LRC-III-14

SOIL DEPTH AND QUALITY REQUIREMENTS FOR RECLAMATION OF RANGELANDS

A Research Proposal
Submitted to the North Dakota Industrial
Commission by the Land Reclamation Research Center of the
the NDSU Agricultural Experiment Station
and the North Dakota Lignite Council

Principal Investigators:

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ABSTRACT

Soil replacement is a critical step in the reclamation process in North Dakota, where virtually all mined land must be reclaimed to cropland or rangeland. However, the amount of soil needed to return the mined land to productive use depends on a variety of factors, including soil quality, regraded spoil quality, intended land use, topography, and others. If excess soil is replaced, mining and reclamation costs will increase without any concurrent improvement in the quality of reclaimed land. If too little soil is replaced, the productivity of the reclaimed land may be adversely affected.

More than ten years of soils and reclamation research in North Dakota have resulted in recent regulatory changes which address soil replacement requirements based on a number of critical parameters identified by the researchers. The regulations, and most of the research, have been aimed at providing soil reclamation standards on cropland. Maximization of crop yields and soil uniformity are emphasized. While these standards may be excellent measures of cropland reclamation success, they do not address some important regulatory requirements related to rangeland reclamation.

NDAC 69-05.2-22-07(4)(a) states that success of revegetation on native grassland and tame pasture-land will be determined based on diversity, seasonality, ground cover, and permanence, as well as productivity. Diverse and permanent stands of native and tame pasture grasses have become established on a number of reclaimed lands where much less soil was respread than is required by current regulations. Furthermore, the ground cover and productivity of these reclaimed areas are often better than before mining occurred. Diversity, seasonality, ground cover, and permanence all depend on there being a variety of native species established on the site, which, in turn, suggests an emphasis on multiformity of environmental conditions, rather than the "approximate uniform thickness" of soil, for example, required by NDAC 69-05.215-04(3)(a).

Soil removal and replacement are major reclamation costs. Soil handling beyond what is necessary translates into higher electrical costs and reduced competitiveness of North Dakota lignite.

The purpose of this research will be to further define the relationships between soil depth, soil quality and reclaimed grassland productivity and species diversity. This project is designed to complement ongoing research in mine land soils by the Land Reclamation Research Center. Field work will be done on reclaimed grasslands at various North Dakota coal mines established since 1972. Results will be used to determine what reconstructed soil characteristics and replacement depths are necessary for rangeland areas.

The project will commence July 1, 1988. Data will be collected over three field seasons with the final report due July 1, 1991. Major participants will include soil scientists from the NDSU Land Reclamation Research Center, range scientists, graduate and undergraduate students associated with the NDSU Animal and Range Science Department and member organizations of the North Dakota Lignite Council. Contractual arrangements will be made between the North Dakota Industrial Commission and the NDSU Agricultural Experiment Station and the North Dakota Lignite Council. All funds will be administered through the North Dakota Agricultural Experiment Station.

Total Project Cost: $166,855

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RESEARCH OBJECTIVE

To determine soil replacement depths and quality necessary to meet productivity and species diversity requirements for reclaimed grassland as compared to reference areas within similar topoedaphic units.

Reclaimed pasture or rangeland has to produce at a level equal to or greater than the land prior to mining. The amount of replaced topsoil necessary to accomplish this is dependent on a number of variables including soil quality, soil and spoil texture and is influenced by such variables as topography. How these variables interact on a given reclaimed grassland site is not well understood. This research will attempt to quantify the affect these variables have on diversity and productivity of a given rangeland site. This data should tell us how much soil replacement is necessary to achieve a certain level of production and diversity.

Soil removal and replacement is a major reclamation cost. If this research shows that more topsoil and subsoil are being replaced than necessary it may be possible to reduce topsoil and subsoil requirements on reclaimed grasslands. This should translate into lower energy costs and greater competitiveness of North Dakota lignite.

BACKGROUND INFORMATION

Since soil replacement requirements began in 1972, reclamation rangelands have been established where depths of suitable plant growth material (SPGM) have varied from a few inches up to 5 feet. Some stands, where only one soil lift was removed and replaced are now 13-14 years old. The first research project in North Dakota to test the relationship between yield and soil depth was conducted at the Glenharold Mine in 1972.

The persistence of these old plots as well as the stability and productivity of grasslands established with less SPGM and quality control than presently required is also evident from field observations and data collected by industry specialists. These observations indicate that less soil may be replaced and still meet productivity standards where rangeland is the post mining land use. Rules that require a uniform replacement depth across an entire rangeland reclamation area may be counterproductive to establishing and maintaining a diverse grassland stand.

Data exists which indicates that reclamation to grassland may require less topsoil and subsoil than land reclaimed to cropland. In a study at the Glenharold Mine a 40 acre area was spread with one lift to an average depth of 20 inches and was seeded in June of 1979 to a mixture of native species. Production (except 1983) and cover data were collected from 1980 through 1987. Excluding 1980, yields on this area have been greater than a comparable reference area each year comparisons were made (Figure 1). Higher yields were recorded despite mixing of topsoil and subsoil (one lift removal), uneven soil redistribution, presence of "toxic" spoil and typical alterations to soil structure due to the operation of heavy equipment.

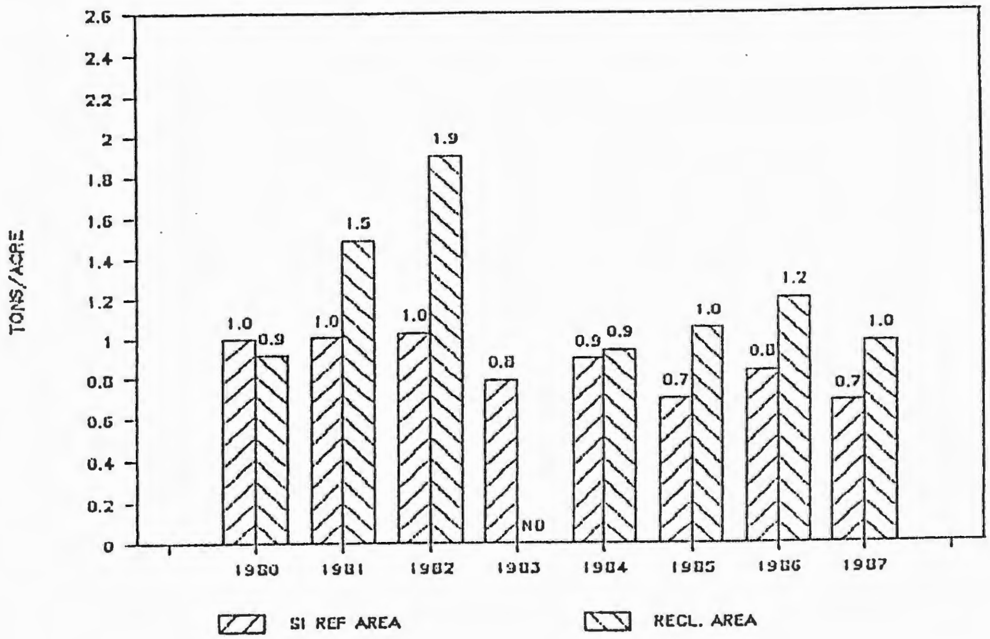


Figure 1. Comparison of yield between the Glenharold silty reference area and the Glenharold grassland demonstration area between 1980 and 1987.

Figure 2 illustrates 1987 productivity relative to SPGM depths recorded from 10 permanent soil sampling stations. Similar to reported research, yield was lowest at the sample point where the mean SPGM depth was only 11 inches. However on soils with deeper depths of topsoil yields were inconsistent and fluctuated above and below the mean yield obtained from the area and well above the mean yield recorded on the reference area. From a statistical standpoint total production on the demonstration area was significantly higher than the reference area.

The relationship between vegetative parameters such as production and soil depth is more complex than simply expecting a certain yield given a specific soil depth. For example, different chemical and physical properties of the soil can affect available water. These include salinity, sodicity, hydraulic conductivity, available water holding capacity and bulk density. In other words, 20 inches of SPGM that exhibit "poor" qualities as a growth medium should produce less than 20 inches of SPGM with characteristics that increase plant available water. Also, as reflected in current research and regulations, certain spoil material can qualify as root zone material and contribute to above ground yields.

In addition to the influence of soil depth, soil chemical and physical properties, slope and aspect will affect mean productivity and species diversity at certain locations across an area. These factors result in an uneven distribution of soil water not unlike an undisturbed grassland area. Existing research has pointed out the affect of these variables on soil moisture and yields. In NDSU Agr. Exp. Sta. Bulletin 514, Doll et al (1984) summarized average (1976-1979) native grass yields on the Stanton wedge plots and attributed higher yields at the midpoint to rainfall runon and snow accumulation. Using data from Bulletin 514,

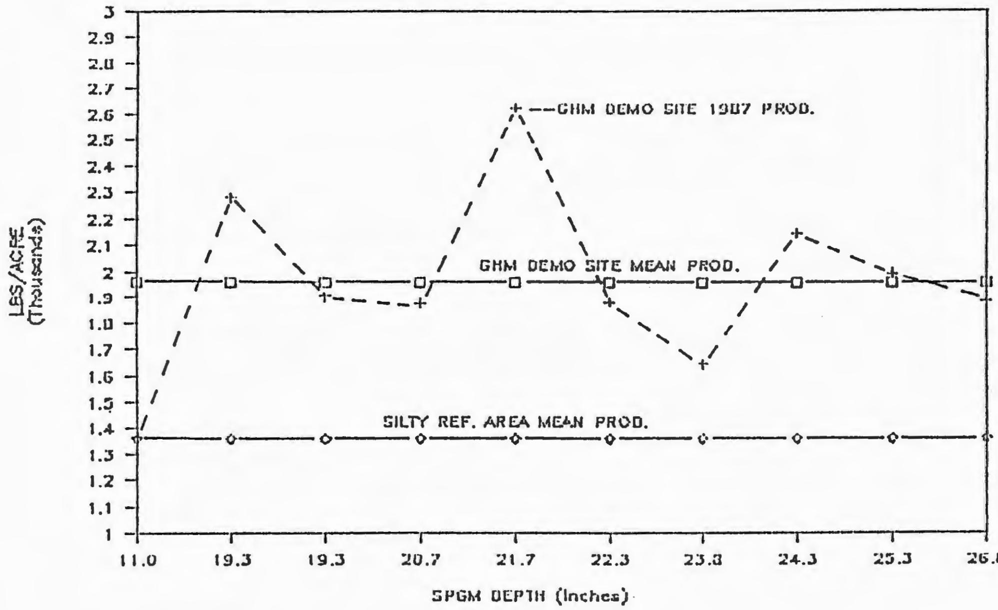


Figure 2. Glenharold demonstration area productivity relative to soil depth and the silty reference area (1987 data).

yields of native grasses at the 28 and 36 inch depth near the midpoint were 30 percent higher than where 80 inches was used at the top of the slope. Yields at the 20 inch depth were 20 percent higher than the yield at the top. Figure 3 graphically illustrates how yields changed across the plot. Similarly, at the Zap double wedge experiment, higher yields of crested wheatgrass were reported near the midpoint and on the north slope.

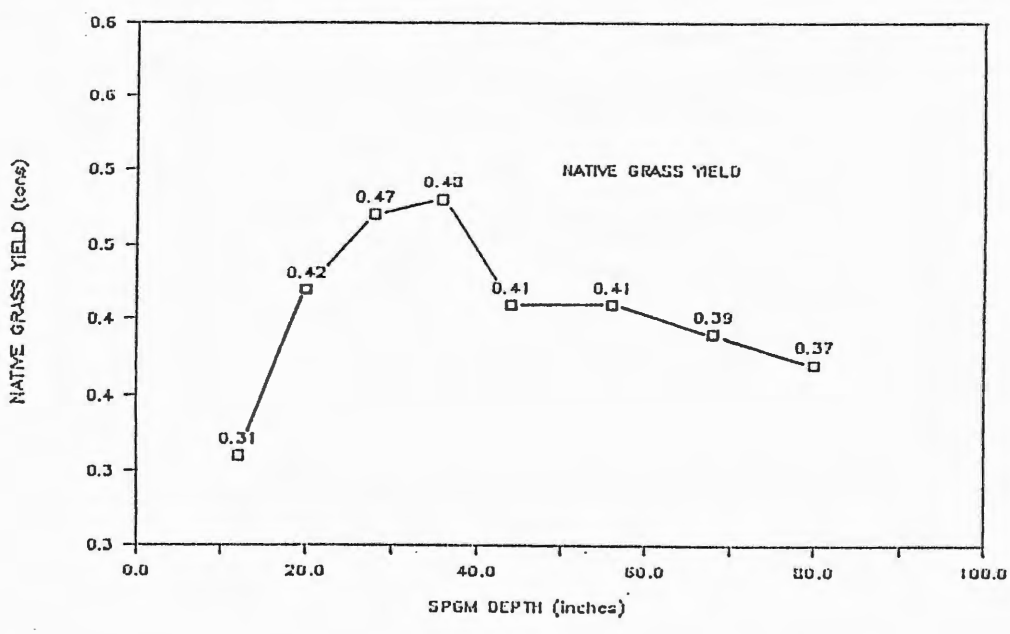


Figure 3. Mean (1976-1979) yields across the Stanton native grass wedge plot (data from ND Agr. Exp. Sta. Bull. 514).

From these results and industry observations, it is apparent that more research is necessary to delineate how factors such as soil depth, soil quality, and available water interact to achieve a certain level of production.

Although moisture and soil properties affect rangeland productivity, it is also important to recognize how a reestablished grass stand will react to a reconstructed environment. It is readily apparent that different species have different morphological and external phenological characteristics. Morphological features such as leaf size, shape, and orientation or changes in plant phenology during drought for example, will affect total water use, radiation absorption, gas exchange etc. Similarly, numerous internal physiological characteristics can regulate photosynthesis, respiration and transpiration. Fairbourn (1982) reported that a mixture of pasture grasses (primarily introduced cool season species) had a transpiration rate 1.5 times as great as that for native species. Similarly, differences can exist between native species particularly those that exhibit C3 and C4 carbon fixation pathways. Moore (1977) summarized some of the characteristics typical of C4 species. These included, but were not limited to, high optimal temperatures for net photosynthesis, efficient use of low CO_2 concentrations, generally high net photosynthetic rates, and high net photosynthesis to transpiration ratios.

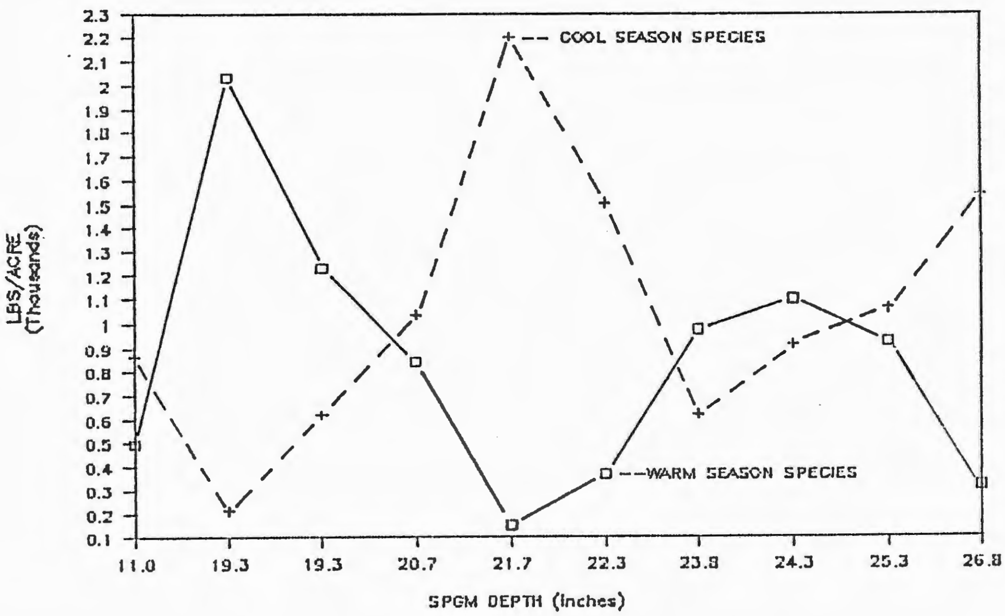
Typically a native mixture of C3 and C4 species is used where native rangeland is the post mining land use. Consequently, an established stand can have a wide tolerance to weather extremes and conditions in the soil medium reflecting the diverse characteristics of species constituting the mixture. These and other environmental influences, in turn, will determine what species or group of species dominate a particular locale. This sorting via natural processes is occurring on reclamation areas. At the Glenharold demonstration site where production was taken at 10 soil sample points, a highly significant negative relationship ($r = -.87$, p .01) exists between the production of cool and warm season species over a wide range of soil depths (Figure 4).

METHODOLOGY

This project is based on the premise that available soil water is the principle factor regulating plant growth on reclaimed grasslands in North Dakota, assuming that a minimum threshold thickness of soil is present. An increase in soil depth or improvements in soil properties will increase productivity only to the point that plant available water is increased (Merrill et al 1985). Concurrently, the amount of available water necessary for dry matter production is regulated by the water use efficiencies (WUE) of species used in rangeland reclamation. For this study, it is proposed to use undisturbed grasslands or reference areas present at each mine where sites are selected.

Established grassland stand (4 years or older) will be selected from mines where spoil quality and soil thickness vary to provide a comparison between worst and best case situations. Within each site sample sites will be selected based on preliminary coring to determine topsoil and subsoil depth and physical and chemical characteristics. Vegetation data and soils information is available from some mining companies to assist in making this determination. Sample points across site and reference areas will be established such that the entire topographic situation (topography, aspect, soils) are considered.

Figure 4. Cool and warm season grass production relative to SPGM depth on the Glenharold demonstration area.



Figures 2 and 4 suggest factors other than soil depth have influenced productivity and species diversity on the Glenharold Mine demonstration area.

Specific vegetation analyses will include vegetative cover, by species, estimated using the ten point frame method (Arny and Schmid 1942). A minimum of 500 points per site will be sampled. Species diversity will be calculated from the cover data using the Shannon-Wiener diversity index (Shannon and Weaver 1973). Above-ground biomass will be determined by clipping a minimum of 5, 0.25 m^2 quadrats at each site. Separation will include major species, forbs, shrubs, and groups (cool and warm species).

Soil data collected at each sample site will include:

1. Physical soil properties (to at least 48 inches)
   a. topsoil and subsoil depth
   b. texture
   c. bulk density
   d. water holding capacity (soil water)
   e. hydraulic conductivity
   f. saturation percentage
   g. root characterization

2. Chemical soil properties (to at least 48 inches)

   a. SAR
   b. EC
   c. pH
   d. N, P, K

3. Topographical considerations

   a. aspect
   b. sample site slope position

4. Weather data

a. precipitation

Statistical Methodology

The methodological procedure to determine a minimum soil depth for different topsoil and spoil materials that will meet reclamation standards in terms of vegetation production, cover and species diversity will consist of the following steps:

1. First, define topoedaphic units. Next select those variables that can discriminate among topoedaphic units. The aim is to develop a discriminant model so the operator can measure a series of prescribed variables and with the aid of the model determine to which topoedaphic unit the area that needs to be reclaimed belongs. This can be achieved in two ways:

a. Define topoedaphic units a priory and measure within each of the units the set of soil variable outlined above as 1, 2 and 3. Run a discriminant analysis to determine whether the defined topoedaphic units can in fact be differentiated and which of the above mentioned variables are necessary (in a statistical sense) to build a discriminant model.

b. Measure the set of soil variables outlined above as 1, 2 and 3 and use a cluster analysis followed by a discriminant analysis to define topoedaphic units a posteriory.

2. Within the topoedaphic units defined in step 1, areas will be sampled for vegetation production, cover and diversity.

3. Test, with the use of discriminant analysis, whether the vegetation parameters collected in step 2 can also differentiate among the topoedaphic units defined in step 1. The aim is to establish whether vegetation parameters are significantly different among topoedaphic units. If vegetation parameters cannot fully discriminate among topoedaphic units then we will need to go back to step 1 and redefine our topoedaphic units. The reason for this feedback mechanism is that we need to define topoedaphic units that are characterized by distinctively different vegetation structures (production, cover, and diversity) in order for them to be useful in the construction of reclamation standards.

4. Once topoedaphic units with distinct vegetation structures have been found (through steps 1-2-3) we can define minimum standards for reclamation. Because of the multivariate nature of vegetation parameters our rejection region will represent not an individual value for production or diversity or cover, etc. but a hypervolume. The precise shape of this hypervolume will be defined based upon current regulation standards.

5. Within the topoedaphic units defined through steps 1, 2 and 3 we will sample reclaimed areas, characterized by different soil depths, for vegetation production, cover and diversity.

6. The multivariate vegetation parameters measured in step 5 will be used to determine whether a particular reclaimed area with a particular soil depth within a topoedaphic unit falls in or out of the rejection region defined in step 4. For that purpose one-tail multivariate analysis of variance will be used. Based on this test reclaimed areas within topoedaphic units will be classified as pass or fail.

7. Once reclaimed areas within topoedaphic units are classified as pass or fail in terms of vegetation parameters (step 6), we will test whether they are also significantly different in terms of soil depth. If they are then a minimum soil depth standard for each topoedaphic unit can be established.

Schedule:

July 1, 1988 - June 30, 1989

a. Review of existing literature and related research currently in progress.
b. Select sites and conduct steps 1, 2, 3 and 4 as outlined under Statistical Methodology.

July 1, 1989 - June 30, 1990

c. Using topoedaphic units defined in the prior year, sample reclaimed grassland areas along a soil depth gradient during two growing seasons. Vegetative parameters will include cover, production and diversity. Soil data will include those parameters that can vary from year to year including soil, water, SAR, EC, etc.

July 1, 1990 - June 30, 1991

d. Complete data analyses and prepare report.

FACILITIES

The cooperating units of the Department of Animal and Range Sciences and the Land Reclamation Research Center of NDSU have at their disposal the whole range of facilities and equipment available at a university including computers capable of handling all data analysis, laboratories for complete soil and plant analysis and a large library. In addition, the North Dakota Lignite Council, through its members, can provide access to the sites, large equipment if it is necessary and on-site personnel who could help in monitoring the sites.

PERSONNEL: (For details see Appendix)

Principal Investigators:

Donald Kirby

Present Position: Associate Professor, Department of Animal and Range Sciences, North Dakota State University, Fargo, ND 58105.

Education:
- B. S. Range and Wildlife Management (Humboldt State University 1974)
- M. S. Natural Resources Management (Humboldt State University 1976)
- Ph.D. Range Science (Texas A&M University 1980)

Experience:
- 1974-1976 Research Assistant (Humboldt State University)
- 1976-1978 Research Technician (Texas A&M University)
- 1978-1980 Research Assistant (Texas A&M University)
- 1980-1986 Assistant Professor (NDSU)
- 1986-Present Associate Professor (NDSU)

Research Experience:
- 1980-1988 Completed 10 graduate research programs
- 1977-1988 Published 21 research articles
- 1974-1988 Received Forest Service, U.S.D.A., N. D. Beef Commission, N. D. Game & Fish grants

Gary Halvorson

Present Position: Associate Soil Scientist, Land Reclamation Research Center, Mandan, ND.

Education:
- B. A. Chemistry (St. Olaf College)
- M. S. Soil Chemistry (Oregon State University)
- Ph.D. Soil Chemistry (Oregon State University)

Experience:
- 1972-1977 Research Assistant (Oregon State University)
- 1978 - Fellowship to the Timeryazoo Agricultural Academy, Moscow, USSR.
- 1979 - Research Associate (Oregon State University)
- 1979 - Present Associate Soil Scientist (NDSU)

Research Experience:
- 1979-1988 Research on numerous projects associated with reclamation of drastically disturbed lands in North Dakota.

Cooperating Investigators:

Mario Biondini

Present Position: Assistant Professor, Department of Animal and Range Sciences, North Dakota State University, Fargo, ND. 58105.

Education:
- B. S. Agronomy (Argentina 1975)
- M. S. Range Ecology and System Analysis (Texas Tech University 1980)
- Ph. D. Range Science and Statistics (Colorado State University 1984)

Experience:
- 1975-1978 Research Associate (Argentina)
- 1978-1980 Research Assistant (Texas Tech University)
- 1980-1986 Research Associate and Post-Doctoral Fellow (Colorado State University)
- 1984-1986 Consultant to: Goodson and Associate Inc. (Colorado) and Robert Mitchell and Associate (Colorado) and Winroch International (Arkansas)

Research Experience:
- 1980-1986 Associated as an investigator with a Department of Energy funded project in the reclamation of disturbed and mined areas.
- 1984-present Associated with two research projects funded by the National Science Foundation.

Steve Schroeder

Present Position: Associate Soil Scientist Land Reclamation Research Center, Mandan, North Dakota.

Education:
- Associate in Arts and Soils (Sauk Valley Junior College)
- B. S. Agronomy/Soils (Univ. of Illinois)
- M. S. Soil and Water Conservation (Univ. of Illinois)
- Ph.D. Soil Physics (Purdue)

Experience:
- 1974-1979 graduate student (Purdue University)
- 1979-present Associate Soil Scientist (NDSU)

Research Experience:
- 1979-1988 Research on numerous projects associated with reclamation of drastically disturbed land in North Dakota.

QUALIFICATIONS OF THE APPLICANT

Gary Halvorson is an Associate Soil Scientist at LRRC and has been involved in reclamation research in North Dakota since 1979. His main interests are in the area of soil chemistry and soil fertility. Research projects have included studies of the fertility requirements of reclaimed land, topsoil and subsoil requirements of reclaimed land, and topographic influences on the reclamation of prime and nonprime land. He was also a principal investigator in a study of the revegetation of a saltwater blowout area in western North Dakota.

Don Kirby presently holds the rank of Associate Professor in the Department of Animal and Range Sciences and has been employed by NDSU since 1980. His research has been concerned with grazing studies of both cattle and sheep, ecological studies and the composition, production, and nutritional content of wetland vegetation.

Mario Biondini is Associate Professor in the Department of Animal and Range Sciences at NDSU since 1986. His research has been concerned with successional patterns of vegetation on mined land and studies of root exudates. His major research interests include the study and analysis of ecosystems, use of multivariate statistical techniques, modelling of ecological systems and the structural and functional relationships between primary producers and microflora in ecosystem development.

Steve Schroeder is an Associate Soil Scientist at LRRC and has been involved in studying the various factors affecting productivity of reclaimed mine-land soil for eight years. This included factors such as tillage, fertility and topographic influences on small grain and forage yields. Additionally he has also been involved in studying the effects of reclamation on runoff and soil erosion from reclaimed areas as compared to undisturbed areas. Other research includes soil water depletion/recharge by depth under small grains and forage grasses plus tillage effects on compaction and on rooting depths of reclaimed soils.