USE OF SOIL PARAMETERS IN THE EVALUATION OF RECLAMATION SUCCESS IN NORTH DAKOTA[1]

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INTRODUCTION

Reclamation laws and regulations in North Dakota require that agricultural lands stripmined for coal be restored to a productive level equal to or better than existed before mining. If we are to meet this public mandate in the most effective manner, our reclamation techniques must be adequate to restore premine productivity, and reliable techniques for evaluating productivity of reclaimed soils must be developed. Methods for this evaluation must be accurate, rapid, reproducible, easily interpreted and cost-effective. The procedure we are proposing meets these criteria, and we believe it will meet the needs of both the industry and the regulatory agencies in North Dakota.

Our research has shown that comparing yields on reclaimed lands with those from undisturbed "reference areas" is an unreliable and expensive means of evaluating reclamation success. We do not wish to imply that vegetative growth is not important on reclaimed soils; the purpose of reclamation is to restore the capability to support plant growth. An evaluation of vegetative growth and vigor must be a part of the measure of reclamation success. But we are saying that sole dependence upon vegetative establishment and production without measuring the degree of reestablishment of the root zone factors that govern root growth is neither a reliable nor a cost-effective approach.

We contend that the success of reclamation is dependent upon the development of favorable conditions in the root zone for optimum plant growth, that the soil parameters that contribute to productivity can be quantitatively measured, and that these measurements can be used to develop criteria for calculating both the potential and the actual productivity of reclaimed soils.

[1]Paper presented at National Meeting of the American Society for Surface Mining and Reclamation, Denver, Colorado, October 8-10, 1985.

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SOIL PRODUCTIVITY IN WESTERN NORTH DAKOTA

In western North Dakota, crop production is most frequently limited by the lack of sufficient available moisture and by soluble salt and/or sodium levels in the soil. Doll, Merrill and Halvorson (1984) summarized a number of North Dakota research studies and concluded that the most productive soils should have an effective rooting depth of approximately 120 cm, the texture should be medium or finer, the topsoil should contain 2% or more organic matter and be nonsaline and low in sodium, the subsoil should be no more than slightly saline or moderately sodic, free lime should be less than 10% throughout the profile, and the soil should be located in a well-drained concave landscape position which may receive runon water from the surrounding higher soils. When the root zone materials have favorable chemical and physical properties, the most important factor which influences potential productivity is topographic position. Even though North Dakota is in an area of limited moisture and evapotranspiration exceeds precipitation during the growing season, considerable runoff occurs during snowmelt and during short intense storms during the growing season. Consequently average yields from soils in lower topographic positions which received runon water may be two or three times higher than those from the higher surrounding soils where runoff occurs.

The relative production capacity of different soils can be compared by means of productivity indexes (PI) in which a PI of 100 is assigned to the most productive soils and lesser values to lower producing soils. In western North Dakota, PI values for undisturbed soils have been well established by the USDA Soil Conservation Service and the North Dakota Agricultural Experiment Station, using average yields from the different soils over a long period of time. The PI values are based on field classification of soil series using morphological characteristics. The differences in soils that develop from similar parent materials are to a large extent a reflection of their topographic location.

Reclaimed soils, however, cannot be differentiated on the basis of morphological characteristics because of the mixing that occurs during removal and respreading of soil materials. Furthermore, certain characteristics that are inherent in undisturbed soils and do not need to be measured to establish their PI value, such as pore space

https://doi.org/10.21000/JASMR85010091

(bulk density) and pore continuity, are disrupted by the mining operations. For these reasons, we need to develop criteria for evaluating measurable soil parameters to calculate the PI of reclaimed soils. We need to emphasize that the PI is only the relative productive capacity of a soil as compared to other soils; actual yields are a function not only of PI, but of the effect of all external climatic, management and biotic factors that affect the growth of the plant. And herein lies the advantage of using the PI as a measure of reclamation success; the need for measuring and evaluating the relative effects of all these external factors on yields at the different sites to be compared is eliminated. Our research shows conclusively that the effects of these external factors are the major source of error when comparing yields from reclaimed soils and reference sites.

The characteristics and measurable parameters of undisturbed soils with different PI values can be used as a guide to establish criteria for developing PI values for reclaimed soils. However, data from undisturbed soils must be interpreted with care; in undisturbed soils we do not always know which parameters or what portion of these parameters contribute directly to its productive potential and which are the result of soil development processes and do not directly affect productivity. This is particularly true with respect to bulk density, pore-size distribution, soluble salt and sodium levels in the lower root zone, and the depth of the profile and the depth of each horizon within the profile.

The potential productive capacity of a reclaimed soil is determined by its topographic location and upon the amount and properties of the soil and spoil materials available. But this potential capacity cannot be reached until the reestablishment in the root zone of the conditions favorable for plant growth that were disrupted during the disturbance of mining and reclamation. The degree of reestablishment of these conditions can be used as one measure of reclamation success.

The potential productive index of reclaimed soils will be dependent upon the following factors:

1. Topographic location
   a. degree of slope
   b. location (runon vs. runoff water)

2. Root zone properties (topsoil and subsoil)
   a. depth
   b. texture (potential water-holding capacity)
   c. soluble salts (EC)
   d. sodium level (SAR)

For the purposes of this discussion, these will be considered "fixed" soil properties which are not subject to change. However, we must recognize that soluble salts and sodium are subject to redistribution within the reclaimed soil profile. These changes are relatively slow, so these properties will be considered as fixed properties for the purposes of this discussion. Data for all of the above factors is already required for mining permits in North Dakota.

The productive capacity of a reclaimed soil, as predicted by the potential productive index calculated from the above fixed soil properties, cannot be attained until favorable root zone conditions have become established. The most important root zone conditions are the development of adequate pore space (voids not occuppied by soil particles) and the formation of continuous pores to facilitate internal movement of air and water, storage of water, and plant root growth.

A 2-year field study was completed to study the effects of mining and reclamation on water movement and storage. Bulk density, aggregate stability, water retention, and hydraulic conductivity were compared for undisturbed soils and for soils which were reclaimed using materials from similar soil (Wollenhaupt, 1985).

Bulk density was found to be significantly higher in the top 60 cm of reclaimed soils than on similar undisturbed soils. The highest bulk densities were at the first-second lift interface. The density values decreased, especially in the tillage layer, as the reclaimed soils became older. The bulk densities in the reclaimed soils were not high enough to be detrimental to root growth. The increased density, however, results in an average reduction of 16% in the volume of suitable plant growth materials, so should be considered when evaluating soil replacement depths in reclaimed soils.

Available water holding capacities of reclaimed soils were similar to those of similar undisturbed soils. Increases in bulk density decrease macropore space but not available water holding capacities. Available water holding capacity was low when the soil samples contained degraded lignite.

The size distribution of water stable aggregates was distinctly different between various groups of undisturbed soils. Undisturbed soils with a predominance of <2 mm water stable aggregates appeared to be more productive than soils with dominant amounts of >4 mm aggregates. Aggregate size distribution in reclaimed soils tend to be the same as that in the soil materials used in their construction, but total aggregate contents tend to be 30 to 50% lower than in the undisturbed soils from which they were derived.

The hydraulic conductivity of reclaimed soils is highly correlated to and consistently one order of magnitude lower than that of corresponding undisturbed soils. The disruption of pore continuity during removal and respreading of suitable plant growth materials appears to be independent of texture, structure and available water holding capacity.

The results of these studies suggest that after the potential PI has been calculated using the "fixed" properties listed above, the degree of productivity reestablishment can be reliably estimated from measurements of total pore space and of pore space continuity. The total amount of pore space can be calculated from bulk density measurements which are relatively quick and inexpensive. Pore space continuity can be estimated from measurements of hydraulic conductivity; we have adapted an air entry permeameter for field measurements on reclaimed soils. This is an inexpensive instrument, simple to operate, and gives rapid and reproducible field measurements.

Kinney et al. (1983) developed a model for calculating PI based upon the assumption that average crop yields for Missouris soils were largely determined by the effects of the soil environment on root growth. This model was adapted by Pierce et al. (1983) to soils in the North Central region. We have further modified this model as follows to calculate the PI of reclaimed soils:

$$PI = 100\ Topo \sum_{i=1}^{n} (AWC_i x SAR_i x EC_i x Db_i x HC_i x Wf_i)$$

in which Topo = topographic location, AWC = available water capacity, SAR = sodium adsorption ratio, EC = electrical conductivity, Db = bulk density, HC = hydraulic conductivity, and Wf = root depth weighting factor.

Topographic location (Topo) adjusts the PI calculated from soil properties to reflect the moisture status as affected by steepness of slope and position on the slope in relation to runoff and runon water. The available water capacity (AWC) can be considered a fixed soil property, and can be estimated from the soil texture (Wollenhaupt, et al., 1982 a and b). The sodium adsorption ratio (SAR) and the electrical conductivity (EC) are measures of the sodium and soluble salt levels in the soil and are considered fixed properties in this discussion; both are routine laboratory measurements. Bulk density (Db) is a measure of the total pore space in the soil and tends to increase (total pore space decreases) during reclamation. Our current results indicate, however, that high bulk density is not a serious problem in properly reclaimed North Dakota soils. Measurement of bulk density is a relatively simple and inexpensive laboratory procedure. Hydraulic conductivity (HC), actually saturated hydraulic conductivity, is a measure of the rate of water movement through the soil, and is thus a measure of the continuous pores in the soil. Hydraulic conductivity is greatly reduced due to the disruption of continuous pores during removal and respreading of soil materials. We feel that hydraulic conductivity gives our most critical evaluation of the reestablishment of productivity in reclaimed soils. We prefer the field measurement of HC using the air entry permeameter as described by Wollenhaupt et al. (1985); however, laboratory analyses using undisturbed cores give a satisfactory measurement on most soils.

The root depth weighting factor (Wf) is a measure of the relative contribution of various depths within the root zone to the potential productive capacity of the soil, and is calculated from studies of root distribution and of water uptake during the growing season. Doll, et al. (1984) concluded that the effective root zone should be 120 cm in depth; Power et al. (1981) and Pierce et al. (1983) concluded that a root zone 100 cm in depth was adequate. Danielson (1967) stated that irrigated crops tended to use water approximately in the proportion 40:30:20:10 from successively deeper quarter fractions of the root zone. Data from North Dakota on both reclaimed and undisturbed soil support this concept. Weighting factors developed by Kiniry et al. (1983) and Pierce et al. (1983) using root growth distributions also fit this ratio. Within the rooting zone, higher levels of sodium (SAR) and soluble salts (EC) can be tolerated in the subsoil without affecting productivity than in the topsoil; the calculation of a weighted PI for each quarter-fraction increment of the rooting zone and adding these weighted PI's to determine the PI of the soils simplifies the use of different criteria for different root zone depths.

For the measured soil parameters we prefer to use the sufficiency concept similar to that described by Pierce et al. (1983), in which a sufficiency value of 1.0 is assigned to levels of the parameter that are not limiting yields, and decreasing to 0.0 for the level at which root growth ceases. The results of Wollenhaupt (1985), together with the results of other North Dakota research, indicate that there are a broad range of values for these parameters at which yields are not limiting. To calculate the potential PI, actual sufficiency values for the fixed soil parameters (AWC, SAR, and EC) together with the approximate value for topographic position are inserted into the equation using nonlimiting sufficiency values (1.0) for Db and HC. To calculate actual PI, measured sufficiency values for Db and HC are inserted into the equation instead of the nonlimiting values (1.0) used to calculate potential PI.

Comparisons of potential and actual PI values can be used as a measure of reclamation success. The potential postmine PI for the reclaimed area should be calculated before mining begins using premine inventory data and the proposed postmine topographic plan. The premine PI of the area can be calculated using data from the soil survey. We feel that this would be a valuable tool for use in planning mining permit applications. Measurements of actual PI can be made soon after the postmine vegetative cover is established on the reclaimed area to monitor the reclamation program and to identify potential problem areas.

VEGETATIVE EVALUATION

The North Dakota rules for the reclamation of surface-mined land state that the success of revegetation shall be measured using statistically valid techniques. Comparison of ground cover and productivity may be made using reference areas located on similar undisturbed land or using other standards. Currently, emphasis is placed upon comparisons of yields from reference areas and reclaimed soils, and state that ground cover and productivity from reclaimed grasslands and crop yields from reclaimed cropland must be equal to or greater, with 90% statistical confidence, than those from comparable undisturbed reference areas for the last two consecutive years of the 10-year bonding period. On prime soils, yield comparisons must be made for the last three consecutive years.

From the results of a 3-year experiment comparing crop yields from reclaimed and undisturbed soils, located at two different mines, Schroeder and Doll (1984) concluded that because of rainfall differences and insect and small animal damage on sites isolated from other cropped areas, precise evaluation of soil factors contributing to yield differences was not possible. Even though these plots were designed for statistical comparisons, and statistically significant differences were obtained, no consistent trends were obtained. Over the 3-year period, the relation of yields on reclaimed soils to those on undisturbed soils were inconsistent; in some cases they were significantly higher, in others significantly lower, and sometimes not different.

Doll, Merrill and Halvorson (1984) reported the results of another 5-year experiment in which yields from soils which were constructed over different overburden materials with different depths of topsoil were compared with yields from adjacent undisturbed soils. Again, yields from the undisturbed plots were sometimes lower and sometimes higher than yields from soils constructed using similar soil materials. However, since the constructed and undisturbed plots were adjacent, yield differences were not as great as in the experiment reported by Schroeder and Doll (1984).

The results of these experiments support our contention that comparison of yields from a reclaimed soil to those from a nearby reference area is not a viable method of evaluating reclamation success. Yields are affected not only by soil properties, but by variations in local climatic conditions, by biotic factors, and by variations in past cropping and management practices. The design and number of plots needed at each location for statistical validity at the required level make the use of reference areas difficult and imparactical as a measure of reclamation success.

The objective of reclamation is to restore the land to the premine productive level. To measure the degree of restoration of productivity, we must evaluate the reestablishment of favorable root zone properties and we must evaluate vegetative vigor and production. We believe that visual observations of plant density and vigor should be made over the entire reclaimed area at a time when the plants are actively growing and when root development is essentially complete. This will allow an estimate of the stage of restoration of favorable soil properties for root development and will give a qualitative estimate of the uniformity within the reclaimed area. When the crop is native (or for grasslands at the proper vegetative stage), yields should be measured either by harvesting the entire reclaimed area or by using appropriate sampling techniques. Yields could then be compared to those obtained on similar undisturbed soils in the general area, or could be compared with projected yields using one of the NDSU computer programs such as CROP-PAK or WHEAT-PAK in which yields are adjusted to reflect climatic, biotic and management factors. We do not believe that precise statistical yield comparisons are warranted but suggest that yields only be compared with those obtained on farms in the area. Vegetative observations and yields should be used to verify the measured root zone properties. When these soil properties have been adequately restored, and when field observations of plant vigor and growth are favorable, we believe that reclamation success has been established.

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http://dx.doi.org/10.2136/sssaj1981.03615995004500010027x