5	38	64	58
LSD (0.05)	**ns**	**ns**	**2**	**2**

In 2006, ADF was lower for the biosolid treatment for the first harvest only (Table 2). This may have been due to delayed plant maturity as a result of increased PAN for this treatment. Neutral detergent fiber ranged from 54 to 56% and 51 to 54% for the first and second harvests in 2006 and did not differ for the soil reconstruction treatments (Table 2).

In 2007, neither N rate nor soil reconstruction treatment affected the CP concentration in the forage material (Table 1 and 2). The lack of differences observed between the soil reconstructions treatments might be explained by PAN and botanical composition. Two years after the application of bisolids the levels of PAN were likely lower for this treatment causing decreased levels of CP. The levels of legumes in the control and topsoil treatments were higher (Fig. 8) and likely increased the CP concentrations for these treatments. The net result was CP levels that were similar for the soil reconstruction treatments (Table 2). All treatments resulted in CP concentrations that would meet the requirements of both dry and lactating beef cows (Ball et al., 2007).

In 2006, TDN was not affected by N fertilization (Table 1). It was impacted by soil reconstruction treatment for the first harvest only (Table 2). In this harvest the forage from plots that had received biosolids contained more energy (Table 2). The N contained in the biosolids may have may have delayed plant maturity resulting in higher quality forage at the first harvest in 2006.

Table 2. Crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), and total digestible nutrients (TDN) averaged over N fertilization as impacted by soil reconstruction method for the first and second harvest in 2006 and the first and only harvest in 2007.

Harvest-Year	**CP**	**ADF**	**NDF**	**TDN**
		%		
First Harvest, 2006				
Biosolid	18.8	33	56	64
Control	14.2	38	55	57
Topsoil	15.8	36	54	60
LSD (0.05)	**2.4**	**3**	**ns**	**3**
Second Harvest, 2006				
Biosolid	19.4	29	54	68
Control	12.4	31	51	66
Topsoil	11.2	32	51	65
LSD (0.05)	**4.4**	**ns**	**ns**	**ns**
First Harvest, 2007				
Biosolid	13.1	39	66	57
Control	14.8	34	54	62
Topsoil	13.8	36	60	60
LSD (0.05)	**ns**	**3**	**7**	**3**

In 2007, ADF in the forage material was not impacted by N fertilization (Table 1). Neutral detergent fiber was higher for the plots receiving N (Table 1). Acid and neutral detergent fibers were the lowest for the control plots and the highest for the biosolid plots (Table 2). The higher percentage of legumes in the topsoil and control plots (Fig. 8) likely decreased the fiber concentrations for these treatments.

In 2007, TDN, a measure of the energy content of the forage, ranged from 57 to 62% (Table 2). It was highest for the control treatment (Table 2) and the plots not receiving N fertilizer (Table 1). Past research has clearly demonstrated that adding legumes to grass stands increases the nutritive value of the sward (Burns and Standaert, 1985). In this study the control treatment contained more legumes than the biosolids treatment (Fig 8). In 2007, the control and topsoil treatments would meet the energy requirements of beef cows at all stages of the production cycle (Ball et al., 2007). The biosolids treatments would only meet the energy needs of dry cows.

Conclusions

Initial results indicate that properly amended mine soils generated from the mineral sands mining and reclamation process can support the production of high quality forage crops. No yield differences between soil reconstruction treatments could be detected in the first two growing seasons after establishment. However, the biosolid treatment was dominated by grass and contained considerably fewer legumes than the control and topsoil treatments. This shift in botanical composition as a result of biosolid application will continue to be monitored to access the long-term impact on the productivity and stability of plant communities and the establishment of vigorous N cycle.

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