A SPATIAL APPLICATION OF A VEGETATION PRODUCTIVITY EQUATION FOR NEO-SOL RECONSTRUCTION[1]

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Abstract: Reclamation specialists are interested in the application of recently developed soil productivity equations for post-mining reclamation planning and design. This paper presents the application of one recently developed soil productivity equation to a surface coal mine site in Mercer County, North Dakota. Geographic information systems (GIS) technology (Map*Factory 1.1) was combined with a soil productivity equation developed by the author to generate a GIS script to calculate a site's pre-mining productivity per 10 meter grid cell and then summed to calculate the grand and the expected average soil productivity for the site, resulting in a pre-mining baseline numerical spatial scores. Several post-mining alternatives were evaluated to study various soil management strategies to restore post-mining soil productivity, including: an abandoned mine landscape treatment, a reconstructed topsoil treatment with graded gentle slopes, and a reconstructed topsoil treatment with soil improvements. The results indicated that the abandoned mine scenario was significantly different than the other three treatments ($p \leq 0.05$), with the reconstructed topsoil treatment with soil amendments generating the greatest estimated productivity.

Additional Key Words: landscape architecture, agronomy, forestry, range science, soil science, landscape planning, landscape reclamation, agro-ecology

Introduction

Reclamation specialists, including soil scientists, plant scientists, land planners, and landscape architects, are interested in the application of recently developed soil productivity equations for post-mining reclamation planning and design. This paper presents the application of one recently developed soil productivity equation to a surface coal mine site in Mercer County, North Dakota.

Literature

The equation employed for this study was generated in a PhD dissertation by Burley (1995a). This work was preceeded by numerous studies concerning the development of predictive equations for reconstructing soils as illustrated byBurley (1995b), Barnhisel and Hower (1994), Burger *et al.* (1994), Burley and Bauer (1991), Barnhisel *et al.* (1992), Burley (1992), Burley (1991), Gale *et al.* (1991), Burley (1990), Gersmehl and Brown (1990), Burley *et al.* (1989), Burley and Thomsen (1987), and Niell (1979). These studies cite much of the related literature with contributions from a broad pool of reclamation scientists investigating this topic predominately in the great plains, midwest, and Kentucky. Few of these predictive equations have been applied in a spatial manner to access landscape patterns and configurations. Burley and Thomsen (1990) presented a simple sand and gravel mine reclamation application concerning one of their equations by employing GIS (Geographic Information Systems). However, GIS applications in surface mine reclamation planning and design have not been extensively reported. Burley *et al.* (1992) and Lortie *et al.* (1995) describe the numerous potential applications affiliated with GIS technology for surface mine reclamation.

This paper describes a study which illustrates the application of GIS technology and soil productivity equations. To accomplish this task, a study area in Mercer County, North Dakota was selected.

Study Area

Mercer County is predominantly an agricultural landscape, where soil is an important natural resource (Wilhelm 1978). Wilhelm (1978:2) notes that beneath the soil, "A vast amount of lignite coal ... about 5 million tons was mined in Mercer County [1974]." The reserves are estimated to be approximately 29,900 million tons (Wilhelm 1978:2). These reserves reside below a surficial landscape dominated by materials of glacial origin, including till plains, outwash plains, and loess. In addition there exist river flood plains and alluvium terraces (Wilhelm

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1978:107). Wilhelm (1978:3) states, "About 282,000 acres, or 43 percent, of the land area is used as cropland. The rest is mostly in native grass and is used as rangeland or hayland." Wilhelm (1978:223) describes the taxonomic classification of each soil type examined in the study. The predominant soils examined in Mercer County are mollisols such as the Williams series (fine-loamy, mixed, Typic Agriborolls) and the Mandan series (coarse-silty, mixed, Pachic Haploborolls). A few entisols are also included such as the Cohagen series (loamy, mixed, calcareous, frigid, shallow, Typic Ustorthents). The soils are neutral or slightly alkaline. A few soils are saline in character.

The study site for this investigation is located primarily in the southern portion of section 8, Township 144 North, Range 87 West. Along the southern border of this section is North Dakota State Highway 200 and is approximately five miles west of Hazen, North Dakota. The northern, southern, and eastern boundaries of the site contain overburden from an abandoned surface coal mine, represented in Figure 1. These abandoned surface mined lands have been vegetated by naturalized woody plants, grasses and forbs which readily occupy the swales and side slopes of these piles. In many instances the tops of these piles have remained unvegetated for over 60 years. Sometimes, these abandoned surface mines are utilized for wildlife habitat. Consequently today, surface mines in the area are mandated to have a reclamation plan. These laws and regulations were recently examined and compared by Burley (1994).

Figure 1. Abandoned mine land near the study area (courtesy of R. Hopkins and the North Dakota Agricultural Experiment Station 1983).

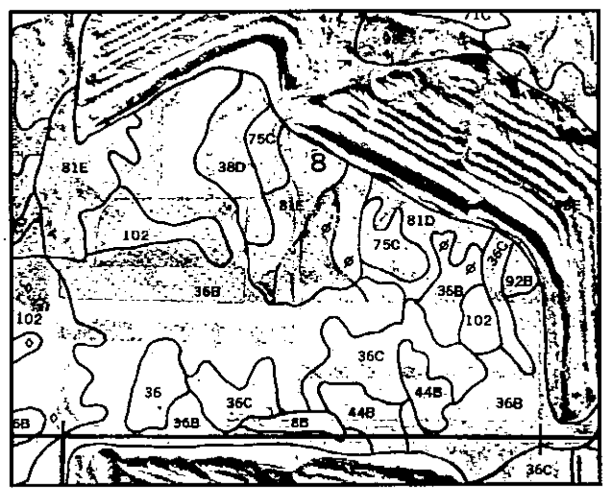

Figure 2. A map of the soils in the study area (Wilhelm 1978).

As of 1978, the undisturbed soils on the site (Figure 2) include Williams loam (~55% of site), Arnegard loam (~3%), Grail silty clay loam (~0.5%), Belfield-Daglum silt loams (~6%), Cabba loam (21.4%), Noonan-Williams loams (~0.5%), and Bowbells loam(~6.0%) (Wilhelm 1978). These deep to shallow but well drained soils were derived from material weathered from glacial till and soft bedrock and reside upon an undulating to steep topographic character (Wilhelm 1978). The site ranges from about 2065 feet above sea level to near 1935 feet above sea level (USGS 1968). The site has several steep slopes and affiliated drainageways in the north west corner and along the central to northern portion of the site. The bedrock immediately below the sparse Coleharbour group glacial till is comprised of the Sentinel Butte Formation (Bluemle 1982). This formation consists of somewhat unconsolidated silt and clay, plus sand cemented with calcium carbonate, and beds of lignite (Bluemle 1980).

An aerial perspective of the site resides on a web page maintained by the North Dakota State University in cooperation with the North Dakota Geological Survey (http://www.ndsu.edu/schwert/ndgs/nd_coal.htm). The photograph is by E. Murphy of the North Dakota Geological Survey illustrating the conditions of surface mined lands prior to 1969 . Before that time, reclamation was not required. The photograph was taken looking north, northwest. Highway 200 runs west to east through the middle of the image. Immediately to the north of the highway and on the left-hand side of the image is an aerial depicting the study site, with the exception of the extreme most westerly part of the site. In the foreground of the aerial, spoil piles similar to the ones illustrated in Figure 1 are present.

Method

The methodological approach was similar to the procedures described by Burley and Thomsen (1990), where a soil productivity equation was selected to produce a grand overall productivity score for the site. The equation (Equation 1), employed in this study was one of the equations derived from Burley (1995a:109). This equation predicts soil productivity for upland settings in Mercer and Oliver counties of North Dakota affiliated with expected success of growing the vegetation listed in Table 1 and for predicting the relative expected rate of growth for these plants. The equation has an overall p-value of 0.0001, and adjusted R-Square of 0.707, explaining over 70% of the variance. All regressors in the equation have a Type II sums of squares with a p-value less than or equal to 0.050 and the equation is not over-specific, meaning low collinearity among the regressors. This equation has a correlation of 0.5151 with results observed from existing reclaimed soils employed in a study by Burley (1995a). Burley *et al.* (1996) describes a somewhat similar equation for Mercer County.

This equation generates a productivity index value, which is a unitless number, indicating relative productivity. o Burley's (1995a) work, a vegetation productivity scores have typically ranged in scale from five to minus ten, where a score of five is a highly productive soil and a score of minus 10 is an unproductive soil. These predictive scores can be applied to grid cells on a GIS map and the cells can be summed to give a grand productivity score. The grand productivity score can be divided by the number of grid cells to produce an average grid cell score. In theory, various landscape treatments for reclaiming the disturbed soils may generate different average grid cell scores. These scores can be examined in a graph representing the 95% confidence limits for the predicted productivity scores to see if the average predicted scores are significantly different.

$$
\begin{aligned}
\text{Transition} = {} & 1.028+[(AW-0.159)*0.032^{-1}*(0.530)] \\
& +[(SL-5.920)*8.129^{-1}*(-1.259)] \\
& +[(FR-1.343)*4.051^{-1}*(-0.362)] \\
& +[OM-0.745)*1.404^{-1}*(1.367)] \\
& +[(TP-2.672)*0.898^{-1})^{2}*(-0.320)] \\
& +[((OM-0.745)*1.404^{-1})^{2}*(-0.377)] \\
& +[((FR-1.343)*4.051^{-1})*((SL-5.920)*8.129^{-1})*(0.366)] \\
& +[((EC-3.698)*2.560^{-1})*((HC-2.897)*4.050^{-1})*(1.219)] \\
& +[((OM-0.745)*1.404^{-1})*((PH-7.513)*0.396^{-1})*(1.058)] \\
& +[((OM-0.745)*1.404^{-1})*((TP-2.672)*0.898^{-1})*(-1.070)]
\end{aligned} \tag{1}
$$

Where:
Transition =Vegetation Productivity Value for Transition Region
AW=Available Water Holding Capacity
SL=% Slope
HC=Hydraulic Conductivity
FR=% Rock Fragments
TP=Topographic Position
EC=Electrical Conductivity
OM=Organic Matter
PH=Soil Reaction (pH)

Table 1. Dependent variables and units of measurement as recorded and published by the U.S. Soil Conservation Service (Wilhelm 1978).

Crop-Woody Plant, Measured Average Yield
Evergreen Trees
Juniperus virginiana, feet/20 years
Picea glauca densata, feet/20 years
Picea pungens,feet/20 years
Pinus ponderosa feet/20 years *scopulorum*
Deciduous Trees
Fraxinus pennsylvanica, feet/20 years
Populus deltoides, feet/20 years
Ulmus pumila, feet/20 years
Deciduous Shrubs
Caragana arborescens, feet/20 years
Prunus americana, feet/20 years
Prunus virginiana, feet/20 years
Agronomic Crops
Spring Wheat, bushels/acre
Barley, bushels/acre
Oat, bushels/acre
Grass/Legume, tons/acre

Where:
I meter = 3.281 feet; 1 foot = 0.3048 meter
1 hectoliter = 2.837 U.S. bushels; 1 U.S. bushel = 0.363 hectoliter
1 hectare = 2.471 acres; 1 acre = 0.405 hectare
1 kilogram = 2.2046 pounds avoirdupois; 1 pound = 0.4536 kilogram
1 kilogram = 1.10 x 10^{-3} ton, 1 ton = 907 kilograms

In this investigation, four treatments were examined. The first treatment is the existing landscape. This is the landscape condition before mining. If this study site were required to be as productive in the post-mining landscape as in the pre-mining landscape, this score is potentially the score against which all other scores should be evaluated. The three other treatments include an abandoned mine landscape treatment, a reconstructed topsoil treatment with gentle slopes, and a reconstructed topsoil treatment with soil amendments and gentle slopes.

The grid cell map for this study area was 6.1 meters by 6.1 meters (20 feet by 20 feet). At this grid cell resolution, there are 47,582 grid cells in the study area, which is equivalent to about 437 acres. Map*Factory (Kirby 1996) was the GIS software employed in the study.

Results

When the equation is applied to the existing soils, the results in an average score for the grid cells is 0.31. This means that the productivity for the site is moderate at best. Some soils such as the Williams loam have fairly high productivity scores, somewhere between 2.0 and 3.0 and comprise over 50% of the study area; however some of the site contains soils such as Cabba with scores near -5.00, resulting in an overall moderate productivity score for the study area. Figure 3 presents a map illustrating the distribution of the predicted productivity scores.

If the site were mined and not reclaimed, meaning that the study site was restructured to be similar to Figure 1, the predicted average productivity score for the grid cells would be somewhere near -4.9. The site would not be usable for crops, rangeland, or trees for windbreaks.

One approach to reclaiming a site is associated with managing the topsoil and grading the post-mining landscape with slopes that are appropriate for the intended post-mining land-use. Many times, the topographic configuration of a pre-mining site contains numerous moderate to steep slopes. The agricultural productivity of sites with steep slopes is quite low. In equation 1, percent slope is a major regressor, where an increase in slope of seven or eight percent results in a drop of relative productivity by over one full point. Therefore, one would expect soils on slopes of twenty to thirty-five percent to be quite low. If the study site were mined, the topsoil carefully replaced, and the site graded to slopes near and around 2% (Figure 4), the predicted average productivity score for the grid cells would be approximately 1.73. In this alternative the site would gently slope from the southwest to the northeast and the big hill on the site would be removed. In the development of the site, large gentle swales would be placed to accommodate site drainage from the southeast to the northwest.

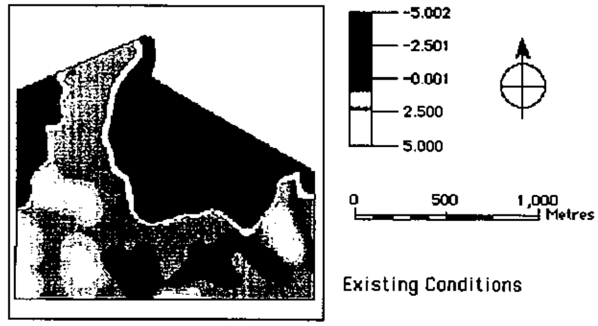

Figure 3. A map illustrating the predicted agricultural productivity scores for the site as it currently exists.

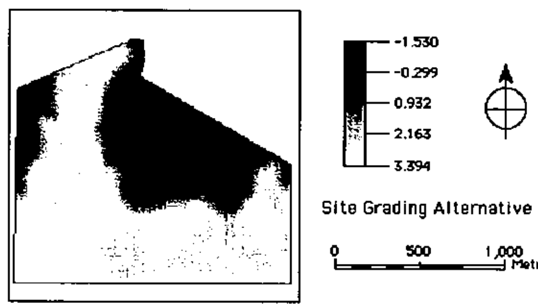

Figure 4. Predicted vegetation productivity scores for a site with topsoil carefully replaced and gentle slopes.

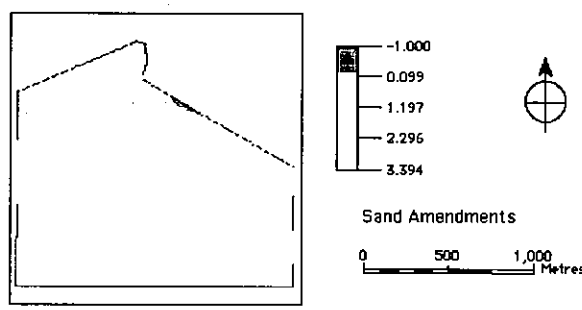

Figure 5. Predicted vegetation productivity scores for the study area based upon topsoil placement, gentle slopes and sand amendments.

A fourth approach that may be considered when reconstructing soils is to amend those soils that have undesirable characteristics. In this case, the Cabba soils and related unconsolidated bedrock that is the parent material for these soils are dense and clayey. Modifying these soils with the addition of sand to derive a more loamy texture, and improve aeration, and hydraulic conductivity would improve the productivity of these soils--converting them from rangeland soils to possibly cropland soils. Providing a suitable sand layer exists in the excavated overburden, this sand could be mixed with the Cabba related soils during the mining operations. The result could be a soil productivity landscape pattern similar to Figure 5. This pattern generates a predicted average productivity score for the grid cells of approximately 2.03.

When the scores of the existing soil productivity average, the abandoned mine scenario, the gentle slope alternative and the amended soil alternative are compared, the abandoned mine average is significantly lower than all other alternatives (Figure 6). The gentle slope alternative is not significantly different than the existing soil productivity average or the amended soil alternative; however, the amended soil alternative is significantly different (greater) than the existing soil productivity average (p-value $\leq$ 0.05).

Discussion and Conclusion

This study illustrates the use of a vegetation productivity equation to assess various conditions and alternatives affiliated with soil reclamation and provides some insight into evaluating the relative merits of various approaches. If the aim of the reclamation project is to generate a site productivity level equal to or greater than existing productivity, the gentle slope alternative appears to be adequate. In fact, this approach is now quite common in reclaiming surface mined lands. The top four feet of the soil profile is reconstructed over the post-mining landscape, severe slopes are made more gentle and as long as the reclamation contractor can place the soil in a state similar to the post-mining physical condition (such as not compacting the soil), productivity is restored or even increased. However, alternatives which significantly increase the productivity of low productivity soils is somewhat conjecture. Soil amendment alternatives require field testing and verification. In addition, amendments can increase the cost of reclamation. For example, in this study, if a suitable sand layer is available, the material must be collected, stored, and mixed with the clayey substrate to produce a loam. Across several hundred acres of landscape, this sorting and mixing is an extra financial burden. While this approach is quite common in the horticulture and turf grass industries to create topsoil for lawns and gardens, this approach may be prohibitive across the great plains. In the long term, these amended soils have questionable productivity longevity and may require different soil cultivation practices. These issues require further study by the soil science community. This study is indicative of the progress that has been made over the last 30 years in the area of predicting soil productivity on reclaimed surface mined sites.

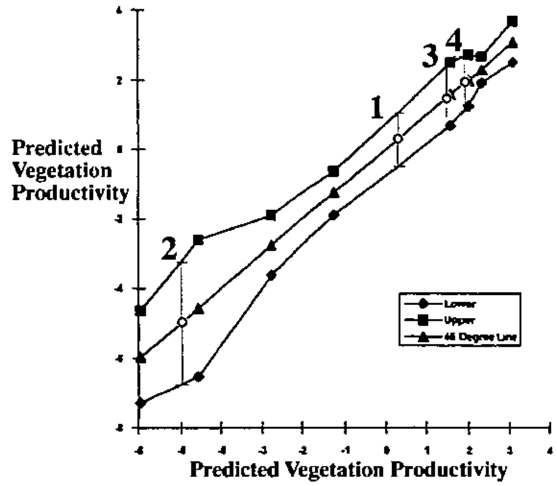

Figure 6. Comparison of various predicted vegetation productivity averages for the existing site (1), the abandoned mine alternative (2), the gently slope alternative (3), and the amended soil alternative (4).

Bibliography

Barnhisel, R.I. and J.M. Hower. 1994. The use of productivity index to predict corn yields on restored prime farmland. International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, Volume 3: Reclamation and Revegetation. United States Department of the Interior, Bureau of Mines Special Publication SP O6C-94:20-27.
https://doi.org/10.21000/JASMR94030020

Barnhisel, R.I., J.M. Hower, and L.D. Beard. 1992. Development of a soil productivity model for use in prime farmland reclamation. Prime Farmland Reclamation. Prime Farmland Reclamation National Symposium, University of Illinois, :205-211.

Bluemle, J.P. 1982. Generalized Bedrock Geological Map of North Dakota. Map, North Dakota Geological Survey, miscellaneous map 22.

Bluemle, J.P. 1980. Guide to the Geology of Southwestern North Dakota. North Dakota Geological Survey, educational series 9.

Burger, J.A., J.E. Johnson, J.A. Andrews, and J.L. Torbert. 1994. Measuring mine soil productivity for forests. International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, Volume 3:

Reclamation and Revegetation. United States Department of the Interior, Bureau of Mines Special Publication SP O6C-94:48-56.
https://doi.org/10.21000/JASMR94030048

Burley, J.B. 1995a. Vegetation productivity soil reclamation equations for the North Dakota coal fields. PhD Dissertation in Landscape Architecture, School of Natural Resources, University of Michigan, Ann Arbor, Michigan.

Burley, J.B. 1995b. A multi-county vegetation productivity equation for soil reclamation. Hynes, T.P. and M.C. Blanchette (Eds.) In: Proceedings of Sudbury '95 - Mining and the Environment. CANMET, Ottawa, Volume 3, 1113-1122.

Burley, J.B. 1994. Vegetation productivity equation compatibility with selected state environmental reclamation laws and regulations. International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acidic Drainage: Volume 4 of 4: Abandoned Mined Lands and Topical Issues. United States Department of the Interior, Bureau of Mines Special Publication SP 06D-94:294-303.
https://doi.org/10.21000/JASMR94040294

Burley, J.B. 1992. Vegetation productivity equations: an overview. Dunker, R.E., R.I. Barnhisel, and R.G. Darmody (eds) In: Proceedings of the 1992 National Symposium on Prime Farmland Reclamation. Department of Agronomy, University of Illinois, Urbana, IL 61801, 259-265.

Burley, J.B. 1991. A vegetation productivity equation for reclaiming surface mines in Clay, County Minnesota. International Journal of Surface Mining and Reclamation 5:1-6.
https://doi.org/10.1080/09208119108944279

Burley, J.B. 1990. Sugarbeet productivity model for Clay County Minnesota. Journal of Sugar Beet Research 27(3 & 4):50-57.
https://doi.org/10.5274/jsbr.27.3.50

Burley, J.B. and A. Bauer. 1993. Neo-sol vegetation productivity equations for reclaiming disturbed landscapes: a central Florida example. Zamora, B.A. and R.E. Conally (eds.) In: The Challenge of Integrating Diverse Perspectives in Reclamation: Proceedings of the 10th Annual National Meeting of the American Society for Surface Mining and Reclamation. ASSMR, Spokane, WA, 334-347.
https://doi.org/10.21000/JASMR93010334

Burley, J.B., G. Fowler, K.J. Polakowski. 1996. Agricultural productivity model for reclaiming surface mines in Mercer County, North Dakota. DesignNet Electronic Journal [Online], 1(1):http://www.ssc.msu.edu/~laej.

Burley, C.J., J.B. Burley, and T.J. Brown. 1992. Geographic information systems for reclamation applications. Jordan, D. (ed) In: Achieving Land Use Potential Through Reclamation: Proceedings of the 9th Annual Meeting of the American Society for Surface Mining and Reclamation. ASSMR, Duluth, Minnesota, 463-476.
https://doi.org/10.21000/JASMR92010463

Burley, J.B. and C.H. Thomsen. 1990. Application of an agricultural soil productivity equation for reclaiming surface mines: Clay County, Minnesota. International Journal of Surface Mining and Reclamation 4:139-144.
https://doi.org/10.1080/09208119008944181

Burley, J.B. and C.H. Thomsen. 1987. Multivariate Techniques to Develop Vegetation Productivity Models for Neo-Soils. 1987 Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation. University of Kentucky, 153-161.

Burley, J.B., C.H. Thomsen, and N. Kenkel. 1989. Development of an agricultural soil productivity equation for reclaiming surface mines in Clay County, Minnesota. Environmental Management 13(5):631-638.
https://doi.org/10.1007/BF01874969

Gale, M.R., D.R. Grigal, and R.B. Harding. 1991. Soil productivity index: Predictions of site quality for white spruce plantations. Soil Science Society of America Journal 55:1701-1708.
https://doi.org/10.2136/sssaj1991.03615995005500060033x

Gersmehl, P.J. and D.A. Brown. 1990. Geographic differences in the validity of a linear scale of innate soil productivity. Journal of Soil and Water Conservation, May-June:379-382.

Kirby, K.C. 1996. Map*Factory Module Reference. ThinkSpace Inc., London Ontario, Canada.

Lortie, B.E., E. vanHuyssteen, and Y. Landriault. 1995. Practical applications of GIS to mine environmental studies. Hynes, T.P. and M.C. Blanchette (Eds.) In: Proceedings of Sudbury

'95 - Mining and the Environment. CANMET, Ottawa, Volume 3, 1151-1160.

Neill, L.L. 1979. An evaluation of soil productivity based on root growth and water depletion. M.S. Thesis, Univ. of Missouri, Columbia.

USGS. 1968. Hazen West, North Dakota. Map 1:24,000, U.S. Geological Survey, Denver, Colorado.

Wilhelm, F.J. 1978. Soil Survey of Mercer County, North Dakota. U.S. Department of Agriculture, Soil Conservation Service.