BARE-PLOT ANALYSIS AS A TOOL FOR DIAGNOSING IMPEDIMENTS TO REVEGETATION AT SURFACE COAL MINES[1]

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Abstract. We studied bare plots on reclaimed surfaces at four coal mines in northwestern New Mexico in order to identify impediments to the germination, growth, or survival of plants. "Bare plots" were areas of approximately 30 m^2 which were relatively lacking in vegetation compared to the surrounding reclaimed surface. Twelve soil properties were analyzed for each bare plot and compared to the values for soil taken from a nearby plot which was similar in slope and aspect, but which had significantly greater coverage and biomass of perennial grasses. There were between four and twelve pairwise comparisons at each mine. Pairwise T-tests were used to identify soil properties which differed significantly between the sets of bare plots and well-vegetated plots at each mine.

None of the twelve measured soil properties were significantly associated with bare plots at all four mines, suggesting that different soil characteristics influence revegetation at different mines, even over a relatively small geographic distance. Soluble sodium was important at two mines; soluble magnesium, pH, electrical conductivity, and soil texture were all important at one of the four mines.

In light of other studies in our program of research at these mines, bare-plot analysis seems to be a fairly quick, easy, and accurate method for casual diagnosis of possible impediments to reclamation. However, it is important (1) to maximize differences in the amount of vegetation between bare plots and control plots, and (2) to sample as many pairs of plots as possible, with six being the minimum. Even when these precautions are taken, the results of bare-plot analyses should be used strictly for the identification of environmental parameters for additional research, not for the immediate reformulation of reclamation policy.

INTRODUCTION

The traditional approach to the study of reclamation has been to conduct glasshouse or field experiments testing the effectiveness of various reclamation practices (Aldon 1986). However, the experimental approach fails to take advantage of the potential information represented by the many acres of mined land which have been reclaimed in the past. In an effort to use this information resource, we have conducted a variety of *post hoc* analyses on revegetated surfaces at four coal mines in the San Juan Basin, an arid to semi-arid physiographic province in northwestern New Mexico.

Of particular interest in this study are the properties of spoil or soil that may have impaired the germination, growth, or survival of perennial grasses, which are the principal species used for revegetation at the four mines. The specific objectives are to determine: (1) which properties

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are detrimental to the success of revegetation at each of the four mines; and (2) if the same soil properties are important to revegetation at all four mines, which are located across a relatively small geographic distance in a relatively discrete, environmentally homogeneous province.

To address these objectives, we used "bare-plot analysis" wherein soil properties at relatively unvegetated areas on reclaimed surfaces are compared to soil properties at nearby, more successfully revegetated areas. The results of these pairwise comparisons are interpreted to identify soil characteristics which may be directly impeding revegetation at the bare plots and which may be limiting the revegetation potential at reclaimed surfaces across the mine.

The context for this study presents an excellent opportunity to evaluate the effectiveness of bare-plot analysis as a diagnostic tool in reclamation science. This is because the bare-plot analysis is part of a larger research program wherein many samples were collected and several analytical approaches were used to identify which ecological factors have influenced the outcomes of past reclamation efforts at the mines. Thus, the findings for the larger, encompassing database can serve to contradict or corroborate the results of bare-plot analyses. The overall research program, along with appendices describing study plots and soil data, are in Reith and Potter (1983), and a detailed interpretation of all soils data is in Reith and Potter (1985).

THE ENVIRONMENT OF THE SAN JUAN BASIN AND THE MINES

The San Juan Basin is the principal coal-bearing region in New Mexico. Figure 1 illustrates the Basin including the four mines in the study, the coal-bearing geologic strata, and the sites where mining is planned or commencing. Coal in the Basin often occurs in association with marine shale strata. Soils derived from these marine shales tend to have low permeabilities to water and high concentrations of salts, both of which pose problems to reclamation (Gould et al. 1975).

The four mines in this study occur at opposite ends of the range of environmental variability in the Basin. Mines A and B are at a relatively low elevation, where conditions are hotter and drier than at Mines C and D. Figure 1 summarizes important environmental data for the mines.

METHODS AND MATERIALS

The study began with the identification of bare plots, which are areas of approximately 30 square meters where vegetation was conspicuously lacking compared to the condition of the surrounding reclaimed surface. For each bare plot, we found an adjacent "control" plot with significantly greater biomass and basal cover of perennial grasses, but with identical slope and aspect. The idea behind the comparison was to control for the effects of management history and environmental factors other than soil properties. Revegetation is influenced by factors such as post-mine topography, age since seeding, and application rates of seed, fertilizer, irrigation, topdressing, and other surface amendments (Reith and Potter 1983). The variability associated with these and other potentially-confounding factors is minimized by locating bare plots and control plots very close to each other, on portions of reclaimed surfaces with similar exposures (slope and aspect) and management histories.

Figure 2 illustrates how soils and vegetation data were collected at each plot. A stake was placed at the middle of the plot, where a shovel was used to collect about 2 kg of soil or spoil from the top 15 cm. This material was analyzed for the following parameters (references describe the analytical procedures used): volumetric stoniness (Reith and Potter 1985); bulk density (Blake 1965); texture (Bouyoucos 1926); pH; electrical conductivity (EC); sodium adsorption ratio (SAR); and soluble sodium (Na), calcium (Ca), and magnesium (Mg) (U.S. Salinity Lab 1954).

Vegetation at each plot was quantified using quarter-square-meter quadrats randomly located along each of eight 3-m long rays originating at the central stake (fig. 2). The percent basal cover and standing biomass of perennial grasses were ocularly estimated in each quadrat. Biomass estimates were calibrated to kg/m^2 by clipping and dry-weighing the grasses in one quadrat per plot. Estimates were regressed against dry weights to predict actual biomasses ["double sampling" (Bonham et al. 1980)]. Standing dead material (carryover) was included in biomass estimates because carryover stabilizes soils and reflects desirable underground biomass (roots and rhizomes). Plant species were

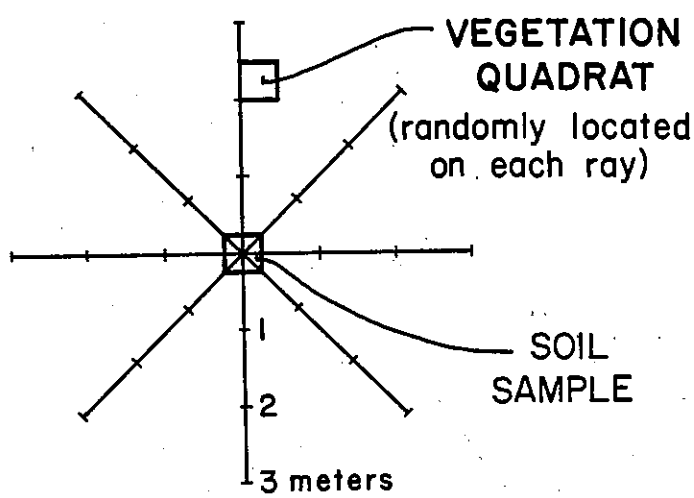
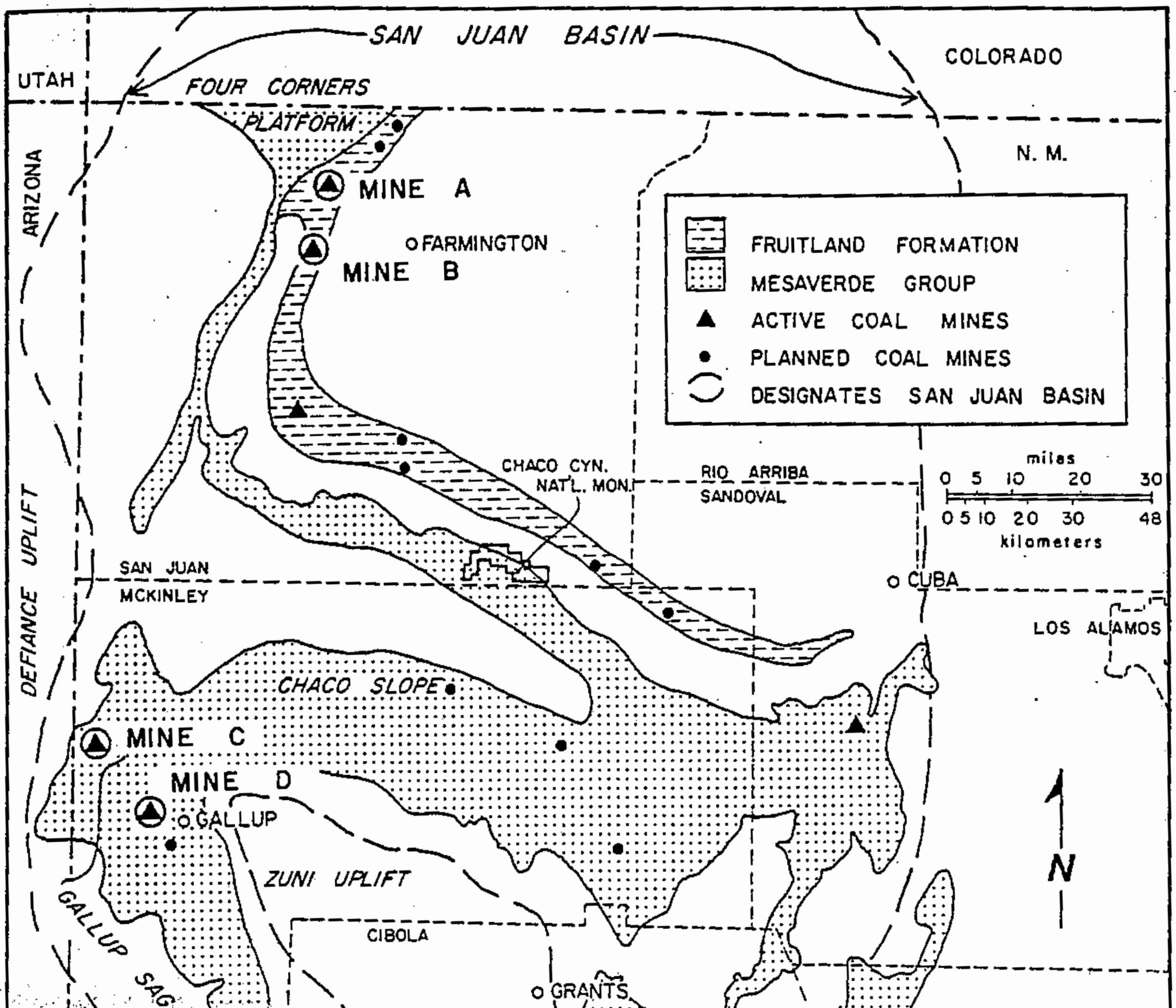


Figure 2.--Sampling array for each bare plot and control plot.



	A	B	C	D
MEAN ANNUAL PPT. (cm)	17.8	14.5	29.0	29.0
MEAN ANNUAL TEMP. (°C)	11.2	10.6	8.9	9.4
MEAN WIND VELOCITY (kph)	9.6	16.1	17.7	16.6
PREVAILING WIND DIRECTION	W	WSW	WSW	WSW
GROWING SEASON (days)	161	151	135	
ELEVATION (meters)	ca. 1600	1590-1700	ca. 2100	1950-2050
NATIVE SOILS	Calciorthids Torripsamments Natargids	Calciorthids Torriorthents Natargids	Haplargids Torrifluvents Camborthids	Haplargids Torrifluvents Camborthids
NATIVE VEGETATION (Trees & Shrubs)	Mixed saltbushes Broom Snakeweed Winterfat	Mixed saltbushes Rabbitbrushes Broom snakeweed Winterfat	Two-needle pinyon Junipers Big sagebrush Rubber rabbitbrush Black greasewood	Big sagebrush Rubber rabbitbrush Fourwing saltbush Black greasewood
(Grasses)	Galleta Alkali sacaton Sand dropseed Indian ricegrass	Galleta Alkali sacaton Sand dropseed Indian ricegrass	Western wheatgrass Blue grama Galleta Sideoats grama	Western wheatgrass Blue grama Galleta Alkali sacaton

Figure 1.--Map of the San Juan Basin in northwestern New Mexico, along with environmental data for the four surface coal mines.

not identified. Instead, perennial grasses were used as a general indicator of revegetation success, specifically the success in germinating and establishing a stabilizing vegetative cover, which is the primary reclamation goal at most mines in the arid Southwest.

The percentage of surface covered by rocks with diameters greater than 2 mm was also ocularly estimated in quadrats at each plot. All vegetation and soil sampling was done during the summer of 1982 on surfaces ranging between two and eight years old. Recently-seeded surfaces were disregarded because vegetation had less time to respond or equilibrate with soil conditions.

Statistical Methods

For a bare-plot/control-plot pair to qualify for the analysis, the bare plot must have significantly less vegetative biomass and basal cover than its control plot. Two-tailed T-tests (Sokal and Rolfe 1969) were conducted at the 0.05 level to identify qualifying pairs. T-tests require data to be approximately normally distributed, so all cover (percentage) data were transformed using the square root of the arcsin, as recommended by Sokal and Rolfe (1969). Then pairwise two-tailed T-tests were used to identify which soil properties, if any, differed significantly between the bare plots and control plots at each mine. Again, all percentage data were transformed prior to application of the T-test.

RESULTS AND DISCUSSION

Interpreting the Histograms

Figure 3 presents the results of the pairwise comparisons. The positions of the bars relative to the axes indicate the conditions of the soils at control plots versus bare plots. For instance, if the bar for electrical conductivity extends fully below the abcissa, as it does at Mine A, then this means that 100% of the control plots had lower ECs than their bare-plot counterparts. The position of the bar for sodium adsorption ratio at Mine A indicates that 83% (10 out of 12) of the control plots had lower SARs. These results suggest that high concentrations of soluble salts (represented by EC), including colloidally adsorbed sodium (represented by SAR), impede the revegetation of soils and spoils at Mine A.

The shading of bars indicates the results of the pairwise two-tailed T-tests. Bars which are fully shaded, such as the EC and SAR bars at Mine A, indicate significant differences at the $p<0.05$ level. Control plots have significantly lower ECs and SARs than bare plots at Mine A. Bars which are hatched indicate differences at the $p<0.10$ level, a level that represents a lower degree of statistical confidence in the significance of the relationship between control plots and bare plots.

Results at Each Mine

Mine A

In the above examples, we indicated that soluble salts, including sodium, are important negative factors at Mine A. Electrical conductivities frequently exceeded 4 mmhos, especially at bare plots; this EC value is considered the level above which the germination and growth of plants is

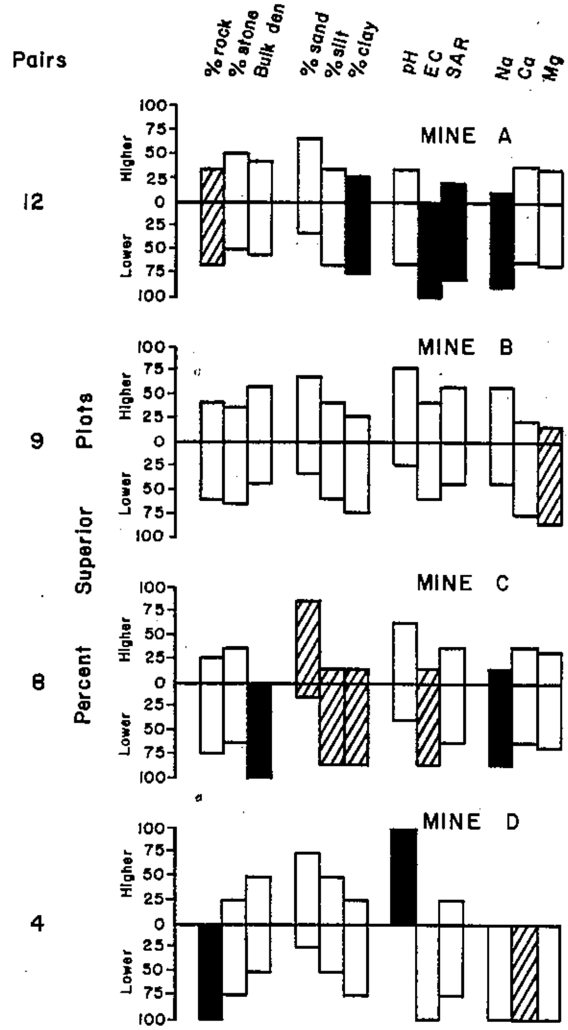


Figure 3.--Results of bare-plot analysis. Soil properties are listed across the top. Bars under each column heading indicate the percentage of control plots which had higher or lower values than the bare-plot counterparts. Black bars indicate differences significant at the $p<0.05$ level and hatched bars indicate differences at the $p<0.1$ level.

potentially inhibited (U.S. Salinity Lab 1954), although reclamation species are less sensitive to soil salts than are crops. High concentrations of soluble salts affect plants by limiting water availability, specifically by osmotically retaining water in the soil [10]. Of the three soluble salts measured at Mine A (Na, Ca, and Mg), sodium seems to be most adverse. Besides its osmotic action, sodium may be toxic to plants (Brady 1974), but more importantly, it may saturate and deflocculate soil colloids, including clays. The result is a loss of soil structure, causing reduced permeability to water and air, both of which are critical to the growth of vegetation (U.S. Salinity Lab 1954). The degree of saturation of soil colloids by sodium is represented by SAR, which has already mentioned to be an important soil parameter at Mine A.

The percentage of clay in spoils at Mine A was also a significant negative factor. Clay particles retain more water in the soil than do sand or silt particles, thus withholding moisture from plants, an effect which can be very undesirable where precipitation is infrequent. This source of adversity is compounded where clays are predominantly smectite, which swells when moistened (Potter et al. 1985), causing surfaces to seal and resist the infiltration of rain or irrigation water.

We interpret the histogram for Mine A to represent the interacting effects of a multiplicity of soil factors--soluble salts, sodium, and clay--on the germination, growth, and survival of plants. Revegetation at Mine A is largely successful, with plant basal coverages equal to or exceeding the values for adjacent native plant communities (Reith and Potter 1983); however, the overall quality of revegetation will be increased and the frequency of bare spots decreased if these soil adversities are mitigated by adjustments in the reclamation program. For instance, clay-rich sodic spoils might be covered by a deeper mantle of sandy, relatively non-sodic topdressing. The decision to implement such a measure should consider costs and benefits and should be made by the mine or appropriate regulatory authority. Bare plot analysis has simply served to diagnose the probable sources of adversity and to suggest mitigating actions.

A final factor of importance to Mine A was the percentage of rocks on the surface, which was significantly lower (at the 0.10 level) at control plots. Rocks could not have directly impeded vegetative growth, because they never covered more than five percent of the soil surface. Instead, rocks were associated with outcrops of underlying sodic spoil through the mantle of sandy topdressing. Thus, the rocks were not themselves responsible for inhibition, but were correlated with inhibitory factors such as the salt and clay content of the soil. Data from bare plot analyses, as from most analytical methods, must be carefully assessed before developing findings.

Mine B

Compared to Mine A, a few soil properties were important in the bare-plot analysis at Mine B. In fact, soluble magnesium content was the only factor for which bare plots significantly differed from control plots, and this difference was significant only at the 0.10 level. Magnesium concentrations averaged much higher at Mine B than at any of the other three mines in the study. Concentrations on one uniformly barren surface exceeded 300 parts per million. The U.S. Salinity Laboratory (1954) states that magnesium may be toxic to vegetation, but they specify no threshold. Such toxicity may be alleviated by applications of calcium.

The lack of significant relationships at Mine B suggests that soil properties play a minor role in determining the outcome of reclamation and that factors such as post-mine topography, age, and management history are more important. However, our analysis of a much larger database at Mine B indicates that this is not true. Multiple regression analyses indicated that soil properties explained about 15 percent more of the variation in revegetation success at Mine B than at Mine A (Reith and Potter 1985). We think the lack of ability of bare-plot analysis to identify these inhibitory factors is because of the uniformly unfavorable conditions which exist on most older surfaces at Mine B. Salinity, sodicity, and other soil adversities are sufficiently widespread on these surfaces that revegetation has been generally, not just locally, impeded. This results in large surfaces where the overall vegetative cover averages less than two percent. The resolution between bare and vegetated patches on such surfaces is inadequate for the bare-plot analysis to diagnose impediments to revegetation.

Mine C

Mine C has the highest elevation and the most precipitation, resulting in the greatest average covers (6 to 16 percent) and biomasses (95 to 112 kg/m^2) of perennial grasses. The most important soil property is bulk density, which was lower at all eight control plots. High bulk densities inhibit vegetation by restricting the infiltration of water and aeration of roots. However, this relationship is difficult to interpret with respect to cause and effect. On one hand, excess soil compaction may well inhibit vegetation, but on the other hand, the lack of vegetation may explain why bulk densities are high. Plants gradually reduce soil compaction by the penetrating action of roots and the addition of organic matter (Brady 1974). In either case, revegetation at Mine C will likely benefit from measures to reduce soil compaction, for instance, by minimizing passages of heavy equipment.

Another significant negative factor at Mine C was soluble sodium, which probably acts in a similar inhibitory fashion as at Mine A. Since electrical conductivity is also a significant negative factor (at the 0.10 level), the action of sodium may be due more to osmotic retention of soil moisture than to deflocculation of soil colloids, which is represented by sodium adsorption ratio. Soil texture was also important at Mine C, with clay and silt being unfavorable and sand being favorable, as ingredients in the substrate for revegetation.

Mine D

Mine D has the newest and smallest reclamation program of the four mines, so our sample size was small and all plots were on young surfaces (two or three years old) where grasses have had little time to grow and become established. The small sample size (four pairs) limits the confidence of our interpretation of the results in figure 3. All four bare plots had lower pH values than their counterpart control plots; an unexpected result since all pHs at Mine D were above 7.0. Ordinarily, one expects less vegetation on more alkaline soil. All four bare plots also differed from control plots in several other parameters including the percentage of surface rock, electrical conductivity, and soluble sodium, calcium, and magnesium. However, these parameters had differing levels of significance due to the behavior of the T-test with such small samples. We attribute the differences between control plots and bare plots to the fact that the bare plots were on outcrops of saline, carbonaceous shale, where the overlying mantle of topdressing had not been adequately applied or had washed away. Control plots were on areas where topdressing was at least 6 cm deep, resulting in improved germination and growth. In any case, our experience at Mine D demonstrated that more than four pairs of samples are needed for a clear and confident interpretation of the results of bare-plot analysis.

Intermine Comparisons

Mines A and C were similar with respect to the soil properties which appear important to revegetation, or at least which appear to explain the presence of bare spots on reclaimed surfaces. Electrical conductivity, soluble sodium, and soil texture (particularly clay content) are all significant negative factors. At Mine B, soluble magnesium is the only significant factor; the importance of this ion is highly site-specific. Soil pH is a significant positive factor at Mine D, a site-specific finding that we cannot fully explain, although all interpretations at Mine D are somewhat qualified by the small sample size there.

One commonality among the histograms in figure 3 is the relative position of the bars for soil texture (the percentage of sand, silt, and clay). At all four mines, the percentage of sand is generally higher, and clay lower, at control plots relative to bare plots. Based on our entire research program at surface mines in the San Juan Basin, we have concluded that sand is generally a favorable ingredient in spoils or topdressings for revegetation. This is because sandy soils have better water-related properties than do clay-rich soils in climates where precipitation is infrequent. Furthermore, sandy soils are less likely to accumulate potentially inhibitory levels of soluble salts, including sodium.

SUMMARY AND CONCLUSIONS

As a diagnostic tool, bare-plot analysis were performed effectively at Mines A and C, where the results were easy to interpret and were consistent with the findings of our larger, encompassing research program (Reith and Potter 1983, 1985). Reclaimed surfaces at these mines were relatively successfully revegetated, with plant coverages and biomasses that compared favorably with adjacent native vegetation communities. The resolution between bare-plots and well-vegetated control plots was large at these mines, which favored the ability of bare-plot analysis to identify responsible factors.

Bare-plot analysis was less successful at Mines B and D. At Mine B, we think this is because soil-related adversities were so widespread as to substantially inhibit revegetation across the mine. This decreased the resolution between bare plots and not-so-well vegetated control plots. At Mine D, the problem was insufficient sample size, due in part to the lack of reclaimed surfaces to sample.

In conclusion, bare-plot analysis works best on mines with relatively large reclaimed surfaces that have some successfully revegetated areas. A clear contrast between bare plots and control plots is essential to the diagnostic power of the analysis. Still, bare-plot analysis is a casual, post hoc test compared to scientific experimentation, so the results must be interpreted carefully and used only to identify factors for further study. Under these conditions, we advocate bare-plot analysis as a useful tool for understanding the results of past reclamation.

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LITERATURE CITED

Aldon, Earl F. 1986. The experimental approach and role of a government experiment station in reclamation research. In Principles and methods of reclamation science. C. C. Reith and L. D. Potter (eds), University of New Mexico Press, Albuquerque, NM (in press).

Blake, G. R. 1965. Bulk density. In methods of soil analysis. C. A. Black, D. D. Evans, J. L. White, L. E. Ensminger, and F. E. Clark (eds), American Society of Agronomy, Madison, WI.

Brady, Nyles C. 1974. The nature and properties of soils. MacMillan Publishing Company, New York, NY.
Bonham, Charles D., Larry L. Larson, and A. Morrison. 1980. A survey of techniques for measurement of herbaceous and shrub production, cover, and diversity on coal lands in the west. Uniscale report to the Office of Surface Mining, Denver, CO.
Bouyoucos, G. J. 1926. Estimation of colloidal material in soils. Science 64:362. see link below
Gould, Walter J., D. Rai, and P. J. Wierenga. 1975. Problems in reclamation of coal mine spoils in New Mexico. p. 107-121. In Practices and problems of land reclamation in Western North America, M. K. Wali (ed), University of North Dakota Press, Grand Forks, ND.
Potter, Loren D., Robert C. Reynolds, Jr., and Ellen T. Louderbough. 1985. Mancos shale and plant community relationships: I. Field observations; II. Analysis of shale, soils, and vegetation transects. J. Arid Environments (in press).
Reith, Charles C., and Loren D. Potter. 1983. An ecological analysis of vegetational reclamation at five surface coal mines in New Mexico. Report to the Office of Surface Mining, Denver, CO.
Reith, Charles C., and Loren D. Potter. 1985. Geographic variation in soil-based models of reclamation success. J. Arid Environments 8:223-234.
Sokal, R. R. and F. J. Rolfe. 1969. Biometry. W. H. Freeman and Company, San Francisco, CA.
U.S. Salinity Laboratory. 1954. Diagnosis and improvement of saline and alkali soils. Agricultural Handbook No. 60, USDA Government Printing Office, Washington, DC.

http://dx.doi.org/10.1126/science.64.1658.362