SOIL RESPREAD DEPTHS: DO WE KNOW ENOUGH TO IMPLEMENT CHANGE?[1]

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Abstract: Current North Dakota soil respread regulations are based on research conducted in the mid 1980's. Regulations include a buffer that was added to the respread depths suggested by research to account for the unknown behavior of reclaimed sites over time as spoil weathers and plant communities mature. These unknowns have since been largely addressed by long-term studies of reclaimed sites. Studies have also shown that season of growth (C_3 vs. C_4) and origin (native vs. introduced) do not change the response of perennial grasses to soil respread depth. Therefore, respread recommendations may now be based on the results of research that include introduced species, and possibly without the addition of a buffer. After a review of literature it appears that respread depths may be reduced. A reduction in soil respread depths would result in less soil salvaged, stockpiled and respread, thus reducing reclamation costs for the mine without negatively effecting reclamation success. However, before changes to respread requirements are made, we must be confident this will not have a negative impact on the revegetation success of a site or of its capability to support other land uses in the future. Therefore, before ND mines can put into practice the recommendations of past research, issues regarding the effects on annual cropland, woody species and the behavior of sodium in the reclaimed soil profile must be resolved.

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Introduction

Soil salvage and replacement on surface mined lands has been a topic of research, discussion, and regulatory action in the Northern Great Plains for approximately three decades. Respread of soil over spoil is an essential part of revegetation (Barth and Martin, 1982; Doll et al., 1984; McGinnies and Nicholas, 1980; Redente et al., 1982b; Schafer and Nielsen, 1979; Schuman et al., 1985). Proper reclamation methods, such as soil respread, can do more to reestablish plant communities than 50 years of succession (Schafer and Nielsen, 1979). Soil replacement helps to ensure adequate infiltration and nutrient and water availability for vegetation establishment (Redente and Hargis, 1985). Revegetation following soil replacement then stabilizes the site, preventing erosion and reducing the invasion of undesirable species. In so doing, the site can be returned to a desirable, productive post mine land use (Barth and Martin, 1984; Bowen et al., 2005; DePuit and Redente, 1988). Although annual precipitation, aspect, and topography of a site have an effect on both vegetation establishment and soil development (Merril et al., 1998), the amount of soil necessary to successfully reclaim and revegetate a site largely depends on the chemical and physical properties of the spoil.

Soil salvage and respread "may do more for restoring ecosystem function on disturbed lands than any other reclamation procedure" (DePuit and Redente, 1988). However, "this process represents the most costly single item in terrestrial reclamation" (Barth and Martin, 1984). Considering these two statements, respread depths are vital to both reclamation success and economic efficiency of the mine. Therefore an optimal respread depth is the amount of soil necessary to maximize reclamation success at minimal expense. After decades of research on this topic, a re-evaluation of what that optimal depth may be is warranted.

Background

Current North Dakota regulations are listed in Table 1. Respread depths listed in the table are for the total soil depth, or topsoil (A horizon) plus subsoil (B and C horizons), which in North Dakota must be salvaged separately. The required total soil depth is dependent upon the quality of spoil being covered. Research has shown that 40 cm or more of soil must be respread over spoil to achieve reclamation success (Merrill et al., 1998; Power et al., 1981, Wick et al., 2005). North Dakota's regulations currently require a minimum of 61 cm. However, in much of the state, topsoil is shallower than either of these minimum depths. Research has shown that reclamation success can be achieved by respreading topsoil over subsoil to achieve the necessary total soil depth (Merrill et al., 1998; Power et al., 1981, Wick et al., 2005). Therefore, in North Dakota all topsoil must be salvaged and respread (NDAC, 2008). The amount of subsoil respread is the difference between the total soil depth required by Table 1, minus the amount of topsoil available.

Table 1: Soil Respread Thickness (NDAC, 2008)

Spoil Properties		Respread Depth
	Sodium Adsorption	(Topsoil Plus Subsoil)
Texture	Ratio (SAR)	Centimeters
Medium*	12	61
Coarse**	12	91
***	12-20	91
***	20	122

* Loam or finer
** Sandy loam or coarser
*** Not applicable

The regulations illustrated by Table 1 were set nearly 20 years ago and were largely based on the recommendations made in Doll et al., (1984) (NDPSC, 1986). These recommendations were higher than the minimum respread depths suggested by research because at the time all of the studies were short in duration, usually five years or less after site revegetation. To account for unknown changes of soil in the root zone and sodium migration over time, scientists were very careful to be conservative in their recommendations until long-term studies could be conducted (Doll et al., 1984; NDPSC, 1986). During the years since soil respread regulations were set, a number of authors have suggested that shallower depths than currently allowed by regulations may be acceptable (Fox, 1993; Kirby et al., 1993; Redente et al., 1997; Schladweiler et al., 2005) and several research projects analyzing long term site development have been conducted (Redente et al., 1997; Bowen et al., 2005; Wick et al., 2005). Researchers at the long term sites found that the sites had stabilized and the amount of soil necessary to maximize reclamation success at minimal expense, i.e. minimal soil depth, was equal to or less than the depths suggested by research conducted initially at the site (Redente et al., 1997; Bowen et al., 2005; Wick et al., 2005). Because none of the long term studies found that deeper soil respread was necessary, it indicated a reconsideration of North Dakota's respread depth requirements may be appropriate and that they could now be based on recommendations of researchers without the conservative approach they were drafted under.

Based on a review of research, a proposal was submitted to the North Dakota Public Service Commission (NDPSC) to reduce soil respread depths. This submittal was a means to determine if questions regarding soil respread depths had been adequately answered. This is important to industry because of the cost savings associated with reducing respread depths while ensuring there is no decrease in the mine's ability to successfully reclaim land and release it from bond. It is important to regulatory personnel to correctly resolve this issue so they can ensure there is no negative impact on the effectiveness of reclamation by allowing a reduction in soil depths. It is also important to the research community so the findings of researchers can be applied and their recommendations followed. Additionally, this submittal and response will help identify areas that need future research, research that will be meaningful and have direct applicability to mine land reclamation. Following is a review of research, proposed changes to soil respread depths and concerns identified by the NDPSC, including applicability of research recommendations to all land uses, native versus introduced species, and long term effects of reduced soil depths.

Land Use Concerns

Native grassland and cropland are the dominant land uses in North Dakota. There are four quantitative standards that must be met in North Dakota to achieve final bond release on reclaimed native grassland: diversity, seasonality, production, and cover. In comparison, success standards for cropland are based solely on production. Less dominant land uses include tame pasture, woodlands and shelterbelts, wetlands, recreation and fish and wildlife habitat. Two studies in Colorado have shown that woody species actually have increased success on shallow soil respread, so woodland and shelterbelts are not expected to suffer from reduced respread (Redente and Hargis, 1985; Redente et al., 1997). However, none of the research has looked at the success of tall shrubs or trees present in woodland and shelterbelt plantings, so the NDPSC has raised concerns regarding the possible effects a reduction in respread depths may have. Although current respread depths are not based on research that included trees and tall shrubs, it has been raised as an issue so will need to be addressed.

Standards for the remaining land uses have similar criteria to either cropland or rangeland, so it is expected that respread depths capable of supporting a successfully reclaimed native grassland community and productive cropland would also be capable of supporting the remaining land uses that exist in North Dakota. Because of this and the dominance of these two land uses, they are the focus of this paper.

Respread depth has an effect on all four native grassland standards (diversity, seasonality, production and cover). Diversity is often higher at shallower soil respread depths (Bowen et al., 2005; Redente and Hargis, 1985; Redente et al., 1982a; Redente et al., 1982b; Redente et al., 1997; Stark and Redente, 1985; Schladweiler et al., 2005; Wick et al., 2005). This is because cool season grass species (C_3) have a competitive advantage over warm season grass species (C_4), forbs, and shrubs (Bowen et al., 2005; DePuit and Coenenberg, 1979; Redente et al., 1997). Shallower depths create interspaces where less aggressive warm season species, forbs and shrubs can establish (Bowen et al., 2005). Increased competition for resources and space with deeper topsoil depths reduced species diversity over time, eventually resulting in a site dominated by highly productive cool season grasses (Bowen et al., 2005; Wick et al., 2005).

Seasonality is the proportion of warm and cool season grass species. Warm and cool season native and introduced grasses were found to grow best at similar depths when planted in separate plots (Power et al, 1976; Power et al., 1979; Power et al., 1981; Power et al., 1982). However, when planted in a mixture, shallower depths allowed warm season species to be able to compete with cool season grasses, resulting in a plant community with more seasonal diversity (Wick et al., 2005). Because of the competitive ability of cool season grasses, native grassland seasonality standards focus mostly on ensuring that an adequate percent composition and number of warm season species are present. Therefore, a reduction in soil depth is expected to make it easier to meet this revegetation success standard and result in greater species and seasonal diversity.

Production and cover are the final parameters monitored to determine revegetation success. Production and cover increase linearly with soil thickness to an optimal depth, after which additional soil does not result in a marked improvement in either parameter (Power et al., 1981; Merrill et al., 1998; Redente and Hargis, 1985). The optimal depth for production and cover therefore sets the lower limit for soil respread depths. Although adequate cover is vital because it helps to ensure site stability by preventing erosion, cover values often parallel production in soil respread depth studies (Redente and Hargis, 1985; Bowen et al., 2005), which is probably why studies did not usually track results of both parameters. Production is influenced by stand density, nutrient and water availability, and soil quality; therefore it is a good measurement of adequate soil depth (Hargis and Redente, 1984). Because agriculture is the predominant land use in the region (Fox, 1993), production is also the primary item of concern to most operators and landowners. Production was the parameter most commonly measured by researchers to determine the success of various respread depths. Because it sets the lower limit for respread depths, is a good indicator of many site characteristics, is the primary concern of most landowners and the general public, and because of its widespread use in research, it will be the parameter most commonly discussed in the review that follows.

Similar to rangeland production, cropland production increases linearly with soil thickness up to an optimal depth (Merrill et al., 1998 and Power et al., 1981). However, research conducted on wedge plots near Zap, North Dakota indicated that the depth necessary to maximize production of annual crops may be greater than what is required for perennial grasses (Merrill et al., 1998 and Power et al., 1981). Therefore in the proposal as originally submitted, it was suggested that soil respread depths be reduced for perennially vegetated land uses, but that cropland remain unchanged until more research is available. However, in North Dakota reclaimed land must be capable of supporting a variety of uses, including the same land uses as it was prior to mining (NDCC, 2008). Therefore, it can be argued that unless slopes are so severe as to prohibit future tillage, which is relatively rare, reclaimed land must also be able to support cropland after reclamation even if that is not the designated post mine land use. Because of this, respread depth regulations for all land uses must be based on research that includes annual crops. Variable respread depths and a landscape approach to reducing respread depths have been proposed by several researchers, but were not included in this proposal because of the increased logistical complexity it would add to the reclamation process.

Comparison of Introduced and Native Species

Many studies comparing the effects of various soil depths utilized introduced cool-season (C_3) grass species, usually crested wheatgrass. Additionally, research sites analyzed in long-term studies were frequently invaded by this species, because of its competitive ability and common use on reclaimed lands in the late 1970's and early 1980's. However, every study that included introduced and native grass species concluded that the same soil depth was necessary for both types of species. Schuman et al. (1985) used only native grasses in their study, but by the time Bowen et al. (2005) did their follow up study, crested wheatgrass (*Agropyron cristatum*) had become dominant along with the seeded native western wheatgrass. The same soil depths were still optimal after the invasion of the introduced species crested wheatgrass. All of the Power et al. (1976, 1979, 1981, and 1982) research studied soil depth effects on both warm season (C_4) native species blue grama (*Bouteloua gracilis*) and sideoats grama (*Bouteloua curtipendula*) and a cool season introduced species (crested wheatgrass). All of the study results found similar growth trends and depth recommendations for both types of species. Barth and Martin (1984) found that responses to varying soil depths between four cool season native grasses and crested wheatgrass were parallel and not statistically different. Yield trends were also similar between crested wheatgrass and native cool season (western wheatgrass [*Pascopyrum smithii*]) and warm season (blue grama and sideoats grama) grasses in an earlier study conducted by Ries et al. (1978). There have been no studies that recommend differing respread depths based on species origin (native vs. introduced). Therefore, the following research, whether based on warm or cool season native or cool season introduced grass species, is applicable to both reclaimed tame pasture and native grassland.

Long Term Study Results

Several studies have re-visited previously established research sites to assess the long-term effects of various respread depths in the western USA. Comparison of initial study results with follow up research illustrates changes that may have occurred through time and help to resolve the previous conservative recommendations for respread depths established 20 years ago. If it can be shown that soil depths necessary for successful reclamation did not increase as the site matured, soil depth recommendations, no matter the maturity of the site, can be directly followed without concerns for issues that may arise as the reclaimed land ages. Three follow up studies were conducted in the Northern Great Plains to resolve these issues.

A research site was established in northwest Colorado by Redente and Hargis (1985). In 1980, soil was respread at thicknesses of 15, 30, 45, and 60 cm over generic spoil. Generic spoil refers to material without negative properties or nutrient deficiencies that inhibit growth. Initially, the site was sampled after three and five years. At both times, total seeded species production and total site production were significantly greater on 60 cm of soil, as was total root biomass. Grass production and cover were directly related to soil depth while forb and shrub production and cover were inversely related to soil depth. Ten years after the study was initiated, Redente et al. (1997) revisited the site. Total production was still significantly greater with 60 cm of soil than 30 and 45 cm, but forbs had become well established on 15 cm of soil, which was now as productive as the 60 cm plots. Shallower respread depths also had greater diversity and shrub density than were found with thicker respread depths. Because 60 cm was the deepest soil thickness studied, it is unknown how deeper soil would affect plant productivity. However, when compared to the undisturbed native community, all treatments resulted in equivalent or greater production. Therefore, 60 cm did result in successful site revegetation for this parameter.

The natural vegetation type in the study area is sagebrush-grass, so shrubs and forbs are significant components in the ecosystem (Redente et al., 1997). North Dakota is dominated by grasslands with few shrubs present (Power et al., 1978), so reclamation standards are based on grass species only. Therefore, although Redente et al. recommended shallow respread depths over non-toxic spoil, such shallow depths may not be directly transferable to North Dakota as the plant community goals are different. However, this study did show that after ten years, any changes that occurred in the spoil did not affect the appropriateness of the respread depth recommended by the early research. The respread depth necessary to achieve the highest total aboveground biomass and grass production did not change over time and the reclaimed site still had production and cover levels higher than the surrounding undisturbed community.

In 1977, a study was initiated in south-central Wyoming with varying depths of topsoil respread over generic spoil (Schuman et al., 1985). After five years, they sampled aboveground biomass of seeded cool-season native grasses (Pinchak et al., 1985). Their recommendation was that 40 cm was the optimal depth for seeded species production and limited recruitment of undesirable non-seeded species. Approximately 20 years later, Bowen et al. (2005) revisited the study. Both of the deeper soil depths (40, 60 cm) had higher aboveground biomass, litter cover, soil organic carbon, total nitrogen, and phosphorous than the shallower sites (0, 20 cm), but were not significantly different from each other. The increased production on deeper respread depths resulted in higher infiltration rates and increased water storage. However, there were changes since Pinchak et al.'s evaluation. Initially, the favorable growing conditions of the deeper soil depths increased species richness and diversity. But as the site matured and plant communities became stable, competitive exclusion from the cool season grasses, which grew well at deeper soil depths, prevented natural recruitment. The shallower soils, with their less conducive growth environment, had more open space and with less competition, saw more natural recruitment. Bowen et al., (2005) determined that for greater diversity, species richness, and forb cover, shallower depths are better. Despite these changes in species composition and diversity, the researchers observed that the site had stabilized and recommended respread depths on the 24 year old site were the same as those recommended by initial research: 40 cm was ideal, with no significant difference between it and the deeper depth. No negative changes occurred in soil properties over time that would necessitate deeper soil respread depths than was necessary for initial establishment.

Two studies were established in North Dakota in the mid 1970's. In 1975 wedge plots were constructed near Zap over moderately sodic spoil (SAR=14.6) to study the effects of subsoil type and soil depth (Merrill et al., 1998). They were seeded to crested wheatgrass Russian wildrye (*Psathyrostachys juncea*), and spring wheat (*Triticum aestivum*) the following year. After five years of data collection, results were analyzed. Production was highest for both perennial grasses with 51-81 cm of soil and for wheat with 89-100 cm. Spring wheat plots were seeded to smooth brome (*Bromus inermis*) at the end of the study. At approximately the same time, wedge plots over sodic spoil (SAR=25) were established near Stanton (Power et al., 1981). Maximum yields were achieved with 70 cm of soil for crested wheatgrass plots and those seeded to a warm season native grass mix and with 90 cm of soil for alfalfa (*Medicago sativa*) and spring wheat. Spring wheat plots were seeded to smooth brome at the end of this study as well. In 2003, Wick et al (2005) revisited these sites. After more than a quarter century, total production decreased on the monoculture plots of crested wheatgrass and Russian wildrye due to invasion by less productive species.

As the plant community and soil properties changed over time, the sites had achieved stability. Because after 29-30 years there was only a weak relationship between soil depth, soil properties, and vegetation production, cover, and diversity, Wick et al. (2005) concluded that the soil depth recommendations made by previous studies were more important for initial establishment than for the long-term success of the plant community. Changes in soil properties, such as the upward movement of sodium, did not occur over time to make initial respread depth recommendations inadequate. Wick et al.'s (2005) conclusion suggests that if soil respread depths are initially adequate for site revegetation, long term changes will only make the site more favorable for vegetation, not the opposite, which was the concern of early researchers.

In all of these long-term studies, the soil depth recommendations made by early researchers were sufficient for long term success. If anything, over time the site conditions became more favorable to the plant communities as leaching took place and the site stabilized. Wick (2004) found that the importance of soil depth and soil characteristics decreases over time due to leaching and weathering, and that other site properties, such as slope, seed mix, organic matter, porosity, and microbial activity, have a greater effect on the long term reclamation success of the site. Although it can be inferred that there is minimal upward movement of significant amounts of sodium, because of the lack of deleterious effects it had on plant communities, it is unknown what is actually happening to the soil. So although increasing soil depths were not needed as the site matured, the NDPSC is concerned about the lack of long term data on sodium behavior at the soil-spoil interface and possibly upward through the soil profile. Field trials and laboratory experiments have concluded that significant amounts of sodium will not move more than 7-15 cm upward into soil (Barth and Martin, 1984; Merrill et al., 1980; Merrill et al., 1983a; Pole et al., 1979; Sandoval and Gould, 1978)., but none of these studies were over a long period of time. The long term study on sodic spoil concluded there was no deleterious effects from sodium migration (Wick et al., 2005), but it remains an issue that will need regulatory resolution before soil depth regulations can be changed.

Respread Depths by Spoil Type

Respread recommendations in the sections that follow are based on some of the same research that was used to determine the current respread regulations. However, with the support of long term study results, previous research findings can now be directly applied without first adjusting them for the unknowns discussed by Doll et al. (1984).

Sodic Spoil (SAR > 20)

Sodic spoil is unfavorable for plant growth (Sandoval and Gould, 1978). Roots usually penetrate only 10 cm into sodic spoil and root biomass abruptly decreases at the soil-spoil interface (Barth and Martin, 1984; DePuit et al., 1980; DePuit et al., 1982; McGinnies and Nicholas, 1983; and Merrill et al., 1985). Additionally, infiltration into spoil is a third that of soil (Barth and Martin, 1984). However, Merrill et al., (1985) found that neither root density nor the water content of the spoil was the limiting factors for growth; it was actually the extremely low hydraulic conductivity (HC) of the spoil. Even though there was a water source in the spoil, it was unavailable for plant use. A companion study, also on sodic spoil, illustrated that nutrient uptake, namely nitrogen, was not limited by available supply, but by ineffective root function and depth (Power et al., 1985). Therefore, for plants to have adequate water and nutrient availability, roots of plants must be located in material that does not limit their function or have an extremely low HC.

A layer of soil can act as a buffer against the negative properties of a material that does not support plant growth, such as sodic spoil, providing the soil is sufficiently thick for the root zone of plants (Hargis and Redente, 1984). There have been many papers written on this topic, with slightly varying recommendations for respread depths (Barth and Martin, 1982; Barth and Martin, 1984; Doll et al., 1984, Hargis and Redente, 1984; Merrill et al., 1980; Merrill et al., 1983a; Merrill et al., 1985; Power et al., 1976; Power et al., 1979; Power et al., 1981; Power et al., 1982; Power et al., 1985; Redente et al., 1982b; Ries et al., 1978; Sandoval and Gould, 1978; Schuman and Power, 1981).

Merrill et al. (1980), Ries et al. (1978), and Sandoval and Gould (1978) all concluded that at least 30 cm of soil was necessary to cover sodic spoil to achieve maximum yields. Research conducted by Power et al. (1979) found that production of mixed native grasses, dominated by blue grama and sideoats grama, was highest when 70 cm of soil was respread over sodic spoil. Higher respread depths did not result in significantly greater production levels. A later study by Power et al., (1981) reported similar results for crested wheatgrass and native grasses. Maximum yields were reached with 70 cm of soil for these grass species, although 90 cm was necessary for the two annual crops they included in the study.

Barth and Martin (1982; 1984) recommended comparable depths. They found that perennial grasses reached their greatest productivity on 70 cm of soil over sodic spoil. Schuman and Power (1981) suggested that slightly higher respread depths of 76 cm may be necessary. Power et al. (1981) found that 20 cm of topsoil was necessary for maximum production for all plant species used, but that crested wheatgrass and native grasses needed only 50 cm of subsoil (70 cm of soil), while alfalfa and spring wheat required 70 cm of subsoil (90 cm of soil) to achieve maximum production. Additional research supported that 90 cm of soil may be required (Power et al., 1976; Power et al., 1982; Redente et al., 1982a; Redente et al., 1982b). Redente et al.'s research was on retorted oil shale, but their results are applicable here because of its comparable unsuitability as a plant growth medium.

Two other papers focused on the effects of four soil respread depths: 25, 50, 75, and 100 cm (Power et al., 1985; Merrill et al., 1985). Maximum productivity and root function were not achieved until 100 cm of soil was respread over spoil. Other than these two studies, 90 cm was the deepest respread depth found to be necessary, and since these two studies did not analyze depths between 75 and 100 cm, maximum growth may have been reached at the lesser, unanalyzed depth of 90 cm. Additional research conducted by Power et al. (1982) found that water withdrawal and rooting depth of native grasses seldom reached a depth greater than 90 cm.

This is supported by research conducted on undisturbed native grasslands. Coupland and Johnson (1965) studied the rooting depths and patterns of several dominant grassland species of the Northern Great Plains, including *Stipa comata, Stipa spartea, Pascopyrum smithii, Bouteloua gracilis, Koeleria cristata, Phlox hoodii, Anemone patens, and Gutierrezia diversifolia*. In central North Dakota's soil zone, none of the listed species had roots that were found in great number, or "penetrate in a dense network," below 90 cm (Coupland, 1961; Coupland and Johnson, 1965). Maximum depths may reach several feet below this level (Power et al., 1974), especially for *Pascopyrum smithii*, but even this species was found to have 70% of its roots in the top 30 cm of the soil (Coupland and Johnson, 1965). Therefore, based on the rooting depths of these species, 90 cm of soil is suitable to support native perennial species.

However, this depth of soil must be physically and chemically conducive to plant growth. These properties may be compromised if sodium migrates upward into the soil from the underlying sodic spoil. In trying to account for this possible change, after reviewing the 1981 Power et al. research, Doll et al. (1984) recommended respread depths of 122 cm over sodic spoil, which is significantly greater than the respread depth necessary to maximize production. He added in this paper and in later testimony that this depth was more than adequate for restoration of full productivity and was recommended to account for the unknown behavior of sodium (Doll et al., 1984). This recommendation was translated into ND's current soil respread depth requirements (NDPSC, 1986).

Based on the rooting depths of native grassland species and research discussed above, 90 cm of soil is sufficiently deep for roots to provide moisture and nutrients to above ground growth, resulting in the maximum plant yields experienced in field trials, both short and long term. A 90 cm soil respread depth over sodic spoil would result in a 32 cm reduction from current requirements. This reduction would be achieved by reducing subsoil depths while topsoil depths would stay the same. As defined earlier, an optimal respread depth would maximize reclamation success and minimize reclamation costs. Based on research, this reduction would still maximize reclamation success, but the reduced depths would translate into savings of $1,500-$2,500 per acre.

<u>Moderately Sodic or Coarse Spoil (SAR 12-20; SAR <12, Coarse Texture)</u>

A study at the Knife River Mine using spoil with an SAR of 12 determined there was no significant difference in production between 30 and 60 cm of topsoil (Pole et al., 1979). However, the SAR of this spoil was at the very lower limit of the moderately sodic category, so these soil depths may not be adequate for maximum production as SAR values approach 20. Fox (1993) conducted research on reclaimed rangeland with an average SAR of 20 and he found productivity was related more to topoedaphic conditions than respread depths. Reclaimed sites were more productive than undisturbed reference areas despite shallow and uneven respread depths and increased bulk densities from compaction. He concluded at the currently required depth of 90 cm soils are being replaced deeper than needed to maximize productivity, although he did not specify a minimal depth needed. In 1975, a wedge experiment was initiated at the Indian Head Mine on more sodic spoil (SAR=15) (Merrill et al., 1998). They were seeded the following year and after five years of growth, vegetation data was compared. The optimal soil depth for both crested wheatgrass and Russian wildrye production was 51-81 cm and for spring wheat was 89-100 cm, depending on the texture of the subsoil and landscape position. The site was revisited in 2003, and by then the highest production occurred on 40 cm of soil (Wick, 2005). They determined that deeper respread depths are needed more for vegetation establishment than for long term community success. Unfortunately, the spring wheat plots were seeded to smooth brome after Merrill et al.'s (1998) study so no data was collected on the success of annual crops on the site after it matured. The 89-100 cm of soil that Merrill et al. (1998) found necessary to maximize spring wheat production is as deep or deeper than Power et al.'s (1978 and 1981) recommendations for respread depths over sodic spoil. This suggests that a shallower respread depth than what Merrill et al.'s (1998) research recommends over moderately sodic spoil may be appropriate. When ND set its requirements, Dr. Merrill supported a 91 cm respread depth which was closer to an average of his data for the species studied (NDPSC, 1986).

If spoil material is coarse textured and has resulting low water holding capacity, respread soil is necessary to increase the water holding capacity of the root zone (Omodt et al., 1975). Halvorson et al. (1980, 1982 and 1986) and Halvorson and Doll (1985) studied respread requirements over coarse textured spoil. At the conclusion of these studies, they recommended that a minimum of 70 cm needs to be respread over coarse textured spoil (Halvorson et al., 1986). Based on data from 1982 and 1983, 69 cm of topsoil resulted in wheat and corn silage yields that were 85% of those found on undisturbed plots (Halvorson and Doll 1985). Through extrapolation, 81-89 cm of soil would be necessary to achieve maximum yields of these annual crops (Halvorson and Doll 1985).

Based on the depths recommended by research, coarse textured or moderately sodic spoil is slightly limiting for plant growth, but not completely inhospitable. Unlike with sodic spoil, root function and water availability are not so severely limited that the lower depths of the root system cannot lie in spoil for the plants to achieve maximum growth. However, current regulations require 91 cm of soil to be respread over this quality of spoil so that nearly the entire root system is above the spoil. A respread depth less than the 90 cm rooting depth (Coupland and Johnson, 1965) may be appropriate. The deepest optimal soil depth for native grasses on moderately sodic spoil was 81 cm. However, there is little data on annual crops for moderately sodic spoil. Other than Halvorson et al.'s (1985) extrapolations to identify a depth that would maximize crop production, only Merrill et al.'s (1998) study included annual crops and he testified that respread depths shallower than suggested by his research on spring wheat are appropriate (NDPSC, 1986). Therefore, it appears that this is an area that needs more research to determine actual requirements for cropland. If the limited research on annual crops is excluded and the deepest optimal depth for native grasses is used, it would result in a 10 cm reduction in respread depths from current regulations. But now that the NDPSC has raised concerns about the ability of nearly all reclaimed land for future use as cropland, more information may be required before any reductions can be made. Alternately, coarse textured spoil and spoil with SAR values approaching 20 may be grouped with the sodic spoil respread depths, as proposed at 90 cm. This would result in no change in respread depths from current regulations. Spoil with SAR values closer to 12 may be more appropriately grouped with generic spoil (Pole et al., 1979). This type of reclassification would also require more research to support it. At this time, no reduction for moderately sodic or coarse textured spoil is proposed.

<u>Generic Spoil (SAR <12, Medium Texture)</u>

In spoil without negative properties or nutrient deficiencies that inhibit growth, the spoil can act as a rooting medium for plants (Redente and Hargis, 1985). Therefore, shallow soil respread depths are adequate. In effect, the spoil acts as the subsoil of the reclaimed site (DePuit, 1984). Although the depth of replaced soil doesn't determine the thickness of the root zone as it did over sodic spoil, it may affect the nutrient and water status of the upper portion of the root zone (Redente and Hargis, 1985).

Several studies have been conducted to determine the soil respread depth necessary for generic spoil (Barth and Martin, 1982; Bowen et al., 2005; McGinnies and Nicholas, 1980; McGinnies and Nicholas, 1983; Pinchak et al., 1985; Redente and Hargis, 1985; Redente et al., 1997; Schuman et al., 1985). After five years of growth, Schuman et al. (1985) and Pinchak et al. (1985) found that production increased with additional soil up to 40 cm, with no further benefit to respreading additional depths. A second study was done at the same site, 24 years after reclamation, and they also found that there was no significant difference in cover or production when more than 40 cm of soil was respread and that there was significantly more forbs and greater species richness on the 40 cm respread than with 60 cm (Bowen et al., 2005). In a study of mulches and topsoil depths, native grass production and infiltration were optimal at 40 cm of topsoil (Schuman et al., 1985). Through greenhouse and field trials of introduced and native perennial grass species, McGinnies and Nicholas (1980, 1983) concluded that a minimum of 46 cm of soil was necessary. Barth and Martin's research recommended 50 cm of soil over generic spoil for maximum cool season perennial grass growth (1984). Redente and Hargis (1985) found that there was significantly greater production when 60 cm of soil was respread, but that by respreading 45 cm of soil, there was an increase in diversity without a serious compromise in production. This was further substantiated by more recent research (Redente et al., 1997) that found there was no significant difference in total production between various respread depths from 15 to 60 cm of soil, but there was a direct relationship between soil depth and grass production and an inverse relationship between soil depth and forb production. Because their research with generic spoil used respread intervals (0, 15, 30, 45, and 60 cm) that were on either side of what appears to be the optimal soil depth (50 cm), it can be determined that some unknown value between 45 and 60 cm was necessary to maximize production in their study. Other than Redente et al.'s research, it would appear that optimal soil depth over generic spoil is at most 50 cm. Therefore, based on reviewed literature, a soil respread depth of 50 cm is ideal for operational efficiency and reclamation of diverse, productive native grassland. This 10 cm reduction would result in savings of $500-$850 per acre.

Conclusions

Researchers have made many recommendations regarding soil respread depths based on their results, as summarized in Table 2. However, mines cannot reduce respread depths without a regulatory change. A reduction in respread depths is viewed as a potential reduction in the effectiveness of reclamation, so all concerns must be addressed for the regulatory community to approve this change. There appears to be three main issues that have yet to be resolved. First, more data is needed on respread depths for annual crops on moderately sodic or coarse spoil. Also, although some research has been done regarding woody species, there is little published research that studied the effects on tall shrubs and trees. Therefore the NDPSC is concerned the postmine capability of a site may be limited for some woody species if respread depths are reduced. And finally, there is no long term research on upward movement of sodium so the NDPSC still have concerns about this as well.

The economic impact of a 32 cm reduction for sodic spoil and 11 cm reduction for generic spoil would be $1,500-$2,500 per acre and $500-$850 per acre, respectively. These two categories represent a majority of the land reclaimed at The Coteau Properties Mine, so even by excluding the moderately sodic and coarse spoil category at this time and prime farmland, which must be respread with 122 cm of soil, this proposal would still have a large impact. Furthermore, because this process is “the most costly single item in terrestrial reclamation” (Barth and Martin, 1984), even small reductions in soil respread depths would result in large savings for mines while still maximizing reclamation success.

Table 2. Summary of Soil Respread Depths over Variably Sodic Spoil

Source [3]	Location	Spoil Quality	Min. Rspd for Max. Prod. (cm)	Topsoil Treatments (cm) [4]	Subsoil Treatments (cm) [4]	Notes
Current Regulations	**ND**	**Generic**	**61 (1)**			
Bowen et al., 2005	WY	Generic	40	0-60 wedge	0	Follow up to Pinchak et al., 1985
Pinchak et al., 1985	WY	Generic	40	0-60 wedge	0	
McGinnies and Nicholas, 1983	CO	Generic	≥ 46 (2)	0, 10, 20, 30, 46	0	
Barth and Martin, 1984	ND, WY, MT	Generic	50	0-152 wedge	0	
Current Regulations	**ND**	**M. Sodic /Coarse**	**91 (1)**			
Pole et al., 1979	ND	M. Sodic	30	30, 60	0	
Wick et al., 2005	ND	M. Sodic	40	20	0-137	Follow up to Merrill et al., 1998
Halvorson et al., 1980	ND	Coarse	≥ 70 (2)	23, 46, 69	127, 104, 81	1.5 m soil respread on all plots
Halvorson and Doll, 1985	ND	Coarse	81-89 (2)	-	-	Extrapolated from earlier study
Merrill et al., 1998	ND	M. Sodic	51-100 (2)	20	0-120	51-81 cm for perennial grasses; 89-100 cm for spring wheat
Current Regulations	**ND**	**Sodic**	**122 (1)**			
Merrill et al., 1980	ND	Sodic	≥ 30	0, 20, 60, mix	0-210 wedge	Same site as Power et al., 1981
Wick et al., 2005	ND	Sodic	65	0, 20, 60, mix	0-210 wedge	Follow up to Power et al., 1981
Barth and Martin, 1984	ND, WY, MT	Sodic	71	0-152 wedge	none	
Power et al., 1981	ND	Sodic	71; 90 (2)	0, 20, 60, mix	0-210 wedge	20 cm of TS needed; SS depths varied depending on species

[1] NDAC, 2008
[2] Study included annual crops
[3] Some literature cited in the text of this paper was excluded for brevity. Only one source was included in this summary for each study or follow-up study unless results differed.
[4] Several studies were conducted on the same site but described slightly different treatment depths. This appeared to be from rounding when the depths were converted from inches as originally published to centimeters as used in later publications. Because there was no actual change in treatment depths, to avoid confusion the depths reported in this table correspond to what was published in the original source for all studies conducted at that site.

Summary

Current North Dakota soil respread regulations are based on research conducted in the mid 1980's. Regulations include a buffer that was added to the respread depths suggested by research to account for the unknown behavior of reclaimed sites over time as spoil weathers and plant communities mature. These unknowns have since been largely addressed by long-term studies of reclaimed sites. Studies have also shown that season of growth (C_3 vs. C_4) and origin (native vs. introduced) do not change the response of perennial grasses to soil respread depth. Therefore, respread recommendations may now be based on the results of research that include introduced species, and possibly without the addition of a buffer. After a review of literature it appears that respread depths may be reduced. A reduction in soil respread depths would result in less soil salvaged, stockpiled and respread, thus reducing reclamation costs for the mine without negatively effecting reclamation success. However, before changes to respread requirements are made, we must be confident this will not have a negative impact on the revegetation success of a site or of its capability to support other land uses in the future. Therefore, before ND mines can put into practice the recommendations of past research, issues regarding the effects on annual cropland, woody species and the behavior of sodium in the reclaimed soil profile must be resolved.

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