MINDED LAND RECLAMATION IN THE NORTHERN GREAT PLAINS: HAVE WE BEEN SUCCESSFUL ?[1]

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Abstract. The enactment of state reclamation laws in the 1960's and enactment of Surface Mining Control and Reclamation Act (SMCRA) in 1977 brought the subject of mine land reclamation to the forefront. Early reclamation research was aimed at protection of the soil and water resources. Therefore, early emphasis was placed on proper topsoil salvage technology and re-establishment of a plant community that would protect the soil from erosion. With resource stability accomplished came the desire to establish a more diverse plant community and landscape that would allow the multiple use of the lands in this region, e.g. season-long forage production, recreation/aesthetics, watershed and wildlife habitat. Much research needs to be undertaken and technology developed before we will be able to create the diverse plant communities required to fully meet these multiple uses. Because of a general lack of understanding of many of the basic mechanisms by which plant communities develop, function and succeed, requirements for re-establishment of native warm-season grasses, forbs, and shrubs in the reclaimed community to reflect the diversity of the native or desired landscape remain unresolved. Past research has focused on community level issues in reclamation and has not assessed reclaimed lands at the ecosystem and landscape level, leading to considerable discussion and confusion as to a working definition of reclamation success and subsequent bond release. It is critical that all interested parties come together to develop the definition of reclamation success and understand the role of plant succession in achieving "final" reclamation success. To achieve successful reclamation that meets the needs of potential land uses and takes into account natural succession will require a broader and more open-minded regulatory approach.

Additional Key Words: topsoil, plant establishment, reclamation success, species diversity, mulch, erosion.

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[1]Paper was presented at the 2002 National Meeting of the American Society of Mining and Reclamation, Lexington, Kentucky, June 9-13, 2002. Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

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https://doi.org/10.21000/JASMR02010842

Introduction

Mining in the Northern Great Plains has been a major part of the history of this region. However, the coal boom started in the late 1960's to early 1970's when exploration showed vast amounts of low sulfur coal deposits in the Powder River Basin of Wyoming and Montana. Vast deposits of coal are also present in North Dakota, Colorado and Utah but were generally present in somewhat different ecosystems in those states than that of northeastern Wyoming and southeastern Montana. The predominant landscapes of the Powder River Basin were shrub-grasslands used for livestock grazing and wildlife habitat. These lands are composed of very diverse plant communities and shallow soils in an arid to semi-arid climate. An early evaluation of mining and reclamation by the National Academy of Sciences recommended that lands receiving less than 25 cm of precipitation not be mined because successful reclamation would not be possible without considerable and long-term inputs of water, fertilizer, and management (Box, 1974). However, despite this recommendation, mining was permitted in these areas because other earlier information from land revegetation associated with road construction and other land disturbances indicated that reclamation could be accomplished.

Soil Considerations

The importance of topsoil in achieving reclamation was identified early and was addressed in the early mining laws. SMCRA gave thorough coverage of topsoil management and addressed the need to salvage topsoil/plant growth material and the importance of soil surveys in the overall mining and reclamation planning process. However, these laws also addressed the issue of substitute plant growth media in instances where the topsoil was either inadequate or degraded (saline, sodic, toxic elements).

Topsoil management Topsoil salvage and storage was studied by numerous scientists in the 1970's. Studies showed that topsoil salvage and stockpiling resulted in a reduction in bacteria, actinomycetes, fungi, algae, arthropods and nematodes (Miller and Cameron, 1976; Stanton, 1976). Allen and Allen (1980) showed that disturbed lands contained fewer mycorrhizal propagules than did undisturbed lands; therefore, it was not surprising when Reeves et al. (1979) reported that plants normally mycorrhizal in undisturbed soils tended to lack mycorrhizal associations in severely disturbed soils. Even though the disturbance and salvage process may reduce mycorrhizal inoculum levels in the soil, this may be more of an academic issue rather than a concern for general revegetation of mined lands in this region. Loree and Williams (1984) found that native grasses became infected with arbuscular mycorrhizae (AM) within one year after stockpiled topsoil was respread and seeded in Wyoming. Schuman et al. (1998) also reported that no differences were evident in Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) seedling AM infection 34 months after direct-placed topsoil and 5-year old stockpiled topsoil was respread on coal mine spoils.

However, Stahl et al. (1998), in greenhouse studies, showed that AM significantly increased the drought stress tolerance of Wyoming big sagebrush seedlings indicating that AM may play a major role in determining successful re-establishment of this species on mined lands in arid and semiarid regions. Schuman et al. (1998) however, did show an increase in Wyoming big sagebrush density on direct-placed topsoil compared to stockpiled topsoil, particularly in the first 2 years after seeding. This probably was the response to differences in soil moisture observed in the direct- placed topsoil treatment compared to the stockpiled and the greater level of AM inoculum reported by them.

Important attributes of direct-placed topsoil that are often overlooked are the better soil physical characteristics compared to stockpiled topsoil. Aggregation is not totally destroyed as it is during the salvage, stockpiling and subsequent respreading processes. However, Schuman and Booth (1998) and Booth (2002) in a corollary study did not find any significant difference between these topsoil treatments as it related to sagebrush establishment. However, because of the duration of this corollary study, the longevity of sagebrush seed viability and repeated sagebrush over-seeding, this study did not assess the true effects of topsoil management. As noted earlier AM inoculum is rapidly dispersed naturally to respread stockpiled topsoil so the effects of AM on seedling establishment and the changes in other edaphic characteristics after 6 years prevented the evaluation of topsoil management. Interpretation of this study was confounded by a significant replication effect where a greater sagebrush density was observed on one replication of the stockpiled topsoil treatment, yet, two replications showed a greater sagebrush density on the direct-placed topsoil treatment.Topsoil has also been highly touted as a seedbank important for achieving species diversity (Beauchamp et al., 1975; Hodder, 1977; Howard and Samuel, 1979). However, the majority of the species represented in the soil seedbank are generally dominated by those found in the pioneer stages of secondary succession (Hodder, 1977). Rice (1989) pointed out that in grassland communities there is a distinct difference between soil seed reserves and the surface vegetation. He further states that soil seedbanks appear to contain (a) more annuals than perennials, (b) more forbs than grasses, (c) more leguminous species, and (d) common weedy species that typically colonize disturbances or gaps in the vegetation. Schuman et al. (1998) evaluated direct-placed topsoil benefits on Wyoming big sagebrush establishment and found no sagebrush seedlings had become established over a 4-year period where sagebrush had not been seeded. Howard and Samuel (1979) evaluated fresh-stripped topsoil as a source of native vegetation propagules and found that it did supply some native species propagules, especially those that can reproduce from rhizomes and root crown material. However, the density was very low and would still require seeding to ensure soil stability and to achieve establishment of most of the desired species.

A prime consideration that one needs to keep in mind is that if topsoil is intended to act as a seedbank, only the surface 3-5 cm of soil should be taken and respread on the surface and this material should not be stockpiled. The nature and size of coal strip mines and other mining does not lend itself to direct-placement of topsoil at all times; therefore, to some extent the role of topsoil as a seedbank may be an academic issue and not one that can readily be included in a reclamation plan. In this context, we should be very careful to remember the complexity of the mine and reclamation planning, and also keep in mind the somewhat limited potential benefits that can be realized from seedbank reserves. Seed longevity, production and quality are extremely diverse and very dependent upon the climatic variables of a given year–both from a seed production standpoint and a germination standpoint.

Topsoil Depth

Topsoil depth was another of those subjects that was evaluated in the early phases of reclamation research. McGinnies and Nicholas (1980), Power et al. (1981), Barth and Martin (1982), Redente and Hargis (1985), and Schuman et al. (1985) all initiated research to determine the “optimum” topsoil depth replacement for establishing permanent vegetation cover. Generally topsoil replacement was based upon the amount of topsoil resource available and the quality of the spoil material that was being covered. Most of the studies were generally focused upon soil stabilization and forage production and were relatively short-term (3-5 years). The general recommendation by the regulatory agencies and practices by the industry was to replace topsoil at a uniform depth over regraded spoil or subsoil material. However, shortly after many of these studies were initiated, Schafer and Nielson (1979), Munshower (1982), and DePuit (1984) began proposing topsoil management practices that more closely represented natural soil landscapes (variable replacement depths). DePuit (1984) and Munshower (1982) postulated that depth of replaced topsoil might benefit plant community diversity by simulating the edaphic diversity naturally created by erosion and deposition. For many reasons, varying the depth of replaced topsoil has not become a standard practice in the industry and has been questioned in the past by regulatory agencies. However, because of the renewed interest on the effects of varying topsoil depth on plant community development, some scientists involved in the earlier topsoil depth research have returned to those sites to evaluate long-term effects on plant community composition. Redente et al. (1997) reported greater diversity, increased forb production, and increased shrub density at shallower topsoil depths 10 years after initial establishment. Bowen et al. (2002), at this conference, reported that after 24 years, species richness and diversity indices were highest and total canopy cover lowest where no topsoil replacement had occurred in 1977. They, like Redente et al. (1997), reported total biomass was greatest at 40 and 60 cm of topsoil and was composed primarily of cool-season grasses. These recent findings indicate that edaphic characteristics play a significant role in plant community development and warrant further evaluation as to how this might be utilized in mine reclamation planning to enhance vegetation and landscape diversity.

Substitute Plant Growth Medium

SMCRA permits the use of substitute plant growth material in the reconstruction of mine lands and this subject received some attention in early research and has recently received some attention in Wyoming. Early studies assessing the role of a substitute plant growth media in Wyoming showed that geologic material was not a suitable substitute for the topsoil (Schuman and Taylor, 1978). They found that even though this material had no detrimental characteristics, the material required significant fertilizer inputs to be productive. Later studies of a reclaimed mine site where this material had been used in place of topsoil showed that this material had very low levels of soil organic matter and microbial biomass and the nitrogen mineralization potential was so low that this system would not be sustainable (Woods and Schuman, 1986) without significant fertilizer inputs. Woodmansee et al. (1978) stated that direct revegetation of unweathered mine spoil would not be successful because up to 2100 years of succession would be required for the nitrogen pool to develop to a stage that would support a sustainable plant-soil system. Therefore, careful consideration and evaluation should be accomplished before a substitute plant growth material is used in place of the topsoil present before mining.

Soil organic matter level in the topsoil is very important for microbial activity and without an adequate level of soil organic matter sustainable nutrient cycling is not possible and long-term inputs of nitrogen and other nutrients will be required. In turn, this may not only prevent the development of a sustainable plant community but could potentially impact bond release. Smith et al. (1987) stated that soil organic matter was only of minor to moderate importance in mined land reclamation planning; however, later in their chapter they recommend that soil organic matter in the reclaimed topsoil should be maintained at the baseline level present in the topsoil prior to disturbance. They further stressed the importance of topsoil salvage planning to prevent "diluting" the soil organic matter with soil horizons that have very low inherent levels of this important constituent. Stahl et al. (2001) recently reported on research they have initiated that attempts to establish a "minimum level" of soil organic matter in reclaimed mined lands necessary to ensure sustainability of the reclaimed landscape. Such a minimum standard would prevent reclamation practices where substitute soil or subsoil materials are used and may result in modifying topsoil salvage practices. Interestingly, some state mine reclamation regulations do not require that soil organic matter be assessed; therefore, this shortcoming will need to be addressed first. Careful consideration should be given to the long-term potential impacts of permitting substitute plant growth material for topsoil both from a management standpoint and a bond release standpoint. Natural buildup of soil organic matter is extremely slow and without large amounts of organic amendments will require decades or centuries to achieve the levels found in productive native soils.

Vegetation Considerations

Mulching

Mulching is an issue that raises many diverse opinions as to its benefits and the need to mulch or not mulch. Mulching is seen by some as an unnecessary practice and cost, but it has been shown in many situations to protect the soil from erosion if done properly. The use of mulch to protect the soil resource during initial phases of grass re-establishment is a common practice in mine reclamation as well as on road construction and other construction sites. Schuman et al. (1985) reported that a stubble mulch (established from growing barley) greatly reduced the establishment and production of non-seeded species (mainly forbs) compared to where a surface applied mulch was used. Establishing the stubble creates moisture competition in the initial year after respreading of the topsoil and greatly limits the potential for annual forb establishment and seed production. The stubble also resulted in greater establishment and production of the subsequently seeded perennial grass mixture on the reclaimed site. Another advantage noted by Schuman et al. (1980) was that not only did stubble mulch significantly reduce the chance of bringing noxious weed seed onto the mine site via the purchase of straw for a surface mulch it also resulted in about a 75 to 95% savings compared to buying, transporting, spreading and anchoring a surface mulch. Moreover, they reported that the stubble mulch reduced diurnal temperature fluctuations at the soil surface and resulted in a 25% greater water infiltration than did a surface applied mulch. Stubble mulches improve infiltration and physical characteristics of the soil by contributing a significant amount of plant and root residue to the topsoil. The author is aware of an annual grain crop being grown for 2-4 consecutive years before seeding of the permanent perennial plant mixture in an attempt to improve soil physical and biological properties of the topsoil (Strat Murdock, personal communication). Schuman et al. (1998) also showed that either a stubble or surface mulch greatly increased the establishment of Wyoming big sagebrush on mined lands. They attributed the increase in sagebrush density to the effect of the mulch on creating safe-sites for big sagebrush germination and growth.

Hartley and Schuman (1984) also reported that stubble or surface applied mulch reduced erosion by 50% compared to non-mulched areas. The period of peak erosion hazard on mulched plots occurred during the early part of the second summer following mulching and seeding. By this time, the surface mulch cover has been reduced by wind, and the vegetation established gives only limited protection to the soil. Therefore, the stubble mulch would be more effective because it is not readily lost from the site because of the anchoring by the root system; therefore, resulting in greater ground cover in the second season. Under these conditions stubble mulch is much more effective in minimizing soil erosion since the soil is bound by the stubble root system. Whereas much of the surface applied mulch has been removed by the wind and provides limited protection from erosion.

Whether to mulch or not mulch is still debated. However, many positive improvements in the biological system can be enhanced by using a mulch and cost does not have to be a big factor if a stubble mulch practice is utilized in the reclamation plan. The stubble mulch system requires that either the grain crop be mowed before seed set or that a sterile hybrid used to prevent subsequent year volunteering and competition.

Grass Establishment

In the early 1970's, a very large percentage of the reclamation used a mixture of native and easy to establish introduced grass species. The reclamation specialists saw this as a way to ensure that something came up that provided protection from erosion for the newly regraded and topsoiled spoil. In most cases, the seed mixture included crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.], a vigorous and highly competitive species. In a study requested by the industry and regulatory agencies, Schuman et al. (1982) evaluated the competition of crested wheatgrass against a number of native grass species and a mixture of native species. Crested wheatgrass (25% seed numbers) was planted with western wheatgrass [*Pascopyrum smithii* (Rydb.) A. Love], thickspike wheatgrass [*Elymus lanceolatus* (Scribner & J.G. Smith) Gould], green needlegrass (*Stipa viridula Trin.*), slender wheatgrass [*E. trachycaulus* (Link) Gould ex Shinners], and a mixture of these four grasses (each mixture was comprised of 75% (seed numbers) of each native species or the mixture of native species). In the first year of establishment crested wheatgrass production represented 29.5, 57.5, 77.5, and 77.4% when planted with slender, thickspike and western wheatgrass and green needlegrass, respectively. After 4 years, crested wheatgrass represented 97.4, 84.5, 84.5, and 64% when seeded with slender, thickspike and western wheatgrass and green needlegrass, respectively. When crested wheatgrass was seeded with a mixture of the four native, cool-season grasses crested wheatgrass represented 37.6, 68.8, 78.7, and 95.7% of the production in year 1, 2, 3, and 4, respectively. It is easy to see that if you include crested wheatgrass in a grass seed mixture, it will become the dominant species within a few years. From this research came the recommendation and regulatory agency guideline that crested wheatgrass not be included in a grass mixture. This research also showed that to ensure that some grass establishment for erosion protection is achieved, slender wheatgrass should be included in the seed mix. In the first year, slender wheatgrass represented 76.8% of the production of the native species indicating that it is relatively easy to establish but then declines (it only represented 18.2% of the production in year 4). This is not to say that introduced species should not be used in reclamation but they would best be used in a monoculture or as a mixture of introduced grass species. This will avoid the competition created by most introduced grass species and also simplify later management of the reseeded area because of different responses to grazing and different maturation times.

Establishment of a diverse, perennial, self-sustaining community on reclaimed mined lands continues to be a challenge. Native cool-season species are relatively easy to establish and although during period of severe drought they also are vulnerable, experience has shown that even in these cases one must be careful not to jump to the conclusion that a failure has occurred, because the seed may still be viable and will germinate the following year. Establishment of a diverse grass community still remains an issue that has not been adequately resolved by research or through various practices evaluated by the industry, particularly in regards to warm-season native grass establishment. In recent conversations with several reclamation specialists, they concluded that the best way to ensure establishment of warm-season native grass species was to seed them alone or with shrub species. They also stated that the two-step procedure of seeding warm-season species one year and then following up with the cool-season species seeded perpendicular to the warm-season planting doesn't guarantee success. The successes I have seen with regard to warm-season establishment is where they were seeded alone, seeded with cool-season species and above average precipitation was experienced or when warm- and cool-season grass species were seeded together but at a very low total seeding rate (<8 kg/ha). I believe this is a subject area where additional research is needed to address this problem adequately.

Shrub Establishment

Re-establishment of shrubs on coal mined lands is a topic that received only limited serious attention until August 6, 1996 when Wyoming passed a shrub standard that is required to be met on all lands disturbed by coal mining after that date. Proof of shrub seed purchase and planting were the only real mandates aimed at shrub re-establishment on mined lands in Wyoming until the shrub standard was made law. Up to that time many different approaches were used to attempt to re-establish shrubs on mined lands.In the 1970's, "island transplants" were attempted where large loaders were used to move a patch of shrubs and small trees in a soil volume adequate to limit root disturbance. These patches were somewhat successful but did not produce an adequate density on a landscape basis and generally did not meet expectations as a seed source for further recruitment and spread of shrubs. Many of the earlier plantings of shrub species were accomplished by mixing the shrub species with the wide range of grass seed and drill seeding them.

However, a number of reclamationists and researchers have reported that many of the shrub species required surface broadcasting or very shallow seeding to enable germination and emergence. Research also demonstrated that the appendages on seeds/fruits such as winterfat [*Ceratoides lanata* (Pursh) J.T. Howell] should not be removed to improve seed flow through a drill because these appendages play both metabolic and physiological roles in germination and establishment (Booth and Schuman, 1983; Booth, 1989). This single finding greatly improved the success of establishing many of these species during the 1980's. Wyoming big sagebrush is a species that has garnered a great deal of attention because of its wide distribution and the role it plays in wildlife habitat in the western U.S. and specifically in Wyoming. In the 1990's several research projects were initiated to study the effects of topsoil management, mulching and grass seeding rates on the establishment of Wyoming big sagebrush. Schuman et al. (1998) showed that mulching, topsoil management and competition from perennial grass species influenced sagebrush seedling establishment. Direct-placed topsoil significantly increased sagebrush seedling establishment in the first year after seeding compared to stockpiled topsoil. This may have been due to the effects of AM infection on seedling drought stress tolerance on the direct-placed topsoil where AM inoculum was higher compared to the stockpiled topsoil during the first 12-18 months after being replaced on the regraded spoil (Stahl et al., 1998). Schuman et al. (1998) also found that mulching significantly increased sagebrush seedling density and grass competition reduced sagebrush seedling density. Williams et al. (2002) tried to further refine the grass competition effects on sagebrush seedling density at a mine site in northeastern Wyoming by evaluating seven grass seeding rates between 0 and 14 kg pure live seed (PLS)/ha and three sagebrush seeding rates (1, 2, and 4 kg PLS/ha). However, they did not find significant differences in sagebrush seedling densities across grass seeding rates of 2 to 14 kg PLS/ha. Even though not statistically different, sagebrush seedling density was about 50% lower at the 14 kg PLS/ha grass seeding rate compared to the 10 kg PLS/ha grass seeding rate. They believe that the lack of a significant response to the grass competition was the result of two normal or above normal precipitation years during the first two years of the study and the fact that the lower grass seeding rates (<6 kg PLS/ha) had significant annual weed densities and production during the first year and represented similar competition for resources (moisture and space) as the higher grass seeding rates. Schuman et al. (2001) continued to assess the Williams research study site and found that sagebrush seedling mortality was quite high in 2001 and even though not significant, sagebrush seedling density has begun to exhibit more of a response to the higher grass seeding rates. However, sagebrush seedling size (volume-cm^3) did show a significant response to grass competition in 2001. Sagebrush seedlings present at grass seeding rates ≥6 kg

PLS/ha were significantly smaller than those at lower grass seeding rates. Sagebrush seedling size was 2 to 4 times greater at the seeding rates of 0 to 6 kg PLS/ha than at the higher rates and will undoubtedly effect future sagebrush seedling survival. Williams et al. (2002) reported no differences in grass aboveground biomass between the 4 and 14 kg PLS/ha grass seeding rates in 2000 and Schuman et al. (2001) found no differences in grass biomass between 2 and 14 kg PLS/ha grass seeding rates. Williams et al. (2002) also reported significantly greater sagebrush seedling density at higher sagebrush seeding rates when seeded at 1, 2, and 4 kg PLS/ha. This response to shrub seeding rate has been reported by others (Richardson et al.,1986; Gores, 1995; Booth et al., 1999). Most past research has dealt with the initial establishment of big sagebrush (1-4 years). However, two studies have assessed long-term survival and reported survival rates of 28-32% (Kiger et al.,1987) and 59% (Schuman and Belden, 2002) survival after 11 and 8 years, respectively.Williams et al. (2002), based on the above information on Wyoming big sagebrush establishment and survival, recommended that grass seeding rates of 6 or 8 kg PLS/ha and sagebrush seeding rates of 2 or 4 kg PLS/ha be used with a stubble mulch to ensure that the shrub density of 1 shrub/m^2 will be achieved. The sagebrush seeding rates take into account the fact that the recent research has shown the viability of the sagebrush seed to be at least 3-4 years. This extended viability will greatly increase the likelihood of an “optimum climatic” year occurring that will result in adequate sagebrush germination and establishment. Schuman et al. (2001) further evaluated these data and calculated the cost of a surviving sagebrush seedling compared to using nursery grown transplant stock to achieve the shrub density required in Wyoming. They concluded that even with the best scenario of $0.50 per transplant and 100% survival of the transplants compared to $300/kg PLS Wyoming big sagebrush seed and 33% long-term survival of the seedlings; direct seeding would only cost 9.6% of what transplantation would cost to meet the shrub standard. If we were to use 2000 cost estimates for transplants, $2.00 per transplant, (Kleinman and Richmond, 2000) and 100% survival, direct seeding would only cost 2.4% of the cost of nursery grown transplants. However, there may be very site specific situations and/or requirements where nursery grown transplants may be necessary to achieve reclamation, especially where seed propagation is not an option.

Research has answered many questions as it relates to the successful establishment of Wyoming big sagebrush and other species on mined lands. The single most critical issue in shrub establishment is to ensure the use of good quality seed. Some components of the research highlighted here may well apply to other native shrub species; however, these practices have not been evaluated for many of the desired species but significant advances in the understanding of shrub seedbed ecology have been made over the last decade and these advances have led to more consistent and successful establishment of native shrubs on mined lands in the Northern Great Plains.

Management of Reclaimed Lands

Using grazing as a management tool has been practiced for many years in rangeland agriculture and it has long been acknowledged season of grazing and intensity can be used to modify the plant community. Vicklund (1999) described how the Belle Ayr Mine near Gillette, Wyoming has used grazing both as a management tool and to demonstrate the reclaimed lands potential to support livestock grazing. State regulations recommend that the reclaimed plant communities be evaluated to demonstrate that they can sustain grazing without detriment. She showed that grazing has increased cool-season grasses on reclaimed lands and that livestock gains were also better than that observed on adjacent native rangelands. She also stated that reclaimed lands that have been grazed have shown slight increases in the warm-season grass component of the reclaimed plant community and suggests that further refinement of the grazing program could have further impacts on this trend. Vicklund (1999) also proposed that managed grazing can reduce undesirable species that become established in the early stages of reclamation, and may also be useful in aiding the establishment of shrub species. Other reclamation officials are also using grazing as a tool to manage plant community development and to demonstrate the capability of the reclaimed lands to support livestock grazing. I have simply used Vicklund's (1999) work as an example to demonstrate this practice.

Assessment of Reclamation Success

Assessment of reclamation success is an especially hot topic at this time because reclamation under SMCRA is becoming available for final bond release. There is, however, no clear understanding or interpretation as to what constitutes final bond release as set forth in SMCRA or State criteria. Each case seems to be handled as a separate evaluation with each state regulatory agency taking a different approach to what constitutes successful reclamation.

Development of reclamation success criteria during the writing of SMCRA led to the use of reference areas. This approach was very much an "idealistic" approach and one that was considered by most practitioners and scientists as an unachievable goal. The reference area concept compares an ecologically mature ecosystem to one that is very immature and in early successional stages, i.e. reclaimed mine site. Many of the species present in a pre-mine ecosystem represent species difficult if not impossible to re-establish for one reason or another during the 10-year bond period. Murdock (1980) recommended an alternative approach to the evaluation of reclamation success. The utilitarian method, he proposed, assesses the capability of the reclaimed land to properly function and thereby sustain its intended post-mining land use. If livestock grazing was the primary post-mining land use, the question would be whether reclaimed lands could sustain grazing without any detrimental effect to the ecosystem while producing forage and livestock gains appropriate for the region. Schuman et al. (1990) carried out one of the first grazing studies on reclaimed mined lands where native species were used to accomplish the revegetation. They reported that livestock gains, using a season-long grazing management scenario, were equal to or better than that achieved on native rangelands in the local area. They also reported that grazing increased basal ground cover by stimulating rhizome production and increasing litter cover. This study demonstrated that proper grazing of reclaimed mine lands could be used to assess reclamation success from a utilitarian standpoint and also improve desirable characteristics that indicate greater sustainability and erosion protection (Hofmann et al. 1983). Schuman (1999) described an "ecological trend analyses" as a procedure that effectively assesses long-term sustainability and successional potential thus, reclamation success. For example, he stated that species diversity could be monitored over the 10 year bonding period and if the trend is toward an increasing number of species during this time and these species are desirable ones and are representative of the native plant community then the criteria for species diversity could be considered being met. He proposed that a minimum number of species could be established as a standard. Using this kind of approach would actually give more weight to natural succession and would remove the illogical comparison of the early succession, reclaimed plant community to a more mature reference area. He further proposed that evaluating such criteria as plant cover, species diversity, plant community composition, and production over the 10 year period described in SMCRA would be a more appropriate and more effective way of assessing reclamation success and would be better than making this evaluation only during the last couple of years of the bonding period. Evaluating the desired criteria over a period of many years allows one to determine if the specific parameter is moving in an ecologically desirable direction and one that would indicate reclamation success.

The shrub density standard in Wyoming is one of those success factors that I believe can readily be met but the shrub community may and in most cases will not provide desirable wildlife benefits or habitat. Many examples exist in this region where the shrub density standard can readily be met but, because of excessive wildlife browse, these plants do not provide cover or other habitat quality necessary for wildlife. It is important to understand why we have such a wide range of response by wildlife to newly established shrubs ranging from no browse to extremely heavy browse that limits establishment success (Strait et al. 2001). The key point in these discussions is that we must now direct our research to the next level and assess mined land reclamation on a broader scale than just that of a given piece of disturbed land or even a single mine. Adjacent mines and the affected and adjacent rangeland condition undoubtedly impact reclamation success and sustainability in the long term.

Summary

This review of our knowledge in the areas of topsoil management (topsoil depth and substitute soil materials), mulching, grass establishment, shrub establishment, reclamation management, and reclamation success in the Northern Great Plains clearly demonstrates that we have a great deal of knowledge on the subject, but that we do not have answers for all of the concerns and questions confronting the mining or regulatory industry. This review concentrates on recent research carried out in the region by myself and co-workers because that was the request of the symposium organizer and by no means should be interpreted to mean that other research is not important in answering critical reclamation questions. Areas where sound recommendations can be made are as follows:

(1) Where possible, direct-placed topsoil should be used because it has better AM levels and it has better physical characteristics and a greater potential, even though very limited, for seedbank benefits including rhizomes or crowns.

(2) Recent data collected on long-term research sites indicate that replacing the topsoil at variable depths will enhance landscape and plant community diversity.

(3) Topsoil substitution or use of overburden for plant growth medium should not be allowed without thorough evaluation of other alternatives because these unweathered geologic materials have extremely low or no organic carbon and sustainable nutrient cycling likely will not be achievable for 50-100 years without substantial inputs to the system.

(4) Mulches play a role in the development of "safe sites" that aid establishment of native shrubs and a stubble mulch has many benefits including economic, water conservation and infiltration, and is not prone to being blown away.

(5) Direct seeding of Wyoming big sagebrush can be used to establish this species on mined lands and is much cheaper than using transplants to meet the general shrub density standard. Good quality seed is of key importance.

(6) Browsing by wildlife can have a huge negative impact on successful shrub establishment and wildlife habitat development.

(7) Grazing reclaimed lands with livestock can be used as a tool to manipulate plant community development and has demonstrated these land's capability of sustaining this intended post-mine land use.

(8) Use of the reference area concept and shrub density standard is not a good approach for evaluating reclamation success and subsequent bond release. Other more ecological approaches would be better and take into account natural succession.

(9) The reclamation process should be planned and carried out at the landscape level rather than at the small specific plant community level. This would greatly improve the overall appearance and success of the reclamation in meeting the multiple uses typically expected of them.

(10) Establishment of warm-season native grass on mined lands continues to be an area of some uncertainty. I don't believe we can expect to achieve successful establishment of some of these species, i.e. blue grama, on a regular basis because of the specific soil moisture requirements and competition factors that we either have no way of controlling or do not fully understand. The most consistent successes of establishing these species have been achieved by seeding them alone, not with the more vigorous native cool-season species (there are always exceptions to these observations) that generally dominate the native plant community and provide the majority of the annual forage production.

We have much of the basic knowledge for good soil management, plant establishment, and protection of the basic natural resources. The single biggest knowledge gap we have is that we have looked at many "pieces" of reclamation but we have not looked at the processes and importance of reclamation on a landscape level. I believe we must consider the landscape level approach to fully assess mined land reclamation success. We definitely need to be more flexible and open-minded about what comprises reclamation success and definitely modify or abolish the reference area approach. The reference area approach to bond release does not improve reclamation and in many cases it could lead to failure because we are trying to force succession (plant community composition and development) into a finite time frame without considering other factors, especially climatic and edaphic factors.

We basically know how to stabilize the soil and restore vegetative productivity to the land, now we have to think in a different paradigm and refine our knowledge to address those factors that will ensure that the desired successional trends are achieved. When we have those answers we can be assured that reclamation success will be achieved.The title of this paper asked the question–"Mined land reclamation in the Northern Great Plains: Have we been successful?" I believe we have been successful in reclaiming these lands to a level of productivity greater than or equal to that prior to mining and these reclaimed lands supply a season-long forage base for livestock and wildlife. The law also stated that the vegetation must possess a similar season of use and research has shown that a mixture of cool-season plants can achieve this season of use factor without having any warm-season plants present. In short we have successfully stabilized the soil and we have returned the lands to productivity. However, we have not been fully successful in achieving species diversity, including shrub species, that resemble the diversity (number of species) of the adjacent native rangelands. Can we or is it reasonable to think we can achieve this diversity in the 10 year bonding period? I don't think we can achieve this diversity within the bonding period because little is known about the ecology of many of these native species and seed or good quality seed is not available for many of them. These sites, much like other severely disturbed sites, will require considerable time for natural recruitment to occur. As edaphic characteristics of these sites improve, vegetation diversity will likely develop. Reclamation can aid the process of succession but I believe it is unrealistic to believe that we can achieve such lofty goals (comparable diversity of native lands) within such a short time. We have achieved stability of the system and experience and history have shown us that species diversity, through succession, will follow. Research will continue on understanding the germination requirements and seedbed ecology of many of these native species and as knowledge is achieved in these areas it will be implemented into reclamation technology to further enhance reclamation success.

Acknowledgments

The author would like to acknowledge all of the research carried out in the Northern Great Plains that is not cited in this paper. The paper was intended to address the key issues of reclamation, particularly soil stabilization and revegetation, where significant advances have

been made and was not intended to be a thorough review of the literature. Those references cited were used to express a specific point or used as an example to demonstrate a point.

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