# Guidance for Soil and Cover Material Handling and Suitability for Part 5 Existing Mines

Energy, Minerals & Natural
Resources Department

Mining and Minerals Division
1220 S. St. Francis Drive
Santa Fe, NM 87505

DECEMBER 2022

# Table of Contents

# Mining and Minerals Division ("MMD") Guidance for Soil and Cover Material Handling and Suitability for Part 5 Existing Mines

## 1.0 INTRODUCTION

This document ("Guidance") recommends how to organize, support, and submit soils information to the New Mining and Minerals Division ("MMD") for Existing Mine Operations based on the requirements described in the New Mexico Mining Act, NMSA 1978, Section 69-36-1 *et. seq.* ("the Act") and more specifically, Title 9, Chapter 10, Part 5 of the New Mexico Administrative Code ("NMAC"). This Guidance also explains MMD's understanding on how best to manage soils on mine sites across soil types, climates, and ecosystems.

This Guidance is not meant to be interpreted as requirements or rules, but guidelines that will give the operator an option to incorporate best management practices into soil management and evaluate soil conditions if vegetative requirements are not being met. The Guidance was developed from years of regulatory experience in New Mexico, current scientific principles and literature, in addition to topsoil and overburden suitability guidelines developed by other regulatory mining programs and agencies in the western states, including the Office of Surface Mining Reclamation and Enforcement on Federal Lands, the New Mexico Coal Mine Reclamation Program, the Montana Department of Environmental Quality, the Oklahoma Department of Mines, the Colorado Mined Land Reclamation Division, the Wyoming Department of Environmental Quality, and the Utah Department of Natural Resources.

Understanding the importance of soils and how soils can be managed to achieve ecological goals is crucial when planning and implementing mine Reclamation activities. This Guidance provides mine operators with the tools they need to analyze undisturbed native soils and proposed Cover Material, create and maintain topsoil and Cover Material stockpiles, and create an overall soils management plan to establish and maintain a Self-Sustaining Ecosystem. Soils play a key role in ecosystem health and resiliency including but not limited to providing a medium for plant growth, regulating surface and subsurface water storage and cycling, recycling nutrients and contaminants (including carbon storage), modifying the atmosphere, and providing micro- and macro-invertebrate niches.

New Mexico soils are the product of diversity within each of the five soil forming factors: biological activity, topography, geology, climate, and time. Considering this diversity within the fifth largest state in the United States, it is not surprising that those factors result in a state with 6 of 12 soil orders, a rich representation of soil series, and a wide range in soil health resiliency factors. Applying a one-size-fits-all policy to soil management on mine sites in New Mexico ignores the complexity of soil types and the plant communities that have adapted to unique soil types across the state.

This Guidance is <u>not an administrative rule and does not carry the force of law</u>; it is intended to provide assistance to applicants, mine operators, government agencies, and the public.

# 2.0 DEFINITIONS

The following definitions are used throughout this Guidance:

**Cover Material:** suitable material that consists of one or more mediums used to cover areas disturbed by mining at Reclamation for the purpose of creating a living soil medium, providing an adequate plant growth medium, and where applicable, a store-and-release cover that will protect surface and groundwater pursuant to 20.6.2 and 20.6.7 NMAC (NMWQCC Ground and Surface Water Protection Regulations, under the regulatory authority of the New Mexico Environment Department). At least one topdressing, topsoil, or soil layer capable of supporting the re-establishment of a Self-Sustaining Ecosystem must be included as a top layer in the Cover Material pursuant to 19.10.5.507.A and 19.10.5.508 NMAC. Suitable Cover Material resists erosion, offers adequate plant available water holding capacity, and provides the structural, chemical, and biological composition to sustain a locally adapted plant community and Self-Sustaining Ecosystem.

**Disturbed Area** (19.10.1.7.D(2) NMAC): "an area where the earth's surface is disturbed as a result of mining or activities facilitating mining."

**Healthy Soil** (Healthy Soil Act 76-25-1 to 76-25-5 NMSA 1978)**:**

a. "Soil that enhances its continuing capacity to function as a biological system, increases its organic matter and improves its structure and water- and nutrient-holding capacity."
b. Achieves the five "soil health principles" of general soil management as (1) keeping soil covered, (2) minimizing soil disturbance, (3) maximizing biodiversity, (4) maintaining a living root, and (5) integrating animals into land management, including grazing animals, birds, beneficial insects or keystone species, such as earthworms.

**Organic Amendment:** an organic material added to the soil for the purpose of improving the physical and chemical properties of the existing soil, such as structure, porosity, infiltration, plant available water holding capacity (through particle aggregation and pore size distribution), cation exchange capacity, pH buffering, slow release of nutrients, chelation potential, and biological food sources to maintain sustainable levels of nutrient cycling by microorganisms. Common Organic Amendments include composted sewage effluent/sludges/biosolids, composted animal manure, food processing wastes, and forest waste (*e.g.* paper sludge, composted wood chips, etc.). Inorganic amendments, such as products intended as fertilizers without supplying a significant amount of carbon, are not considered Organic Amendments. See Section 6.3.10 *Organic Matter* for more information on effects of Organic Amendments on soils.

**Permit Area** (19.10.1.7.P(3) NMAC): "the geographical area defined in the permit… for an existing mining operation on which mining operations are conducted or cause disturbance."

**Reclamation** (19.10.1.7.R(1) NMAC): “the employment during and after a mining operation of measures designed to mitigate the disturbance of affected areas and Permit Areas and to the extent practicable, provide for the stabilization of a Permit Area following closure that will minimize future impact to the environment from the mining operation and protect air and water resources.”

**Self-Sustaining Ecosystem** (19.10.1.7.S(2) NMAC): “reclaimed land that is self-renewing without augmented seeding, amendments, or other assistance which is capable of supporting communities of living organisms and their environment. A self-sustaining ecosystem includes hydrologic and nutrient cycles functioning at levels of productivity sufficient to support biological diversity.”

**Soil** (not capitalized in text):

a. “The collection of natural bodies occupying parts of the Earth’s surface that support plants and that have properties due to the integrated effect of climate and living matter acting upon parent material, as conditioned by relief, over periods of time.” (Brady and Weil, 2000)
b. “The layer(s) of generally loose mineral and/or organic material that are affected by physical, chemical, and/or biological processes at or near the planetary surface, and usually hold liquids, gases and biota and support plants.” (Soil Science Society of America)
c. A mixture of organic and unconsolidated mineral material, dead and live organisms, air, and water on the Earth’s surface that is a result of and subject to weathering. It is a natural medium for plant growth and animal habitat and is a result of and continuously influenced by parent material, climate, organisms, topography, and time.

**Stabilize** (19.10.1.7.S(4) NMAC): “to control movement of soil or areas of disturbed earth by modifying the landform, or by otherwise modifying physical or chemical properties, such as by providing a protective surface coating or vegetation.”

**Topdressing** (19.10.1.7.T(1) NMAC): “geological material and other amendments capable of supporting vegetation.”

**Topsoil** (19.10.1.7.T(2) NMAC) (not capitalized in text): “the "A" soil horizon or other soil material capable of supporting vegetation.”

# 3.0 REGULATORY AUTHORITY

The purpose of this Guidance is to assist regulators and mine operators in the implementation and compliance of The New Mexico Mining Act, Chapter 69, Title 36 NMSA ("the Act") and Part 5 *Existing Mining Operations* of the New Mexico Mining Act Rules, Title 19, Chapter 10 NMAC ("the Rules"). The Rules require that mined land be reclaimed to achieve a Self-Sustaining Ecosystem appropriate for the life zone of the surrounding areas following closure unless conflicting with the approved post-mining land use (19.10.5.506.J(3) NMAC). Since soil has a fundamental role in a functioning Self-Sustaining Ecosystem, this Guidance provides recommendations for soil management. This includes recommendations for identifying and comparing site-specific pre-mining and/or adjacent undisturbed soil types and Reclamation Cover Material suitability. Provisions of the Act and the Rules that inform this Guidance are set forth, below.

> **Section 69-36-11(B)(3):** "*the closeout plan specifies incremental work to be done within specific time frames that, if followed, will reclaim the physical environment of the permit area to a condition that allows for the reestablishment of a self-sustaining ecosystem on the permit area following closure, appropriate for the life zone of the surrounding areas unless conflicting with the approved post-mining land use…*"
>
> **NMAC 19.10.1.7.S(2):** "*Self-sustaining ecosystem' means reclaimed land that is self-renewing without augmented seeding, amendments, or other assistance which is capable of supporting communities of living organisms and their environment. A self-sustaining ecosystem includes hydrologic and nutrient cycles functioning at levels of productivity sufficient to support biological diversity."*
>
> **NMAC 19.10.5.506.B**: "*A proposed closeout plan or a proposed closeout plan for a portion of the mine shall include a detailed description of how the permit area will be reclaimed to meet the requirements of Section 69-36-11B(3) of the Act and the performance and reclamation standards and requirements of 19.10.5 NMAC.*"
>
> **NMAC 19.10.5.506.J(3)**: "*The Director shall approve an application to incorporate a closeout plan or closeout plan for a portion of the mine if: . . . (3) the applicant has demonstrated that the work to be done will reclaim disturbed areas within the permit area to a condition that allows for the re-establishment of a self-sustaining ecosystem on the permit area following closure, appropriate for the life zone of the surrounding areas unless conflicting with the approved post-mining land use; provided that for purposes of 19.10.5 NMAC[.]*"
>
> **NMAC 19.10.5.507.A**: "*The permit area will be reclaimed to a condition that allows for re-establishment of a self-sustaining ecosystem appropriate for the life zone of the surrounding areas following closure unless conflicting with the approved post-mining land use. Each closeout plan must be developed to meet the site-specific characteristics of the mining operation and the site. The closeout plan must specify incremental work to be done within specific time frames to accomplish the reclamation.*"
>
> **NMAC 19.10.5.508**: ***"New Units" -*** "*New discrete processing, leaching, excavation, storage or stockpile units located within the permit area of an existing mining operation*

*and not identified in the permit of an existing mining operation, and for each expansion of such a unit identified in the permit for an existing mining operation that exceeds the design limits specified in the permit must meet the reclamation standard set forth in Subsection A of 19.10.5.507 NMAC[.]*"

**NMAC 19.10.5.508.A**: *"**Most Appropriate Technology and Best Management Practices** – The mining operation and reclamation plan shall be designed and operated using the most appropriate technology and the best management practices."*

**NMAC 19.10.5.508.B(7): "*Minimization of Mass Movement*** *- All man-made piles such as waste dumps, topsoil stockpiles and ore piles shall be constructed and maintained to minimize mass movement."*

**NMAC 19.10.5.508.C: "*Site Stabilization and Surface Configuration*** *– The permit area shall be stabilized, to the extent practicable, to minimize future impact to the environment and protect air and water resources. The final surface configuration of the disturbed area shall be suitable for achieving a self-sustaining ecosystem or approved post-mining land use.*
*(1) Final slopes and drainage configurations must be compatible with a self-sustaining ecosystem or approved post-mining land use.*
*(2) All reconstructed slopes, embankments and roads shall be designed, constructed and maintained to minimize mass movement.*
*(3) Measures must be taken to reduce, to the extent practicable, the formation of acid and other toxic drainage that may otherwise occur following closure to prevent releases that cause federal or state standards to be exceeded.*
*(4) Nonpoint source surface releases for acid or other toxic substances shall be contained within the permit area.*

**NMAC 19.10.5.508.D: "*Erosion Control -*** *Reclamation of disturbed lands must result in a condition that controls erosion. Revegetated lands must not contribute suspended solids above background levels to intermittent and perennial streams. Acceptable practices to control erosion include but are not limited to the following:*
*(1) stabilizing disturbed areas through land shaping, berming, or grading to final contour;*
*(2) minimizing reconstructed slope lengths and gradients;*
*(3) diverting runoff;*
*(4) establishing vegetation;*
*(5) regulating channel velocity of water;*
*(6) lining drainage channels with rock, vegetation or other geotechnical materials; and*
*(7) mulching.*"

This Guidance should be considered in conjunction with MMD's Self-Sustaining Ecosystem Guidance, which can be found at https://www.emnrd.nm.gov/mmd/mining-act-reclamation-program/guidelines/.

# 4.0 SOIL CLASSIFICATION – NEW UNITS

This section describes recommendations for soil classification of undisturbed areas within proposed new units, as described in 19.10.5.508 NMAC. As a best management practice, described in 19.10.5.508.A NMAC, and to better understand the pre-mining soil conditions and surrounding soil types within proposed new unit areas, operators should provide a soil survey and associated soil map. This information can also be useful in identifying undisturbed vegetative reference areas. A survey should include, at a minimum, a list of the soil series within and surrounding the Permit Area, a map showing where the soil series are located, descriptions of those soil series (including depth of soil), and any limitations of the soil series (*e.g.*, erodibility, salt accumulation, textural concerns, etc.).

Although there are a wide variety of soil types in New Mexico, the most common soil suborder throughout the state is the clay-rich Argids group within the Aridisols soil order. These are characterized by areas of low precipitation and variable plant cover. Due to low precipitation, these soils are unable to leach certain materials out of the soil profile, resulting in higher concentrations of calcium carbonate, gypsum, soluble salts, and exchangeable sodium accumulation lower in the soil profile. They are also characterized by being well-drained, having a lighter color, and frequently having low levels of organic matter, resulting in a low resiliency to structural changes such as compaction, crusting, petrocalcic horizons (hard, very low impermeability layers of caliche or hardpan), and erosion. Less common soil orders in New Mexico include Alfisols (forest soils), Entisols (young soils), Mollisols (grassland soils, high in organic matter), Inceptisols (early development soils), and Vertisols (shrinking/swelling clay soils).

## 4.1 Soils Mapping

For any proposed New Unit (19.10.5.508 NMAC), MMD recommends preparation of a Soil Survey and Description of Soil Types in and around the Permit Area at an approximate scale of 1:15,000 or larger.

At a minimum, the survey and description should define an Area of Interest ("AOI") and include a soils map from: https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm. As an alternative, operators may download the most recent Soil Survey Geographic Database ("gSSURGO") data for New Mexico (https://nrcs.app.box.com/v/soils). Any submittal should include a map and interpretation of the soils data for the area of proposed disturbance and/or reference soil comparison to existing Disturbed Areas.

Local United States Department of Agriculture Natural Resources Conservation Services ("USDA/NRCS") offices can also provide soils and Ecological Site Description ("ESD") maps at no charge (https://www.nrcs.usda.gov/wps/portal/nrcs/site/nm/home/).

## 4.2 Soils Sampling

Soil sampling should be performed by a qualified soil scientist on any proposed new disturbance areas within the Permit Area and reported as baseline data for determining topsoil characterization for Reclamation.

An Order I Soil Survey should be used to collect enough information for soil salvage, storage, and reclamation planning (USDA/NRCS Soil Survey Manual, Chapter 4. *Soil Mapping Concepts*, 2017 found at https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054254). See Section 6.2 *Soil and Cover Material Sampling* for more guidance on soil sampling.

## 4.3 Soils Sampling and Mapping Reporting

Use the survey and recommended sampling data from Sections 4.1 *Soils Mapping* and 4.2 *Soils Sampling* to provide a narrative with the following information:

a. A brief description of each soil series, including depth to bedrock, drainage class, parent material characterization, precipitation, general soil characteristics, and erodibility.
b. Depth(s) of soil to salvage and stockpile prior to any disturbance which can be used to estimate if the volume of soil removed will provide sufficient cover at Reclamation.
c. Identify any limiting factors for Reclamation success – *e.g.*, soil depth, sodic soils, low cation exchange capacity or plant-available water holding capacity, steep slopes, erodible material, percent rock fragment, etc. and review ESDs within the Permit Area.

# 5.0 SOIL STORAGE AND HANDLING

## 5.1 Native Soil Retention and Salvaging

With few exceptions, salvaged, previously undisturbed soil is more desirable and will be a better Reclamation growth medium than mixed overburden or some other source such as run-of- mine rock material. Mine operators should consider salvage at an early stage of mine planning and throughout the life of the mine to protect the soils and any other suitable Cover Material from subsequent mining activity or contamination with unsuitable Cover Material. As the mine operation progresses, development of new mining and waste units may come at the expense of existing soil stockpiles unless coordination for the closeout plan continues between mine planners, environmental managers, and state regulatory agencies. Preparation of an appropriate long-term soil storage plan can help reduce the adverse impacts on soil stockpiles during the lifetime of the mine. This plan should include:

a. A map of proposed soil stockpile locations;
b. Proposed native seed mix, seeding rate, and mulch type and rate for soil stockpiles;
c. Compaction mitigation for soil stockpiles;
d. Berm design and stormwater controls for soil stockpiles;
e. Plan for monitoring and maintenance of soil stockpiles;
f. Contingency plan for weed control for soil stockpiles; and,
g. Long-term mine plan indicating location and areas of mine features to be reclaimed and amount of soil to be used in reclamation of those areas.

Stripping and salvaging of soil should be done under supervision of a qualified soil scientist. Soil aggregate structure may be negatively impacted during salvaging. Stripping soil when the soil is neither too wet nor too dry could lessen the impact of soil aggregate destruction. All native soil should be salvaged, stockpiled, and managed to reduce erosion and contamination from unsuitable overburden (*e.g.*, unsuitable parent material and/or blasted bedrock) and/or mine waste material. Ideally, soil stockpiles are designed and constructed in a wide, shallow geometry to minimize compaction, increase the surface area for plant growth (including a future seed bank) and promote microbial activity.

When possible, all soil layers, potentially including parent material (*i.e.*, horizons A and B, possibly C), should be removed and separated into segregated stockpiles based on soil horizons, and/ other soil properties prior to mining a new unit.

When possible, vegetation should be grubbed, chipped, and partially incorporated into the A horizon soil stockpile or stockpiled separately for use as a mulch cover.

## 5.2 Soil Stockpile Maintenance

Soil stockpiles should be surrounded by a berm designed for the 100-year, 24-hour storm, but no less than a 10-year, 24-hr storm event. A 500-year, 24-hr storm event design should be considered based on site-specific conditions around the perimeter to capture eroded material and prevent stormwater run on. Larger and flatter soil stockpiles may require an additional berm around the top of the pile. Soil stockpiles and berms should be seeded with a native seed mix (including annual and perennial species) while not in use. Signage should be provided to prevent unintentional removal or contamination.

Keeping the soil stockpiles covered with growing native vegetation during the growing season will improve the Cover Material for use during Reclamation by:

a. Building organic matter during soil storage;
b. Continuing nutrient cycling and building a Healthy Soil microbiome;
c. Contributing to the seed bank of the soil stockpile; and
d. Reducing erosion to maximize the amount of material available for Reclamation.

## 5.3 Reclamation Design

### *5.3.1 Soil Salvage Volume Calculation*

The Closeout Plan requirement (Section 19.20.5.506.B.3 NMAC) "*of a topographic map with an anticipated surface configuration of the permit area upon completion of the closeout plan,"* presents an opportunity to plan for soil salvage and manage soil organic matter in a manner that promotes successful Reclamation at mine closeout. Plans for soil and grubbed plant salvage should be updated with any expansion or modification of new or existing units.

Operators should tabulate the volume of native soil material that is available for salvage prior to disturbance of the expansion of existing units or new units based on total depth of suitable soil horizons. While this amount may not satisfy total cover depth requirements at Reclamation, even small amounts of topsoil material combined with other Cover Materials can optimize the plant growth medium to assist in the re-establishment of a Self-Sustaining Ecosystem. Such designs can significantly reduce the need for amending less desirable Cover Materials with Organic Amendments.

Table 1 provides an example calculation for determining the estimated amount of soil to be salvaged (with estimated handling losses) across undisturbed mining units (existing and new).

"Mapping Unit" refers to each soil type within the proposed area of disturbance.
"Depth to be Removed" is the average amount (depth) of soil that can be salvaged based on soil survey and/or sampling data for that particular soil type.
"Proposed Area to be Disturbed" is the anticipated area of disturbance in acres.
"Volume (ac-ft)" is calculated by multiplying "Depth to be Removed" by "Proposed Area to be Disturbed" and dividing by 12in/ft.
"Volume (cu yd)" is calculated by multiplying "Volume (ac-ft)" by 43,560ft/ac and dividing by 27ft/cu yd.

Estimates should allow for at least 10% handling loss in planning. Please note that in Table 1 (below) under "Depth to be Removed" for Mapping Unit A uses 0in as an example of a soil type that may have limited or no topsoil for salvage. For instance, salvaging a soil that is just a few inches thick on average may not be practical or economically feasible. However, if topsoil will not be salvaged on a proposed new mining unit, operators should provide a reasonable explanation for why soil will not be salvaged.

**Table 1.** Topsoil salvaging calculation example

| Mapping Unit | Depth to be Removed (in) | Proposed Area to be Disturbed (ac) | Volume (ac-ft) | Volume (cu yd) | Average Post-loss Topsoil Depth for Reclamation (in) |
|---|---|---|---|---|---|
| A | 0 | 21 | 0 | 0 | |
| B | 5 | 42 | 17.5 | 28233 | |
| C | 15 | 29 | 36.3 | 58483 | |
| D | 9 | 8 | 6.0 | 9680 | |
| | TOTALS | 100 | 60 | 96397 | |
| | 10% Handling loss | 100 | 54 | 9640 | **6.5** |

Operators should also calculate the salvageable volume for each Cover Material stockpile (topsoil, Topdressing, approved overburden, etc.) to demonstrate that there is sufficient suitable Cover Material (plus 10% for handling loss) for Reclamation as described in the closeout plan. A map of all Cover Material stockpiles should also be provided. Operators should include updated Cover Material stockpile volume calculations with each closeout plan update (every five years).

### *5.3.2 Erosion Control*

The mechanics of soil erosion involve detachment and transportation of soil particles. The larger and heavier the particles (i.e., sand or gravel), the less likely they will detach and be transported compared to small, light particles, such as silts and clays. The impacts of erosion include reduced root growth, reduced plant available water holding capacity, loss of organic matter, surface water impacts, and susceptibility to more erosion because of a positive feedback process.

A soil's erodibility can be estimated using the Revised Universal Soil Loss Equation (RUSLE):

$$A = R \times K \times LS \times C \times P$$

Where:

A is the predicted annual loss of soil (measured in tons/acre/year),
R is the rainfall erosivity factor,
K is the soil erodibility factor,
LS is a measure of slope length and steepness,
C is soil cover management, and
P is the erosion control practices factor.

While R is a factor outside the control of the operator, all other variables in RUSLE can be manipulated to lower the annual loss of soil (A). For instance, incorporating organic matter can reduce the K factor by improving soil aggregate stability, water infiltration rates, and plant available water holding capacity of the soil. Texture and rock fragment content can also affect the K factor. Slope gradient, shape, and length are often the three largest contributing factors in controlling erosion on reclaimed surfaces and are relatively easy to control with proper planning. For example, contour furrows perpendicular to slopes with gradients of 15% or less can also be used to reduce erosion (A).

More information on RUSLE can be found at: https://www.ars.usda.gov/midwest-area/west-lafayette-in/national-soil-erosion-research/docs/rusle/.

Methods to control erosion include:

a. Maintain a vegetation cover to reduce raindrop impact and promote establishment of biological soil crusts;
b. Keep soil covered through the use of rock, straw, and/or mulch;
c. Install erosion controls at the top of slopes;
d. Decrease runoff velocity; and
e. Divert runoff from eroding or erodible areas.

### *5.3.3 Cover Placement*

After final topsoil or Topdressing placement, the surface may need to be ripped to mitigate compaction from heavy vehicle traffic. Ripping should occur along the contour and never perpendicular to the contour. If used, Organic Amendments may be applied prior to or during the ripping process, especially if there is concern that there will be subsurface shattering and surface settling after ripping. Once the reclaimed areas are ripped, heavy equipment and vehicle traffic should be avoided on reclaimed areas to prevent compaction of the placed growth medium. Fencing is recommended for reclaimed areas that are subject to compaction from livestock or vehicular traffic.

The surface may be scarified through tilling, discing, or raking (*e.g.,* tractor dragging chains, tires, etc.) in lieu of ripping in areas where minor compaction is observed after cover placement. The type of scarification depends on a variety of factors, including slope angle, length, level of current compaction, and soil erodibility factors. With less invasive scarification methods such as raking, seeding may be done prior to scarification. Roughening of the soil surface can reduce erosion, increase infiltration, and provide microclimates for seed germination and seedling protection.

Mulch should be broadcast applied at a rate of 1.5-2 tons/acre after seeding. Any mulch should be certified weed-free. Examples of mulch include certified weed-free straw, wood or chipped wood mulch, and hydro-mulch. Hydraulically applied mulch requires a lower rate of 0.75 tons/acre compared to more traditional mulches. New Mexico State University ("NMSU") provides a list of vendors who provide weed-free mulch options, which can be found at https://aces.nmsu.edu/ces/seedcert/certified-weed-free-fora.html.

# 6.0 COVER MATERIAL SUITABILITY

All proposed Cover Material should be sampled and analyzed to demonstrate that it can achieve a Self-sustaining Ecosystem and be a Healthy Soil. A single suitability index is not practical or accepted for setting quantitative standards for a good plant growth medium across all ecological sites. Appendix 1 contains physical and chemical soil parameters and recommended analytical methods used by other state environmental regulatory agencies to determine Cover Material suitability in mine Reclamation. While this table provides some guidance for determining Cover Material suitability, it does not necessarily capture the variability in composition of native Healthy Soils in New Mexico. To best determine what constitutes a suitable Cover Material for the re-establishment of a locally adapted plant community at Reclamation, operators should sample and analyze the surrounding native soils to provide baseline target data for determining the suitability of proposed Cover Material. Any proposed Cover Material that is not undisturbed native soil should be tested through a test-plot program to demonstrate how the seeded native plant community responds. As an alternative to test plots, opportunities to conduct early or concurrent reclamation of even small areas should be considered in order to gain site-specific reclamation experience.

## 6.1 Reference Soils

In many instances, mine operators propose using a Cover Material that consists of mixed overburden or run- of- mine rock that is not considered soil, as defined in this Guidance. To better understand the suitability of such a Cover Material for a given area, reference soils (undisturbed surrounding native soils) should be identified and outlined in the Closeout Plan and/or permit. Reference soils can provide a general idea of what soil conditions the native plant community is adapted to and can act as a guide when assessing non-soil Cover Material suitability. The location of reference soils should be selected based on Ecological Site and State and the soil series in and around the Permit Area, and the number of reference soils should be determined by the number of soil series within the Disturbed Area. These reference soils may be located within the vegetative reference areas. Reference soils should be sampled concurrently with any other soil sampling in the Permit Area (*e.g.,* Cover Material stockpiles) in accordance with Section 6.2 *Soil and Cover Material Sampling* and analyzed as a baseline for determining Cover Material suitability. The site-specific nature of the reference soils areas affects the soil test parameters and interpretation. The reference soils and plant communities may guide decisions for choosing appropriate soil tests. For instance, vegetation communities on arid sites may be more adapted to sodic conditions, while plant communities on higher elevation, forested sites may have a higher tolerance for relatively low pH and low nutrient levels.

These factors should also be considered when sourcing seed for a given location. Choosing non-local seed sources may result in vegetation failure due to the difference in locally adapted characteristics of a given plant community. Reference soils and proposed cover materials should be analyzed for parameters listed in Section 6.3 *Soil and Cover Material Analysis*. A more extensive suite of soil parameters may be necessary when assessing causes of vegetation failure on test plots and/or reclaimed areas.

## 6.2 Soil and Cover Material Sampling

Sampling plans should be submitted to MMD for approval prior to the commencement of any proposed Cover Material sampling. Operators should also include a justification for why their sampling protocol will be descriptive of the proposed Cover Material. Sampling depths should be appropriate for the sampling medium (native soils versus topsoil stockpiles or Cover Material stockpiles), and, when possible, each soil horizon should be sampled and analyzed separately.

Operators should select a reputable lab that can perform the analyses outlined in Section 6.3 *Soil and Cover Material Analysis*. The lab should list, with references, what preparation and methodologies are used for each soil analysis, including detection limits, where applicable. Operators should include any assumptions (*e.g.,* constant temperatures, particles largely consist of sand, silt, clay, etc.) when proposing methodologies and reporting results.

### *6.2.1 Stockpiled Proposed Cover Material*

Proposed Cover Material may consist of inert tailings impoundments, topdressing, topsoil, native soil, overburden (run-of-mine materials), or a combination of these examples. These materials may already be stockpiled as a result of mining or remain undisturbed in situ. In addition to the original source and geometry, the history of the proposed Cover Material stockpile can play a role in determining a sampling protocol. For instance, many proposed Cover Materials stockpiles have unknown histories, which could include multiple layers of different material from different locations and times throughout the mine history. Therefore, each proposed Cover Material sampling plan will differ based on the depth and maintenance history of that particular stockpile. Mining operators should consider all these factors when developing a soil sampling plan and include a thorough sampling protocol to capture as much variability throughout the pile as possible. This may include sampling pits or drilling cores to sample deeper material within the stockpile. A sampling plan should be submitted to MMD for approval prior to commencement of any proposed Cover Material sampling.

### *6.2.2 Native Soil Sampling (Borrow Material)*

For native, undisturbed soils, a minimum of one composite sample should be taken for each soil type. When sampling native, undisturbed soils, samples should be split into at least two depths: 0-6in (0-15cm) (rooting zone and generally representing the A or A and B horizons in New Mexico) and 6-24in (which could include the B and C (parent material) horizons in New Mexico). Many New Mexico soils are relatively shallow, so the deeper sample may not reach depths of 24in prior to hitting bedrock, or the R horizon. In areas with deep soil deposits sampling should extend to the full depth of suitable materials until bedrock or at least 60in, if feasible. At each subsample location, horizons should be segregated before combining into the full sample, wherever possible. An Order I Soil Survey should be done for all areas where characterization of native soils is necessary. When sampling reference soils within vegetative reference areas, operators should propose a reasonable sampling protocol to capture the variability of the reference soils within the vegetative reference areas. A sampling plan should be submitted to MMD for approval prior to commencement of any proposed Native Soil sampling.

## 6.3 Soil and Cover Material Analysis

Appendix 1 lists current intra/interstate guidelines for **chemical** (pH, EC, Se, Acid Base Potential, organic matter, SAR, ESP, $NO_3$, P, K, B, Fe, Mg, Mn, Cu, Cd, Pb, Hg, Mo, Ni, As, $\%CaCO_3$) and **physical** (texture, rock fragment, erosion factor, total porosity, bulk density) Cover Material suitability and soil analyses methods. This Guidance includes additional parameters to consider to those listed in Appendix 1, including plant available water holding capacity, organic matter, and soil microbial properties. The following sections describe different important physical and chemical soil parameters to analyze when determining Cover Material suitability.

Note that **not all** the parameters identified in this section or in Appendix 1 are recommended for every proposed Cover Material. For instance, Cover Materials, such as salvaged native soil, may not need to be analyzed for any of the parameters in this section or Appendix 1 if they have already demonstrated their capability of supporting a Self-Sustaining Ecosystem. This section is meant to act as a guide to assist operators in identifying deficiencies in Cover Material that has not yet shown to be capable of supporting a Self-Sustaining Ecosystem. Operators should keep an open dialogue with MMD in determining which of the following parameters should be analyzed for a given proposed Cover Material. In most cases for proposed Cover Material that is NOT salvaged soil, test plots are recommended to demonstrate that the proposed Cover Material meets the suitability criteria outlined in Appendix 1 and is capable of supporting a Self-Sustaining Ecosystem.

### *6.3.1 Plant Available Water Holding Capacity ("AWHC")*

Plant available water holding capacity ("AWHC") is the amount of plant-accessible water held by a soil. It is a determination of the maximum potential amount of water that plant roots can extract from any given soil. AWHC is defined by the volume of water held by a soil at pressures between field capacity ("FC") and permanent wilting point ("PWP"). FC is the amount of water that a saturated soil would retain after excess water has been drained away from it. Numerous methods are available to estimate, measure in the field or lab, or predict the field capacity of a soil. The PWP is the volumetric water content of a soil at the limit of a plant's ability to extract water from it. PWP is an insensitive number (relative to FC) in the determination of AWHC because of the highly non-linear relationship between the water content and the soil matric suction. For example, near FC, small changes in pressure often result in large changes in water content, while near PWP, very large changes in pressure often result in small changes in water content. PWP is highly plant specific, is more difficult to determine than FC and is therefore often estimated to be 15 bars or 1500 kPa. AWHC can be determined using, as an example method, techniques from the USDA/NRCS National Soils Handbook, Section 618.6. AWHC should be expressed in in/ft (conversion: 1% = 1 cm/m = 0.12 in/ft).

AWHC is directly related to pore-size distribution in a soil, where smaller pores cling to water more strongly (and require greater extraction pressures to release that water) than larger pores. Generally, AWHC is highest in loamy soils that have a more balanced pore-size distribution. Water in very finely textured soils with an abundance of clay and silt is often too tightly bound to soil particles to be accessed by plants. Conversely, more water will drain readily from soils with higher amounts of rock and sand.

AWHC is dramatically affected in soils with a high content of rocks (particles >2mm diameter) (Arias *et al.*, 2019). Since rock usually has insignificant internal porosity for moisture storage as the proportion of rock increases, the soil AWHC will decrease. Additionally with high enough rock content soils become less matrix supported. Fine earth pockets become increasingly isolated and matrix connectivity of fine earth is reduced. The ability of soil to conduct water within such a system decreases. Thus, unless plant roots can explore these voids and matrix bridges this soil volume becomes isolated from plant roots and cannot effectively participate in plant/soil water exchanges, reducing available water within those affected soil volumes. In a coarse textured soil especially, AWHC can be increased through the addition of Organic Amendments as these amendments can improve soil structure, infiltration, and pore-size distribution/connectivity throughout the soil profile (Brady and Weil, 2000).

Most laboratory methods for determining AWHC use only the fine earth fraction of a soil this value and require a rock fragment adjustment. Also, dissolved salts reduce soil's practical AWHC. Dissolved salts have an energetic attraction for water and require more work from a plant to extract water from soils wet with salty water. The NRCS National Soil Survey Handbook recommends reducing the AWHC 25% per 4 mmhos/cm EC of the saturated extract. See Section 6.3.2 *Rock Fragment and Texture* for information on rock fragment corrections in AWHC calculations.

Please refer to 20.6.7.33.F NMAC ("The Copper Rule") for water holding capacity requirements for cover systems on waste rock piles, leach stockpiles, tailing impoundments, and other units where the potential to generate leachate may cause an exceedance of applicable standards at monitoring well locations. These are specified by 20.6.7.28 NMAC. 20.6.7.33.F(2) that states: "*Soil cover systems shall be designed to limit net-percolation by having the capacity to store within the fine fraction at least 95 percent of the long-term average winter (December, January and February) precipitation or at least 35% of the long-term average summer (June, July and August) precipitation, whichever is greater. The water holding capacity of the cover system will be determined by multiplying the thickness of the cover times the incremental water holding capacity of the approved cover materials. Appropriate field or laboratory test results or published estimates of available water capacity shall be provided by the permittee to show that the proposed cover material meets this performance standard."* The Copper Rule is under the regulatory authority of the New Mexico Environment Department.

### 6.3.2 Rock Fragment and Texture

Rock fragments are defined by the USDA/NRCS as "unattached, cemented pieces of bedrock, bedrock-like material, durinodes, concretions, nodules, or pedogenic horizons (*e.g.*, petrocalcic fragments) 2 mm or larger in diameter and unprocessed woody material 20 mm or larger in diameter in organic soils." As New Mexico lacks Histosols (organic soils), operators will most likely only adjust for non-woody fragments in the soil profile.

While sometimes ignored, a soil's rock content is an important descriptor of soil texture. Texture influences other soil properties besides AWHC, including nutrient holding capacity and organic matter accumulation. In general, a coarse textured, well-drained soil will accumulate less organic carbon than a finer textured, poorly drained soil (Brady and Weil, 2000). Soils that have a higher percentage of clay and silt particles can accumulate more organic carbon because they generally have higher plant nutrient holding capacities, thus higher canopy cover, less aeration, and clay-humus complexes that inhibit the organic carbon from being readily decomposed. Ideal soil textures for Cover Materials include silt loams, sandy loams, loams, sandy clay loam, clay loam, and silty clay loam. In some instances, loamy sands may be an appropriate Cover Material texture, but loamy sands can often lack the water and nutrient holding capacity required for a Reclamation Cover Material without further amendment.

Intrinsic amounts of rock fragments to the surrounding area can help armor soil, particularly on reclaimed slopes where vegetation has not yet become established. This can reduce erosion caused by wind and water, reduce evaporation, increase depth and rate of water infiltration, regulate soil temperature, and provide a stabilizer for fine textured particles to serve as a seed bed. However, rock fragment should be moderated, as too rocky of soils can reduce AWHC and prevent vegetation establishment.

To account for site-specific differences in soil types and plant communities adapted to those soil types, it is always best to assume that the native, undisturbed soil texture and rock content of soils surrounding the Permit Area have a locally adapted plant community association that models the desired Self-Sustaining Ecosystem after Reclamation. Therefore, it is pertinent that operators take the texture and rock content of the reference soils into account when choosing target textures and percent rock fragment in the proposed Cover Material, Topdressing, and/or topsoil.

### *6.3.3 Bulk Density and Total Porosity*

Bulk density, the mass of a unit volume of dry soil, is generally used in mass/volume conversions, and provides an estimate of compaction. Soils with high proportions of solids to total porosity typically have higher bulk densities compared to those with fewer solids and a higher total porosity. Any factor that affects total porosity will thus influence bulk density. Bulk density values are typically lower at the soil surface and increase with depth. Higher levels of organic matter, soil aggregation, and biological activity occur near the soil surface and are associated with greater pore space compared to the subsurface. High bulk densities negatively impact plant growth by reducing root penetration, water infiltration, aeration, and nutrient transport.

Bulk densities of finely textured soils are typically lower than coarse textured soils. While this may seem counter-intuitive, sandy textured soils have a lower total porosity than finer textured soils, though this porosity is usually dominated by macropores. Looser packing and micropores dominate in fine textured soils, resulting in soils with a higher total porosity, and thus a lower bulk density. Additionally, finer textured soils often have more organic matter compared to sandy soils, which also increases the total porosity within the soil. While this is generally true of native soils in situ, soil management coupled with particle size distribution can significantly impact the bulk density-total pore space relationship.

### *6.3.4 Cation Exchange Capacity (“CEC”)*

Cation Exchange Capacity (“CEC”) is a measure of a soil’s ability to adsorb/absorb (sorption) and exchange cations within the soil solution. Soil colloids have positively or negatively charged ions on the colloid surface; the driving force behind a soil’s ability to adsorb nutrients and water. There are two main groups of soil colloids that have high CEC values: humus (organic matter) and clays (silicate and iron and aluminum oxide clays). The nutrient holding potential is often estimated by the CEC, a property that is pH dependent. Aridisols are often high in 2:1 clays and thus have relatively high CEC values. CEC averages 15.2 $\text{cmol}_c$/kg soil in Aridisols, a high value for soils with low organic matter. Calculated CEC values for the soil orders found in New Mexico can be found in Table 2. As CEC varies widely across and within soil types, it is important to compare the CEC values of the proposed Cover Material, test plot area, and/or reclaimed areas to the reference soils.

**Table 2.** Soil organic carbon and CEC in New Mexico soil orders

| **Soil Order** | Organic Carbon (g/100 g soil) in upper 15cm of soil profile[a] | | Cation Exchange Capacity[b] | |
|---|---|---|---|---|
| | **Range** | **Typical** | **CEC ($\text{cmol}_c$/kg)** | **pH** |
| Alfisols | 0.5 - 3.8 | 1.4 | 9.0 | 6.0 |
| Aridisols | 0.1 - 1.0 | 0.6 | 15.2 | 7.26 |
| Entisols | 0.06 - 6.0 | Too variable | 11.6 | 7.32 |
| Inceptisols | 0.06 - 6.0 | Too variable | 14.6 | 7.26 |
| Mollisols | 0.9 - 4.0 | 2.4 | 18.7 | 6.51 |
| Vertisols | 0.5 - 1.8 | 0.9 | 35.6 | 6.72 |

[a] Brady, 1990 and Eswaran, *et al.*, 1993

[b] Holmgren *et al.*, 1993

### 6.3.5 pH and Acid-Base Potential

Soil pH is a measurement often taken as a saturated paste extract and is an indicator of whether a soil is basic (pH > 7.0), neutral (pH = 7.0), or acidic (pH < 7.0). Soil pH drives nutrient and contaminant solubility and mobility through the soil profile. It also dictates plant nutrient availability (Figure 1) (Haby 1993).

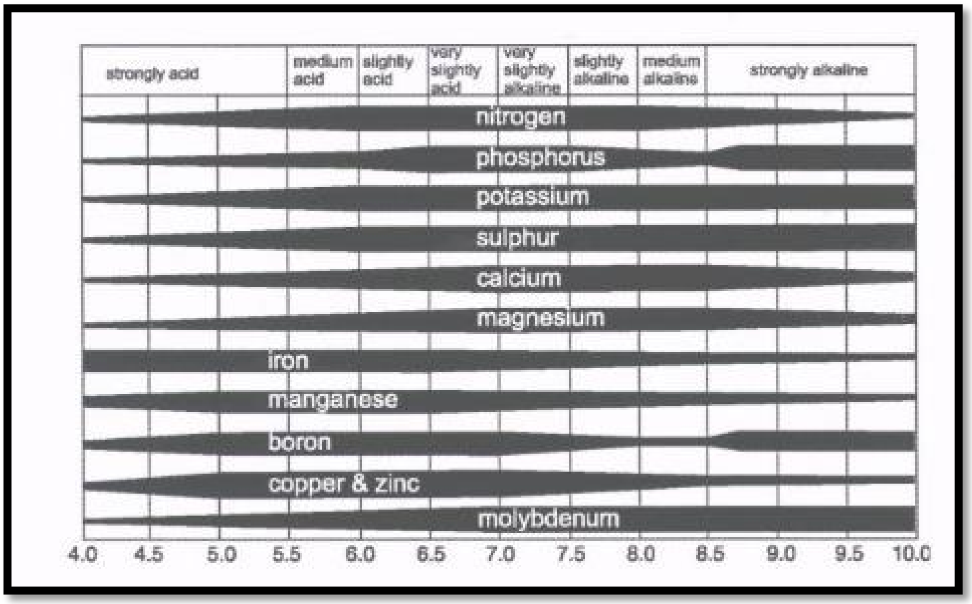

**Figure 1.** pH impacts on plant nutrient availability

The acid-base potential of a soil takes soil pH, total sulfur (sulfides and sulfates), and neutralization potential into account to determine the potential ability of a soil to generate acid. It provides a more thorough understanding of a soil's ability to produce and neutralize acid over time as the soil is exposed to air and water rather than a snap-shot measurement of pH at one point in time. Implications of low neutralization potentials include increasing soil salinity, inhibiting nutrient cycling (nitrification), limiting nutrient availability through a decrease in pH over time, increasing the mobility of metals and organic contaminants, and replacing macro- and micro-nutrients on soils exchange sites with metals (limiting nutrient availability and increasing metal toxicity in plants).

### *6.3.6 Electrical Conductivity ("EC") / Exchangeable Sodium Percentage ("ESP") / Sodium Adsorption Ratio ("SAR")*

Soil salinity is typically measured by EC to determine the total concentration of readily dissolved salts ($Na^+$, $Mg^{2+}$, $Ca^{2+}$, $K^+$, $Cl^-$, $SO4^{2-}$, $HCO^{3-}$, and $CO3^{2-}$) in the soil solution. Excess salts in the soil solution can inhibit plant growth by decreasing the osmotic potential (reducing the ability for plant uptake of water), physically changing clay dispersal within the soil (preventing water and root infiltration and reducing pore space), and producing more alkaline soils (reducing nutrient availability). Sodium levels in soil are often reported as Sodium Adsorption Ratio ("SAR"), which is the ratio of sodium cations to calcium and magnesium cations. While there is a general rule of thumb on what constitutes as a "sodic soil" (SAR ≥ 13), many factors can influence the effects of sodium presence in the soil, such as texture (J.G. Davis, 2012). Exchangeable Sodium Percentage ("ESP") can also be used when assessing a soil's sodium levels in relation to the CEC. ESP is a desirable parameter to consider when analyzing soils with low organic matter, clay content, and CEC.

### *6.3.7 Nutrient Levels*

There are 17 macro- and micro- essential nutrients for plants, consisting of primary macronutrients (carbon, hydrogen, oxygen, nitrogen, potassium, and phosphorus), secondary macronutrients (calcium, magnesium, and sulfur), and micronutrients (iron, boron, manganese, copper, zinc, nickel, molybdenum, and chlorine). Selenium and cobalt are also important for organisms in the soil (*e.g.,* rhizobium), but are not typically used directly by plants (Brady and Weil, 2000).

Information about plant nutrient requirements in soils are almost exclusively based on agricultural-based needs. However, nutrient requirements in native systems are often much lower than agronomic crop requirements and vary drastically across ecosystems and soil types (Charley, 1972; Chapin, 1980; Baig, 1992). They are nonetheless highly important to measure in natural systems. Therefore, it is important to analyze, at a minimum, the nutrient content (in conjunction with soil pH) of the reference soils to understand the nutrient levels available for the surrounding plant community and use those as target nutrient levels within the Cover Material. Providing too high of a concentration of macronutrients could result in weedy species outcompeting the native species, while not providing the ideal nutrient concentrations could result in low plant cover, production, and/or plant vigor.

### *6.3.8 Inorganics (Metals)*

All Cover Materials should be analyzed for arsenic, boron, cadmium, copper, manganese, mercury, molybdenum, nickel, lead, and selenium. Measuring the concentrations of metals and inorganic elements of concern is important when determining how Reclamation Cover Material could affect human health and safety, bioaccumulation, and plant, livestock and wildlife toxicity. Unlike nutrient level recommendations, these elements have well-established suitability concentrations to prevent or limit wildlife, plant, and human exposure to harmful elements. Appendix 1 provides a list of inorganic elements and their respective acceptable concentrations in the soil. Many plant species are adapted to accumulate harmful concentrations of some of these elements in above-ground biomass, so limiting concentrations of these elements throughout the entire Cover Material profile is crucial.

### *6.3.9 Soil Microbial Communities*

Ecosystem functioning after mine Reclamation has historically been measured by the composition of the plant community established post-Reclamation. However, the long-term success of that plant community is dependent on the functionality of the soil microbial community to enhance soil fertility and development. It is estimated that the diversity of organisms belowground exceeds that of the aboveground system with estimates between 2,000 and 8.3 million different species within a single gram of soil (Torsvik *et al.,* 1990; Gans *et al.*, 2005; Schloss and Handelsman, 2006). Soil organisms play a crucial role in soil quality and health, influencing soil stability (structure), nutrient and hydrological cycling, $N_2$ fixation, soil carbon storage, and fate of added organic matter (Turco *et. al.*, 1994; Torsvik and Øvreås, 2002; Bender *et al.*, 2016; Fierer, 2017; Hermans *et al.*, 2017; Hermans *et al.*, 2020; Prasad *et al.*, 2021). These organisms also affect the rate of weathering of rocks and minerals, which contribute to soil formation.

While soil organisms occur in a variety of sizes (from bacteria to gophers), this section will focus on organisms that include nematodes, bacteria, fungi, protozoa, and algae. Understanding the composition and functions of the microbial community is difficult and complex, but existing indicators of a Healthy Soil microbiome may be used to estimate whether a soil achieves a Self-Sustaining Ecosystem and is considered a "Healthy Soil". *"A self-sustaining ecosystem includes hydrologic and nutrient cycles functioning at levels of productivity sufficient to support biological diversity."*

Soil microbial populations have been shown to fluctuate for the first few years after mine Reclamation has been completed, but can eventually stabilize under favorable soil conditions, as outlined by this Guidance. Reclaimed mine surfaces that do not have favorable soil conditions have been found to have lower microbial numbers, less microbial diversity, and lower rates of cellulose decomposition compared to surrounding native soils (Segal and Mancinelli, 1987). For instance, soil pH has a significant influence on soil microbial communities (Rousk, 2010). Soils with less microbial diversity also tend to release more carbon dioxide into the atmosphere (Zhang and Zhang, 2016). Additionally, reclaimed mines often lack the established fungal community, both mycorrhizal and saprotrophic communities, and associations that play an important role in nutrient and water availability and uptake for plants, found in undisturbed systems (Cundell, 1977; Waaland and Allen, 1987; Mummey *et al.*, 2002; Dangi *et al.*, 2012). The addition of organic matter can significantly increase the number and diversity of soil microorganisms on reclaimed arid land (Rao and Venkate-swarlu, 1981; Ros *et al.*, 2003). In general, the soil health principle that minimizing disturbance improves the quality of the soil can be directly applied to the soil microbiome. Thus, disturbance should be minimized and/or eliminated wherever possible, including on adjacent native soils and topsoil stockpiles.

Soil microbial populations typically decrease with increasing soil depth, with most of the soil microbial population living near the surface of the soil. When measuring soil microbial populations, samples should be taken within the rooting zone (a depth of ~6"). However, in some dryland soils (Aridisols and some Entisols) it may be more appropriate to collect samples at a shallower depth in order to analyze the biocrust component of the rhizosphere. See Section 6.2 *Soil and Cover Material Sampling* for information on collecting composite samples. Samples should be taken to compare soil reference area soil microbial populations to test plot or reclaimed land microbial populations (See Section 6.1 *Reference Soils*). It may also be insightful to compare the microbial population near the surface of Cover Material stockpiles to the reference areas soils when test plots or reclaimed areas do not exist in the vicinity of the Permit Area.

A recommended method for measuring soil microbial communities is analyzing the **Phospholipid Fatty Acid ("PLFA")** content of the soil. PLFA analysis provides both a snapshot of the total microbial biomass and the community structure broken down by taxonomic groups, including saprotrophic fungi or free-living fungi, gram-positive and gram-negative bacteria, and protozoans within the sampled soil (Mann *et al.,* 2019). Interpreting the differences of these microbial functional groups between reclaimed areas (or test plots) and reference soils can offer a better understanding of how the reclaimed land or Cover Material is performing and if it meets the definition of a Self-Sustaining Ecosystem through the interpretation of PLFA biomarkers (Willers *et al.,* 2015). For instance, comparing the fungal biomass or the ratio of fungi to bacteria in the reclaimed soil to the reference soil can indicate increased carbon storage and higher stability and resiliency of the reclaimed soil (Malik *et al.,* 2016).

Unlike chemical characteristics of soil, such as soil fertility, soil microbial analysis has no baseline data to compare a healthy microbial population to an unhealthy population. Since microbe populations can change rapidly in response to soil environmental conditions (*e.g.,* moisture, temperature), it is necessary for concurrent sampling of reference soils with reclaimed lands, test plots, and/or Cover Material stockpiles. Many labs across the United States offer this service, but samples will need to be sent separately and with different handling protocols from samples for physical and chemical properties described in Section 6.3 *Soil and Cover Material Analyses.* If monitoring changes in microbial communities over time, it is key to be consistent when selecting a lab. Each lab can use a different set of biomarkers, so it is important to use the same lab over time. It is also important to be consistent with how soil samples are taken and how they are stored before shipping for analysis. If samples are improperly stored before analysis, the results could be wrong and may be representing the changes the community underwent while stored rather than the situ environment.

### *6.3.10 Organic Matter*

Understanding organic matter and organic carbon in soils is crucially important in identifying what constitutes a Self-Sustaining Ecosystem. Organic matter is defined by plant and animal matter in various stages of decomposition by soil organisms. It can significantly influence carbon and nitrogen cycling and the soil microbiomes, plant nutrient availability, nutrient holding capacity, nutrient cycling, chelation and immobilization of contaminants, and water holding capacity (Chen and Aviad, 1990; Fellet *et al.,* 2011; Garcia *et al.,* 2017). As such, it is one of the most important parameters in determining a soil's health as a medium for growing plant communities. Soil organic matter can become depleted quickly by erosion and anthropogenic disturbance through mining, agriculture, etc., with one of the clearest differences being a lack of organic matter on disturbed soils compared to adjacent undisturbed soils (Larney and Angers, 2012).

Aridisols, while generally low in organic matter compared to other soil orders, contain approximately 35 Mg/ha, on average, and combined, contribute 7% of all the stored soil carbon on the Earth (Brady, 1990; Eswaran, *et al.*, 1993). The amount of organic carbon stored in the top 15 cm of a typical Aridisol ranges from 0.1 – 1.0% (g/100g soil). As a rule of thumb, organic matter can be estimated from the organic carbon content by multiplying the organic carbon content by 1.7 – 2.0. That means that a typical Aridisol in New Mexico is expected to have somewhere between 0.17 and 2% organic matter in the top 15 cm. Land management significantly influences the amount of organic carbon in the soil. For instance, land that has been overgrazed by cattle will likely contain less organic matter than undisturbed land. Table 2 provides an organic carbon estimate across soil orders found in New Mexico. These values should be used as a generalized target for understanding the typical organic carbon content of native, undisturbed soils in New Mexico. However, reference soils should be analyzed for organic matter content to develop a target organic matter level in Reclamation Cover Materials.

The addition of organic matter on Disturbed Areas can improve soil health, plant growth, and nutrient cycle functioning (Garcia et al., 2017). Organic Amendments, such as biosolids, biochar, and composted paper mill sludge, have historically outperformed inorganic amendments, such as fertilizer, through the incorporation of organic matter to improve physical and chemical soil properties and a slow release of nutrients (Reid and Naeth, 2005a,b; Gardner *et al.,* 2010; Fellet *et al.*, 2011). However, the use of biosolids such as from municipal and industrial sewage treatment should only be used with adequate precautions. First, any use of biosolids should conform with all applicable laws and regulations. Second, the use of biosolids may not resolved from an environmental viewpoint given its potential to contain metals, pharmaceuticals, pathogens and PFAS among other potentially problematic contents. Many examples of Organic Amendment success in establishing a Self-Sustaining Ecosystem through improved and expedited nutrient cycling, plant production, and soil structure have been documented in the scientific literature (*e.g.*, Shipitalo and Bonta 2008; Salazar *et al.,* 2009). One study conducted by Page-Dumroese *et al.,* (2018) concluded that the application of Organic Amendments had significant impacts on pH, EC, CEC, and total C. Additionally, the biosolids treatment within the study significantly increased the AWHC. Addition of organic matter through Organic Amendments such as animal manure has also shown to increase earthworm abundance and microbial biomass following application (Werner and Dindal 1989; Whalen *et al.,* 1998; Leroy *et al.,* 2008; Ros *et al.,* 2003; Mabuhay *et al.,* 2006; Belyaeva and Haynes 2009). Increased microbial biomass (particularly fungi) and earthworm abundance in turn can increase soil aggregation, infiltration, and plant growth.

MMD discourages the application of inorganic fertilizers. They often produce an artificially high initial flush of nutrients that results in weedy species outcompeting native species. Native species are adapted to low-nutrient environments. Nutrient levels should be characterized through the nutrient analysis on the reference soils. If, after Organic Amendment application, nutrient levels are still insufficient, slow-release or chelated fertilizers may be applied at low rates. In some cases, this may be necessary to increase the phosphorus levels in the Cover Material, as phosphorus is often the limiting nutrient in soils.

Organic Amendments should be used and incorporated into topsoil or Topdressing material that is deficient in physical and/or chemical properties resulting in an unsuccessful establishment of a locally-adapted native plant community. Appendix 1 provides Topdressing and topsoil suitability ranges as set by surrounding states and can be used as a general guide on Topdressing and/or topsoil suitability. However, due to the site-specific nature of soil types and plant communities across New Mexico, testing and quantifying native undisturbed reference soils is recommended when identifying deficiencies within a proposed topsoil and/or Topdressing (see Section 6.1 *Reference Soils*). The following points should be used for determining Organic Amendment suitability:

a. **C/N Ratio**: the C/N ratio is the ratio of carbon to nitrogen in the amendment. This ratio is the driving force behind microbial decomposition of organic matter and dictates the amount of plant-available nitrogen in the soil solution. When the C/N ratio is narrow (<25:1), microorganisms are able to consume organic matter (*e.g.,* proteins) and excrete plant-available ions into the soil solution. This process is called mineralization. When the C/N ratio is wide (>25:1), microbes scavenge for nitrogen in the organic matter, tying up all the plant-available nitrogen. This is called immobilization. Balancing the C/N ratio in mine Reclamation can be challenging, as too narrow of a C/N ratio can quickly leach nitrate out of the soil profile and too wide of a C/N ratio can prevent plants from becoming established by starving them of essential nutrients. As a rule of thumb, the target C/N ratio of the soil at Reclamation to promote a healthy, sustainable soil microbiome and plant growth medium is 24:1. However, the type of organic matter (i.e., lignins, proteins, phenols, carbohydrates, cellulose, etc.) can elasticize that ratio, depending on how easily the particles decompose. For example, soils with lignin contents of greater than 20% will have less net mineralization in a soil with a narrow C/N ratio than if that lignin content was less than 20%. Mine operators should analyze the C:N ratio of any Organic Amendment to be applied and adjust that ratio to a target of 24:1 with a diversity of carbon inputs.

b. **Rate of Application**: Mine Reclamation often uses agronomic application rates based on a particular crop to determine the application rate on mine sites. However, this rate is based on the desired nitrogen levels in the soil for a particular crop and is generally not based on structural improvement targets. As mine operators are reclaiming a Disturbed Area to achieve a Self-Sustaining Ecosystem with a locally adapted plant community, nutrient inputs may not be the primary desired effect of Organic Amendments application. For instance, an Organic Amendment may be applied primarily to increase the soil structure, aggregation, infiltration rates, and AWHC and reduce crusting and compaction rather than provide immediately available nutrients. The application rate should be determined based on the overall improvement and revegetation goals for the proposed Cover Material rather than based solely on target nutrient levels. Application rates also vary based on the moisture content of the amendment, making consistency in application rates across references in the scientific literature a challenge. Application rates should be tested through a test plot program to determine the level of Organic Amendment needed to improve soil structure and vigor of the resulting plant community.

Organic Amendment application rates in mine Reclamation within the literature range from 17 tons/acre (dry) to 100 tons/acre (Pichtel *et al.,* 1994; Jenness, 2001; Salazar *et al.,* 2009). Larney and Angers*,* 2012 provides a review paper on Organic Amendment application on degraded agricultural land, oil and gas sites, and mine Reclamation sites that may provide assistance when determining application rates of Organic Amendments to test on test plots. Organic Amendment application rates that are too low may not show beneficial effects on soil properties, and rates that are too high may favor weedy, non-native species (Castillejo and Castello, 2010).

One recommendation from an EPA technical report (2007) suggests looking at undisturbed nearby reference soils to estimate the amount of organic matter to incorporate into the proposed Cover Material. However, if using this approach, the organic matter content should be doubled to consider the significant decrease in organic matter after initial application. Another recommendation from that same report suggests that the operator propose an application rate based on the successful application of Organic Amendments at another comparable site.

# 7.0 REFERENCES

Arias, Nerea, Virto, I., Enrique, Alberto, Bescansa, Paloma, Walton, Riley and Wendroth, Ole. (2019). Effect of stoniness on the hydraulic properties of a soil from an evaporation experiment using the wind and inverse estimation methods. Water. 11.440.10.3390/w11030440.

Baig MN. (1992). Natural Revegetation of Coal Mine Spoils in the Rocky Mountains of Alberta and Its Significance for Species Selection in Land Restoration. *Mountain Research and Development.* 12(3):285-300.

Belyaeva, O. N. and Haynes, R. J. (2009). Chemical, microbial and physical properties of manufactured soils produced by co-composting municipal green waste with coal fly ash. Bioresour. Technol. 100:5203-5209.

Bender SF, Wagg C, and van der Heijden, MGA. (2016). An Underground Revolution: Biodiversity and Soil Ecological Engineering for Agricultural Sustainability. *Trends in ecology and Evolution*. 31(6): 440-452.

Brady, N.C. (1990). The Nature and Properties of Soils, 10th Ed. (New York: MacMillan).

Brady, N. C., and Weil, R. R. (2000). Elements of the nature and properties of soils.

Castillejo, J. M. and Castello, R. (2010). Influence of the application rate of an organic amendment (Municipal Solid Waste [MSW] compost) on gypsum quarry rehabilitation in semiarid environments. Arid Land Res. Manage. 24:344-364.

Chapin, FS III. (1980). The Mineral Nutrition of Wild Plants. *Annual Review of Ecology and Systematics*. 11:233-60.

Charley, J. L. (1972). The role of shrubs in nutrient cycling. In: McKell, C. M.; Blaisdell, J. P.; Goodin, J. R., tech. eds. Wildland shrubs—their biology and utilization; an international symposium; 1971 July; Logan, UT. Gen. Tech. Rep. INT-1. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 182–203.

Chen, Y. and T. Aviad. (1990). “Effects of humic substances in plant growth,” in P. MacCarthy, C.E. Clapp, R.L. Malcolm, and P.R. Bloom. *Humic substances in soil and crop Sciences: Selected Readings*. (Madison, Wisconsin: ASA Special Publications), 161-186.

Cundell, A.M. 1977. The role of microorganisms in the revegetation of strip-mined land in the western United States. J. Range Manage. 30:229-305.

Dangi, S. R., Peter D. Stahl, P. D. Stahl, Abbey F. Wick, A. F. Wick, Lachlan J. Ingram, L. J. Ingram, & Jeffrey S. Buyer, J. S. Buyer. (2012). Soil Microbial Community Recovery in Reclaimed Soils on a Surface Coal Mine Site. *Soil Science Society of America Journal, 76*, 915-924.

Davis, J.G. May 2012. Colorado State University Extension soils specialist and professor, soil and crop sciences; R.M. Waskom, Colorado Water Institute director; and T.A. Bauder, water quality specialist.

Eswaran, H., E. Van Den Berg, and P. Reich. (1993). "Organic Carbon in soils of the world", Soil Sci. Soc. Amer. J. 57:192-194.

Fellet G, Marchiol L, Delle Vedove G, and Peressotti A. (2011). Application of biochar on mine tailings: Effects and perspectives for land reclamation. *Chemosphere*. 83(9):1262-1267.

Fierer, N. (2017). Embracing the unknown: disentangling the complexities of the soil microbiome. *Nat Rev Microbiol* 15: 579–590.

Gans J, Woilinsky M, Dunbar J . (2005). Computational improvements reveal great bacterial diversity and high metal toxicity in soil. *Science* 309: 1387–1390.

Garcia, C., Hernandez, T., Coll, M.D., and Ondoño, S. (2017). Organic amendments for soil restoration in Arid and semiarid areas: a review. AIMS Environmental Science, 4(5): 640-676.

Gardner, W. C., Broersma, K., Naeth, A., Chanasyk, D. and Jobson, A. (2010). Influence of biosolids and fertilizer Amendments on physical, chemical and microbiological properties of copper mine tailings. Can. J. Soil Sci. 90: 571-583.

Haby, V.A. (1993). Soil pH and plant nutrient availability, Ferti Gram X (2).

Hermans, S.M., Buckley, H.L., Case, B.S., Curran-Cournane, F., Taylor, M., Lear, G., (2017). Bacteria as emerging indicators of soil condition. Applied and Environmental Microbiology 83, e02826-16.

Hermans, S.M., Buckley, H.L., Case, B.S., Curran-Cournane, F., Taylor, M., Lear, G., (2020). Using soil bacterial communities to predict physico-chemical variables and soil quality. Microbiome 8, 79.

Holmgren, G.G.S., M.W. Meyer, R.L. Chaney, and R.B. Daniels. (1993). "Cadmium, lead, zinc, copper, and nickel in agricultural soils in the United States of America," J. Environ. Qual., 22:335-348.

Jenness, N. (2001). Prepared for the U.S. Environmental Protection Agency. Mine Reclamation Using Biosolids. Accessed 9 June 2021 from https://semspub.epa.gov/work/HQ/134488.pdf.

Larney, Francis J. and Angers, Denis A. (2012). The role of organic amendments in soil reclamation: A review. *Canadian J. of Soil Science*. 92(1): 19-38.

Lauber CL, Hamady M, Knight R, and Fierer, N. (2009). Pyrosequencing-Based Assessment of Soil pH as a Predictor of Soil Bacterial Community Structure at the Continental Scale. *Applied and Environmental Microbiology*. 75(15): 5111-5120.

Leroy, B. L. M., Schmidt, O., Van den Bossche, A., Reheul, D. and Moens, M. (2008). Earthworm population dynamics as influenced by the quality of exogenous organic matter. Pedobiologia 52: 139_150.

Mabuhay, J. A., Nakagoshi, N. and Isagi, Y. (2006). Microbial responses to organic and inorganic amendments in eroded soil. Land Degrad. Devel. 17: 321_332.

Malik, A.A., S. Chowdhury, V. Schlager, A. Oliver, J. Puissant, P.G.M. Vazquez, G. Gleixner. (2016). Soil fungal:bacterial ratios are linked to altered carbon cycle. *Front. Microbiol*., 1247, 1-11.

Mann, C., Lynch, D., Fillmore, S., and Mills, A. (2019). Relationships between field management, soil health, and microbial community composition. *Applied Soil Ecology*, *144*, 12-21.

Mummey, D. L., Stahl, P. D., and Buyer, J. S. (2002). Microbial biomarkers as an indicator of ecosystem recovery following surface mine reclamation. *Applied Soil Ecology*, *21*(3), 251-259.

Page-Dumroese, D.S., Ott, M.R., Strawn, D.G., and Tirocke, J.M. (2018). Using Organic Amendments to Restore Soil Physical and Chemical Properties of a Mine Site in Northeastern Oregon, USA. Applied Engineering in Agriculture: 34(1): 43-55.

Pichtel, J.R., Dick, W.A., and Sutton, P. (1994). Comparison of Amendments and Management Practices for Long Term Reclamation of Abandoned Mine Lands. J. Environ.Qual. 23:766-772.

Prasad S. et al. (2021). Soil Microbiomes for Healthy Nutrient Recycling. In: Yadav A.N., Singh J., Singh C., Yadav N. (eds) Current Trends in Microbial Biotechnology for Sustainable Agriculture. Environmental and Microbial Biotechnology. Springer, Singapore.

Rao, C.R., and B. Venkateswarlu. (1981). Distribution of microorganisms in stabilized and unstabilized sand dunes of the Indian desert. J. Arid Environ. 4:203-207.

Reid, N. B. and Naeth, M. A. (2005a). Establishment of a vegetation cover on tundra kimberlite mine tailings: 1. A greenhouse study. Restor. Ecol. 13: 594-601.

Reid, N. B. and Naeth, M. A. (2005b). Establishment of a vegetation cover on tundra kimberlite mine tailings: 2. A Field study. Restor. Ecol. 13: 602-608.

Ros, M., Hernandez, M. T. and Garcia, C. (2003). Soil microbial activity after restoration of a semiarid soil by organic amendments. Soil Biol. Biochem. 35: 463-469.

Rousk J, Baath E, Brookes P, Lauber CL, Lozupone C, Caporaso JG, Knight R, and Fierer N. (2010). Soil bacterial and fungal communities across a pH gradient in an arable soil. *The ISME Journal*. 4(10): 1340-1351.

Salazar, M., Bosch-Serra, A., Estudillos, G. and Poch, R. M. (2009). Rehabilitation of semi-arid coal mine spoil bank soils with mine residues and farm organic by-products. Arid Land Res. Manage. 23: 327-341.

Schloss PD, Handelsman J . (2006). Toward a census of bacteria in soil. *PLOS Computational Biology* 2: 786–793.

Segal, W., and R.L. Mancinelli. (1987). Extent of regeneration of the microbial community in reclaimed spent oil shale land. J. Environ. Qual. 16:44-47.

Shipitalo, M. J. and Bonta, J. V. (2008). Impact of using papermill sludge for surface-mine reclamation on runoff Water quality and plant growth. J. Environ. Qual. 37: 2351-2359.

Torsvik, V., J. Goksoy, and F.L. Daae. (1990). High diversity in DNA of soil bacteria. Appl. Environ. Microbiol. 56:782-787.

Torsvik, V. and Øvreås, L. (2002). Microbial diversity and function in soil: from genes to ecosystems. *Current opinion in microbiology*, *5*(3), 240–245.

Turco, R. F., Kennedy, A. C., and Jawson, M. D. (1994). Microbial indicators of soil quality. *Defining soil quality for a sustainable environment*, *35*, 73-90.

U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). National soil survey handbook, title 430-VI. (accessed 4 August 2019). http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054242

U.S. Department of Agriculture (USDA) Soil Science Division Staff. (2017). Soil survey manual. C. Ditzler, K. Scheffe, and H.C. Monger (eds.). USDA Handbook 18. Government Printing Office, Washington, D.C.

U.S. Environmental Protection Agency (EPA), prepared by the EPA Office of Superfund Remediation and Technology Innovation (OSRTI). (2007). The Use of Soil Amendments for Remediation, Revitalization and Reuse. Report No. EPA 542-R-07-013.

Waaland, M.E., and E.B. Allen. (1987). Relationship between VA mycorrhizal fungi and plant cover following surface mining in Wyoming. 1. Range. Manage. 40:272-276.

Wang H, Xiao B, Wang M, Shao M (2013). Modeling the Soil Water Retention Curves of Soil-Gravel Mixtures with Regression Method on the Loess Plateau of China. PLoS ONE 8(3): e59475. doi:10.1371/journal.pone.0059475.

Werner, M. R. and Dindal, D. L. (1989). Earthworm community dynamics in conventional and low-input agroecosystems. Revue d'Ecologie et de Biologie du Sol 26: 427_437.

Whalen, J. K., Parmelee, R. W. and Edwards, C. A. (1998). Population dynamics of earthworm communities in corn agroecosystems receiving organic or inorganic fertilizer amendments. Biol. Fertil. Soils 27: 400_407.

Willers, C., P.J.J. van Rensburg, S. Claassens. (2015). Phospholipid fatty acid profiling of microbial communities – a review of interpretations and recent applications. *J. Appl. Microbiol*., 119, 1207-1218.

Zhang, F. and Zhang, Q. (2016). Microbial diversity limits soil heterotrophic respiration and mitigates the respiration response to moisture increase, Soil Biology and Biochemistry, 98: 180-185.

*Quantifiable Soil Parameters*

C.A. Black, ed. 1965. Methods of Soil Analysis. Part 1. American Society of Agronomy. Madison, Wisconsin.

L.A. Richards, ed. 1954. Diagnosis and Improvement of Saline and Alkali Soils. Agricultural Handbook No. 60. USDA Washington D.C.

Schoeneberger, P.J., D.A. Wysocki, E.C. Benham, and Soil Survey Staff. (2012). Field book for describing and sampling soils, Version 3.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

A.A. Sobek, *et al.,* 1978. Field and Laboratory Methods Applicable to Mine Soils. U.S. Environmental Protection Agency. Cincinnati, Ohio (EPA-600/278-054).

Tiedemann AR, Lopez CF (1983). Soil nutrient assessments of mine spoils. In: Alden, E. F.; Oaks, W.R., eds. Symposium proceedings—reclamation of mined lands in the Southwest; 1982 October 20-22; Albuquerque, NM. Albuquerque, NM: Soil Conservation Society of America: 66–79.

Tiedemann AR. (1987). Nutrient accumulations in pinon-juniper ecosystems-managing for future site productivity. In: Everett, R. L., comp. Proceedings, pinon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 352–359

USDA-NRCS. 1996. Soil Survey Laboratory Methods Manual. (SSIR No 42) ver. 3.0.

# Appendix 1

| | | | | Suitability | | |
|---|---|---|---|---|---|---|
| **Parameter** | **Source** | **Units** | **Method** | **Good** | **Marginal** | **Unsuitable** |
| Acid Potential | Montana | % sulfur | A.A. Sobek 1978 Field and Lab methods US EPA EPA-600/278-054 | | | |
| | NM Coal | | | | | |
| | Wyoming DEQ | meg H/100g OR % sulfur | Sulfur furnace (Smith et al 1974) OR ASA Monograph #9, Part 2 method 28-2.2.3, pg 512-514 | | | |
| Arsenic | NM MARP | ppm | Tiedmann and Lopez 1983 | | | >2.0 |
| | Wyoming DEQ | | ASA Monograph #9, Part 2 method 3-5.2.3, pg 55 OR method 24-5.4, pg 421 | <2 | >2 | |
| Available Water Holding Capacity | Utah DNR | % OR cm/m | USDA-NRCS, 1996, Method 4C | >10 | 5 - 10 | <5 |
| Boron (water soluble) | Montana | ppm | ASA Monograph #9 | | | >5 |
| | NM Coal | | ASA Monograph #9, Part 2 method 75-4, pg 1062-1063 | <5 | 5 | >5 |
| | NM MARP | | Tiedmann and Lopez 1983 | 0.1 - 5.0 | <0.1 | <0.1, >5.0 |
| | Oklahoma | | USDA Handbook 525 | | | >5 |
| | Wyoming DEQ | | ASA Monograph #9, Part 2 method 25-9.1, pg 443 | <5 | | >5 |
| CaCO3 % | NM Coal | % | USDA Handbook 60, Method 23c, pg 105 | <15 | 15 - 30 | >30 |
| | Utah DNR | | Ibid. pg 99 (Soil Carbonates, Gravimetric Determination after extraction woth 3M HCl) Total Inorganic Carbon = %CaCO3 x 0.12 | | | |
| Cd | NM MARP | ppm | Tiedmann and Lopez 1983 | | | >0.1 |
| Cu | NM MARP | ppm | Tiedmann and Lopez 1983 | <0.2 | 0.2 - 10 | >10 |
| EC | Montana | mmhos/cm | USDA Handbook 525, 1978. Method 1, p.22-24 or ASA Monograph #9, 1982 | | | >4 |
| | NM Coal | | USDA Handbook 60, Method 3a, pg 83 | <4 | 4 - 12 | >12 |
| | Oklahoma | | USDA Handbook 60, Method 3a, pg 83 | <6 | 6 - 12 | >12 |
| | Utah DNR | | Ibid. Chapter 14, pg 420 - 422 and pg 427 - 431 | 0 - 4 | 4 - 15 | >15 |
| | Wyoming DEQ | | USDA Handbook 60, Method 3a, pg 83 | 0 - 8 | 8 - 12 | >12 |
| Erosion Factor (K) | NM Coal | | | <0.37 | >0.37 | |
| | Oklahoma | | | | | >0.37 |
| | Utah DNR | | USDA Soil Conservation Service. 1978. National Soils Handbook Notice 24. (3/31/78). NSH Part II B403.6(a). | | >0.37 | |
| ESP | Oklahoma | % | Soil Survey Investigations Report 1, p. 21 Method 5D1 | <4 | 4 - 15 | >15 |
| Fe | NM MARP | ppm | Tiedmann and Lopez 1983 | 2.0 - 4.0 | <2, >4 | |
| Hg | NM MARP | ppm | Tiedmann and Lopez 1983 | | | >0.4 |
| Mg | NM MARP | ppm | Tiedmann and Lopez 1983 | 25 - 50 | <25, >50 | |
| Mn | NM MARP | ppm | Tiedmann and Lopez 1983 | 0 - 0.75 | >0.75 | >10 |
| Mo | Montana | | ASA Monograph #9, Part 2, method 3-5.2.3, pg 55 or ASA Monograph #9, Part 2 (1st ed) method 74-2.3, pg 1056-1057 | | | >1 |

# Appendix 1

| | | | | Suitability | | |
|---|---|---|---|---|---|---|
| **Parameter** | **Source** | **Units** | **Method** | **Good** | **Marginal** | **Unsuitable** |
| Mo (cont.) | NM MARP | ppm | Tiedmann and Lopez 1983 | <0.1 | 0.1 - 0.2 | >0.3 |
| | Oklahoma | | ASA Monograph #9, Part 2, method 3-5.2.3, pg 55 or ASA Monograph #9, Part 2 (1st ed) method 74-2.3, pg 1056-1057 | | | 1 |
| | Wyoming DEQ | | | <1 | >1 | |
| Neutralization potential | Montana | T CaCO3 Equiv./1000T | A.A. Sobek 1978 Field and Lab methods US EPA EPA-600/278-054 | | | <-5 |
| | NM Coal | | | +5 | 0 | -5 |
| | Oklahoma | | | | | <-5 |
| | Wyoming DEQ | | USDA Handbook 60, method 23c, pg 105 | >-5 | | <-5 |
| Ni | NM MARP | ppm | Tiedmann and Lopez 1983 | | | >1 |
| NO3-N | Montana | ppm | ASA Monograph #9, 1965 | | | >130 |
| | NM MARP | | Tiedmann and Lopez 1983 | >18 | 9 - 18 | <9 |
| | Utah DNR | | Soil Science Society of America. 1996. Series No. 5. Methods of Soil Analysis Part 3 - Chemical Methods. Chapter 38, pg 1129 (KCl extraction) | | | |
| | Wyoming DEQ | | ASA Monograph #9, Part 2 method 33-3.2, pg 649 | | | >50 |
| OM | Montana | % | Western States Laboratory Proficiency Testing Program Soil and Plant Analytical Methods. 1998. v 4.10. pg 86. (Loss on Ignition, convert %LOI to OM by regression intercept value as noted in method) | | | |
| | Utah DNR | % | | | | |
| | Wyoming DEQ | % | ASA Monograph #9, Part 2 method 29-3.5.2, pg 570 | | | |
| Pb | NM MARP | ppm | Tiedmann and Lopez 1983 | | | >10 |
| pH | Montana | | USDA Handbook 60, Method 21a, p.102 or ASA Monograph #9, 1982 Methods of Soil Analysis Part 2, Method 10-3.2, pg 171 and Method 10-2.3.1, pg 169 | | | <5.5, >8.5 |
| | NM Coal | | | 6.0 - 8.4 | 5.5 - 6.0, 8.4 - 8.8 | |
| | Oklahoma | | Soil Survey Investigations Report 1, p. 59 Method 8 | 5.5 - 7.5 | 4.8 - 5.5, 7.5 - 8.4 | <4.8, >8.5 |
| | Utah DNR | | Soil Science Society of America. 1996. Series No. 5. Methods of Soil Analysis Part 3 - Chemical Methods. Chapter 14, pg 420 and Chapter 16, pg 487 | 6.5 - 8.2 | 5.5 - 6.4, 8.2 - 9.0 | <5.5, >9.0 |
| | Wyoming DEQ | | USDA Handbook 60, Method 21a, p.102 | 5.5 - 8.5 | 5.0 - 5.5 | <5.0 |
| Phosphorus | Utah DNR | ppm | Soil Science Society of America. 1996. Series No. 5. Methods of Soil Analysis Part 3 - Chemical Methods. Chapter 32, pg 895 (NaHCO3 extraction) | | | |

# Appendix 1

| | | | | Suitability | | |
|---|---|---|---|---|---|---|
| **Parameter** | **Source** | **Units** | **Method** | **Good** | **Marginal** | **Unsuitable** |
| Phosphorus (Bray) | NM MARP | | Tiedmann and Lopez 1983 | >30 | 16 - 30 | <15 |
| Phosphorus (sodium bicarbonate) | NM MARP | | | >11 | 6 - 11 | <6 |
| Rock fragment (>2mm) | Montana | vol/vol | USDA Soil Survey Investigations Methods 3B1b and 3B2 | | | >35 |
| Rock fragment (>10") | Oklahoma | % | Soil Survey Manual | <3 | 3 - 10 | >10 |
| Rock fragment (3-10") | Oklahoma | % | Soil Survey Manual | <15 | 15 - 35 | >35 |
| Rock fragments (>75mm) | NM Coal | % | | | | |
| SAR | Montana | | USDA Handbook 60, p.26 | | | >15 |
| | Oklahoma | | | 4 | 4 - 12 | >12 |
| | Wyoming DEQ | | | | | |
| SAR - >40% clay | NM Coal | | | <8.0 | 8.0 - 14.0 | >14 |
| SAR - clay loam and loam | NM Coal | | | <10.0 | 10.0 - 16.0 | >16 |
| SAR - clay soils | Utah DNR | | | 0 - 4 | 5 - 14 | >14 |
| SAR - sandy loam | NM Coal | | | <12.0 | 12.0 - 18.0 | >18 |
| SAR - sandy soils | Utah DNR | | | 0 - 4 | 5 - 20 | >20 |
| Saturation % | Montana | % | | | | <25, >90 |
| | NM Coal | | USDA Handbook 60, Method 27a, pg 106 | 25 - 80 | 25 - 80 | <25, >80 |
| | Oklahoma | | USDA Handbook 60, Method 27a or 27b, pg 107 | | | <25, >80 |
| | Utah DNR | | USDA-NRCS. 1996. Soil Survey Lab Methods Manual. (SSIR No 42) ver 3.0, Method 8A, pg 402 | 25 - 55 | 56 - 80 | <25, >80 |
| | Wyoming DEQ | | USDA Handbook 60, Method 27a or 27b, pg 106 | 25 - 80 | <25, >80 | |
| Se | Oklahoma | ppm | Bajo, 1978 | | | >0.5 |
| | Wyoming DEQ | | ASA Monograph #9, Part 2 (1st Ed), method 80-3.2 pg 1122 or ASA Monograph #9, Part 2, method 3-5.2.3, pg 55 | <0.1 | >0.1 | |
| Se (total) | NM Coal | | | <0.2 | 0.2 - 0.5 | >0.5 |
| Se (water soluble) | Montana | | | | | >0.1 |
| Se (water soluble) | NM Coal | | | <0.1 | 0.1 | |
| Soluble Na, K, Mg, Ca | Montana | meq/L | | | | |
| | NM Coal | | USDA Handbook 60, Method 3a, pg 84. Analysis by AA or ICP | | | |
| | Utah DNR | | Ibid. Chapter 14 pg 420-422(saturation extract); Chapter 19 pg 555-557; Chapter 20 pg 586-590 (spectroscopic methods) | | | |
| | Wyoming DEQ | | USDA Handbook 60, Method 3a, pg 84. Analysis by AA or ICP | | | |
| Texture | Montana | | Soil Science Society of America. 1986. Series No. 5. Methods of Soil Analysis Part 1 - Physical and Mineralogical Methods. Chapter 15, pg 398, 404-409 (Hydrometer method) | | | clay, silty clay, silt, sand, sandy clay |
| | NM Coal | | | loamy sand, sandy loam, loam, silt loam, <35% clay | sand, loamy coarse sand, clay loam, silty clay loam, <45% clay | <6% clay, >45% clay |

# Appendix 1

| | | | | Suitability | | |
|---|---|---|---|---|---|---|
| **Parameter** | **Source** | **Units** | **Method** | **Good** | **Marginal** | **Unsuitable** |
| Texture (cont.) | Oklahoma | | ASA Monograph #9 | fine sandy loam, loam, sandy loam, silt loam, sandy clay loam, clay loam | silty clay loam, loamy sand, loamy fine sand, silty clay, sandy clay | clay, sand |
| | Utah DNR | | Soil Science Society of America. 1986. Series No. 5. Methods of Soil Analysis Part 1 - Physical and Mineralogical Methods. Chapter 15, pg 398, 404-409 (Hydrometer method) | sandy loam, loam, silt loam, sandy clay loam, very fine sandy loam, fine sandy loam | clay loam, clay, silty clay loam, sandy clay, loamy sand, loamy fine sand, silty clay, sand, coarse sand, fine sand, very fine sand | gravel, very coarse sand |