THE USE OF AN ELECTROMAGNETIC INDUCTION SOIL CONDUCTIVITY METER TO CONDUCT PRE-SALVAGE SURVEYS OF SOIL SALINITY AT THE ROSEBUD MINE[1]

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Abstract.--The suitability of soils for salvage and reclamation can be limited by the level of soluble salts. In Montana, surface soil materials with electrical conductivities (EC) in excess of 4 mmhos/cm, or subsoil materials with conductivities in excess of 6 to 8 mmhos/cm are considered unsuitable by the regulatory agency. Due to the high variability of soil EC, it becomes necessary to monitor EC levels prior to salvage. Pre-salvage monitoring of soils for soluble salts by conventional sampling and laboratory analysis can be expensive and time consuming.

A method for conducting pre-salvage surveys of soil salinity is presented which makes use of an above-ground electromagnetic induction soil conductivity meter manufactered by Geonics Limited. The instrument facilitates rapid and extensive coverage of the landscape and field readings of EC, which correlate well with actual soil EC, can be used to adjust salvage depths.

INTRODUCTION

The Rosebud Mine is a large surface coal mine located near Colstrip in southeastern Montana. The mine site soils range from nearly level Aridisols to steep Entisols on dissected sedimentary bedrock plains and hills and are salvaged according to quality and reclamation suitability criteria. Aridisols, and in isolated cases, Mollisols, are salvaged in two lifts and used to reclaim grassland, sagebrush-grassland, upland deciduous tree/shrub, and riparian coummunities and cropland. Texture, depth to $CaCO^3$, organic matter and soluble salts are the primary quality parameters used as criteria for the salvage of 0.5 to 1.0 feet of first lift surface soil. Texture, depth to massive structure, and soluble salts provide a basis for the salvage of an additional 1.0 to 1.5 feet of second lift subsoil material. Ponderosa Pine and Skunkbush Sumac communities are reclaimed with a single two foot lift of skeletal material salvaged from Entisols which have been identified as suitable for this purpose.

Soil parameters such as texture, pH and horizon thickness are not highly variable within series and the baseline soil survey can be used effectively as a guide in the salvage operation. However, parameters such as soluble salts can be highly variable within series which can be attributed in part to topographic variation. In Montana, surface soil materials with soluble salt or electrical conductivity (EC) levels in excess of 4 mmhos/cm and subsoil materials with conductivities in excess of 6 to 8 mmhos/cm are considered unsuitable for salvage. Due to high intraseries variability, it becomes necessary to monitor EC levels prior to salvage to insure that materials of suitable quality are used for reclamation.

Pre-salvage monitoring of soils for soluble salts by conventional sampling and laboratory

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analysis methods can be very expensive and time consuming.

A method for conducting pre-salvage surveys of soil salinity is presented which makes use of the EM38, above-ground electromagnetic induction soil conductivity meter manufactered by Geonics Limited. The design, theory and use of the EM38 for salinity surveys has been well documented (1, 2, 3, 4, 5, 6, 7, 8, 9, 10) and will not be addressed in detail. However, it is important to point out that conductivity readings taken with this instrument have correlated well with readings from more conventional field instruments or field samples over a range of moisture and clay contents. The greatest recognized advantage of the EM38, is that an unlimited number of readings can be taken over a large area in a short time. Although the EM38 is a technically advanced field instrument, we can maintain utility by keeping applications and interpretations as simple as possible. A technique for the calibration and utilization of the EM38 for field surveys of soil salinity developed by researchers in North Dakota (9), where the instrument has been extensively used, provided us with the methodology format presented in this paper.

METHODS AND MATERIALS

Samples were collected from 12 soil pedons to a depth of four feet in one-foot intervals. The soil pedons were chosen on the basis that they would represent a minimum to maximum range in salinity typical for Rosebud Mine soils. The samples were analyzed for pH and EC from saturation paste extracts, and percent sand, silt and clay by Northern Engineering and Testing, Inc., of Billings, Montana.

Readings of apparent soil electrical conductivity (EC_a) were taken with the EM38 at each pedon in both the vertical (V) or upright position, and horizontal (H) position or with the instrument lying flat on its side. In the H position, the instrument is very responsive to near surface EC (0-2 feet). In the V position the instrument senses EC at greater depths (0-6 feet). In order to relate EC_a readings obtained with the EM38 with actual saturation paste conductivity levels (EC_e) obtained from samples, the EC_e values must be adjusted or weighted according to the response of the EM38 as a function of depth. The contribution of soil conductivity below a depth z, in the V position is calculated from the expression:

$$R_V(z) = (4z^2 + 1)^{-\frac{1}{2}} \qquad (1)$$

And in the H position:

$$R_H(z) = (4z^2 + 1)^{\frac{1}{2}} - 2z \qquad (2)$$

Where R_V and R_H are response in the V and H position, respectively, and z is the depth (m)/dipole spacing (m). The dipole spacing for the EM38 is one meter. The contributions of each one-foot depth increment for a soil pedon to a depth of four feet is calculated for the V and H positions using equations 1 and 2, and presented in Table 1.

Table 1.--Depth Response and Weighting Factors For The EM38 in the V and H Positions

Depth Feet	R_v	Rv Weighting Factor	R_h	RH Weighting Factor
0-1	0.14	0.22	0.43	0.54
1-2	0.22	0.34	0.21	0.26
2-3	0.16	0.25	0.10	0.13
3-4	0.11	0.17	0.06	0.08
TOTALS	0.63	1.00	0.80	1.00

Although the meter is responsive to depths greater than four feet, particularly in the V position, we calculated weighting factors for each one-foot increment by dividing the sum of the depth response values into each individual value which gives an adjusted 100 percent response for the top four feet. The weighting factors are also presented in Table 1. A weighted EC_e value (EC_w) can then be calculated by multiplying EC_e values for each depth increment by the appropriate weighting factor. The sum of the EC_w values gives a single value of soil salinity which can be correlated with ECa values obtained from the EM38. Using the procedure described, EC_w values were calculated for each soil pedon, and simple linear regression analysis performed using EC_w as the dependent variable and EC_a as the independent variable for both V and H positions. The results of the regression analysis provided:

$$EC_w = 0.1026\ EC_a - 2.0401 \qquad r = 0.70 \qquad (3)$$

for the instrument read in the V position, and

$$EC_w = 0.1084\ EC_a - 1.6074 \qquad r = 0.70 \qquad (4)$$

For the instrument read in the H position where EC_w is the predicted weighted conductivity (mmhos/cm) and EC_a is the apparent electrical conductivity (mmhos/m) obtained from the instrument.

DISCUSSION

Readings taken with the EM38 in the V and H positions provides a two-layered earth assessment of a given soil profile. In other words, if the V reading is greater than the H reading, then the soluble salts are concentrated lower in the profile. If the H reading is greater than the V reading, the salts are concentrated in the near surface zone, a situation which is not typically encountered in the native soils at the Rosebud Mine.

We developed a set of guidelines for using the EM38 in conjunction with presalvage soil evaluations based on the instrument's response to soil salinity, our knowledge of the soils, and DSL guidelines. This information has been incorporated into a single graph of equations 3 and 4 (Figure 1) which can be easily used in the field. Since approximately 60% of the weighted response comes from the surface 2-feet in the H position, and maximum total salvage depth for our soils is 2-2.5 feet, H position readings will provide the best indication of salvage suitability. However, the combination of H and V positions readings are needed to evaluate the depthwise distribution of salts. As illustrated in Figure 1, total salvage depths are adjusted according to the ranges in EC_a and predicted EC_w values.

A considerable amount of EC data have been collected from Rosebud Mine site soils over the years in conjunction with conventional pre-salvage sampling and analysis. The salinity profile for soils which tend to contain elevated levels of soluble salts is typified by EC levels and clay contents which increase with depth. Exceedance levels for EC have rarely been observed above 12 to 18 inches below the surface. This is the case even for soils which occupy drainage or depressional positions. The characteristics of the salinity profiles observed is probably largely a function of soil texture and precipitation which tends to keep soluble salts leached from the surface, and accumulation primarily restricted to subsurface zones. Exceptions are eroded, exposed shale and clay faces where soluble salts may outcrop, or where a high water table may influence the accumulation of salts near the surface. Series at the mine identified as having subsoils which may contain soluble salt levels in excess of allowable limits and subject to salvage depth adjustment include Lonna (fine-silty, mixed Borollic Camborthids), Yamac and Cooers (fine-loamy, mixed Borollic Camborthids), Kobar (fine, montmorillinitic Borallic Camborthids), Vanstel (fine-silty, mixed Borollic Haplargids), Havre (fine-laomy, mixed calcareious frigid, Ustic Torriorthents) and Savage (fine montmorillinitic Typic Argiborallos).

CONCLUSIONS

Approximately 600 acres of soil have been salvaged and reconstructed at the Rosebud Mine since use of the EM38 was initiated. Sampling and analysis conducted on these redistributed surface and subsurface materials has provided verification that the EM38 is an effective monitoring device. Soluble salt levels have been within acceptable limits. One or two hours of monitoring per year with the EM38 for soluble salts has replaced a pre-salvage sampling and analysis program that used to be a labor intensive, full-time job. Use of the EM38 for conducting pre-salvage salinity surveys at other mines where salt-affected soils are more of a concern than we have experienced, should prove to be of even greater value.

Before the EM38 can be used effectively, it must be correlated as described, with soils on a site or mine specific basis. Additional pedon sampling of areas where intermediate readings are encountered, and periodic correlation of data, may improve the realiability of instrument readings.

Links to papers on last page.

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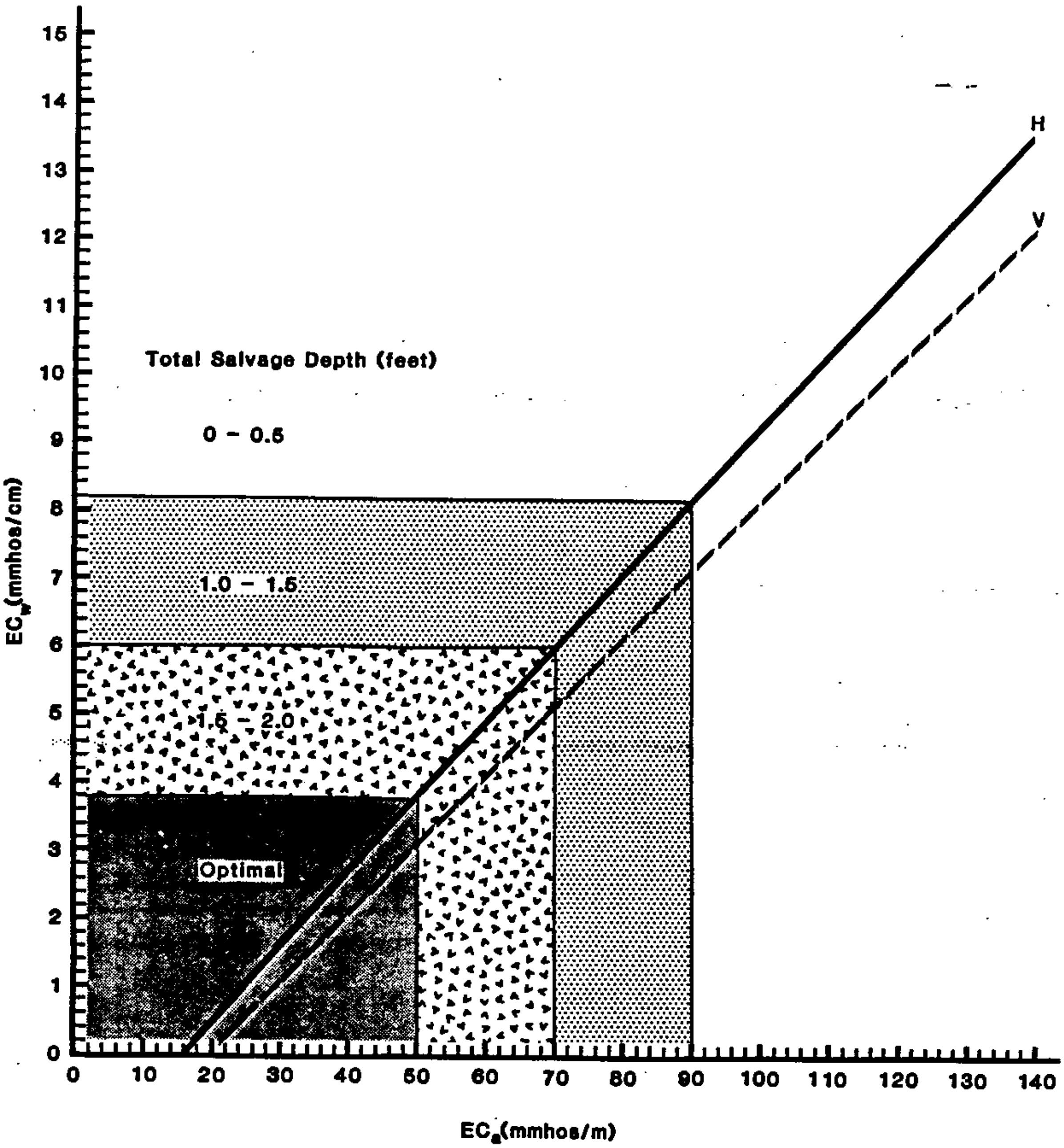

Figure 1.--The relationship between EC_a and EC_v for the EM38 read in the V and H positions and corresponding adjustments to salvage depth

Corwin, http://dx.doi.org/10.2136/sssaj1982.03615995004600030014x
Corwin, http://dx.doi.org/10.2136/sssaj1984.03615995004800020011x
Dejong http://dx.doi.org/10.2136/sssaj1979.03615995004300040040x

Rhoades http://dx.doi.org/10.2136/sssaj1981.03615995004500020006x
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