PRECISION MANAGEMENT OF CATTLE FEEDLOT WASTE

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ABSTRACT

Open-lot cattle feeding operations face challenges in control of nutrient runoff, leaching, and gaseous emissions. This report investigates the use of precision management of saline soils as found on 1) feedlot surfaces and on a 2) vegetative treatment area (VTA) utilized to control feedlot runoff. An electromagnetic induction soil conductivity meter was used to collect apparent soil electrical conductivity (EC_a) from a feedlot pen and a research VTA at the U.S. Meat Animal Research Center, Clay Center, NE. Soil samples were taken from each of the sites. Results from the feedlot site indicate correlations between EC_a and associated volatile solids ($r^2 = 0.77$). Volatile solids were closely associated with nutrients ($r^2 = 0.92$ for total N and $r^2 = 0.80$ for total P). A program, ESAP, developed by the Soil Salinity Lab at Riverside, CA was used to analyze the VTA and to develop a model associating EC_a to Cl^-. The VTA was analyzed and Cl^- (an indicator ion for feedlot runoff) was found to be associated with EC_a (r^2=0.86). The ESAP program provided estimates of the primary variable distribution across the VTA based on soil sample data combined with high density soil conductivity (EC_a) data. Maps of nutrient distribution were produced as well as a table that lists nutrient loading with percent contributing area. Identifying areas of excessive nutrient buildup on feedlots and runoff control areas allows site-specific management, improvement of system performance, and sustainability while reducing nutrient losses to the environment.

Keywords: Electromagnetic induction, Exchangeable Sodium Analysis Program (ESAP), feedlot, multiple linear regression, vegetative treatment area (VTA)

INTRODUCTION

Open-lot cattle feeding operations face challenges in control of nutrient runoff, leaching, and gaseous emissions. Producers are being pressed to provide comprehensive nutrient management plans for nitrogen and phosphorus in order to obtain valid operating permits. Methods have been devised to address nutrient issues at different points in the waste management system. There are several options for nutrient runoff management once the effluent leaves the feedlot following precipitation (Woodbury et al., 2003). Nutrient leaching from the feedlot surface is not a concern for surfaces that are tightly packed, and with water tables far from the surface. However, leaching of nutrients from runoff storage facilities is a concern (Ham, 2002). Gaseous emissions from feedlot soils are being quantified (Harper et al., 1999) but determining spatial distribution is difficult.

A major focus of feedlot nutrient management is the feedlot surface. Assessing and removing nutrient concentrations directly from the feedlot surface presents an option for minimizing environmental impact. Remedial steps taken early in the waste management system increase the effectiveness of treatment 'downstream' in the process. Precision harvesting promises reduction in greenhouse gas production, odor production, nutrient content in liquid runoff, and a reduction in subsequent nutrient leeching. Furthermore, loading and hauling feedlot manure can become a significant fixed cost (Tetra Tech, Inc., 2004); minimizing the number of loads and maximizing the nutrient concentration leads to lower nutrient transport costs.

Another aspect of feedlot nutrient management is dealing with precipitation runoff. Alternative technologies offer advantages by reducing or eliminating long-term storage and recycling of nutrients. These technologies often include a settling basin to retain suspended particles (hydraulic retention times vary from hours to days depending on the discharge design) and a vegetative treatment area (VTA) for liquid distribution and nutrient uptake. Basic systems are gravity driven, eliminating the need for pumps and the associated maintenance and management. The VTA is typically a hayfield that utilizes the nutrient laden liquid from the feedlots that has discharged from the settling basin. Recently, the EPA has indicated that alternative control technology could be used (Koelsch et al., 2006) if the confined animal feeding operation demonstrated equivalent or superior environmental protection compared to holding ponds. Computer models (Wulf and Lorimor, 2005) have been used to compare holding ponds and alternative systems that incorporate a VTA on the basis of liquid discharge from each system. Although these models can predict VTA occurrence and amount of discharge, they cannot evaluate distribution performance within the VTA. Knowledge of this distribution is critical for proper management to ensure sustainability. Typically, monitoring of a VTA is limited to flow monitoring at discharge points to establish basic criteria of discharge events from the VTA. Determination of performance and sustainability of a VTA requires spatial methods to identify nutrient distribution over the surface, as well as movement within the soil.

Methods of identifying manure buildup must rely on characteristics that are specific to the manure. Beef cattle manure contains calcium, chloride, iron magnesium, nitrogen, phosphorus, potassium, sodium, sulfur and other trace minerals which result in average EC values in the range of 3.7 dS/m (Gilbertson, 1975). Soil may have average EC values of 0.1 to 1.1 dS/m, ranging from non-saline/coarse soil to very saline clay (Smith and Doran, 1996). Accumulation of beef manure on feedlot surfaces has been shown to elevate soil EC. Electromagnetic induction (EMI) measurements of electrical conductivity have demonstrated sensitivity to areas of high nutrient levels (Eigenberg et al., 1996). Also, precipitation runoff from feedlots has high salt content (Eigenberg et al.,

2006) and soil conductivity in runoff control areas can be linked to associated ions such as Cl^-.

Spatial estimates on a VTA can be made using numerous soil samples supplemented by high density covariate data such as soil conductivity. Soil conductivity has been shown to be strongly correlated to various salts that are commonly found at feedlot cattle waste management sites (Eigenberg and Nienaber, 1998a); chloride is one ion that is strongly associated with EMI measurements at these sites (Eigenberg et al., 1998b). Traditionally, soil conductivity and specific ions such as Cl^- are then spatially interpolated using methods such as cokriging (Isaaks and Srivastava, 1989). An alternative (ESAP) to this sampling-intensive protocol has been developed by the United States Salinity Laboratory at Riverside, CA (Corwin and Lesch, 2005; Lesch, 2005; Lesch et al., 1995a, b). ESAP has been applied to agricultural fields in southern California to describe salinity patterns in those fields (Lesch et al., 1995a). This approach combines high density electromagnetic induction (EMI) soil conductivity survey data with an associated low density soil sampling protocol to calibrate a suitable linear regression model. This regression based sampling and modeling approach is incorporated into the USDA-ARS ESAP salinity software package[1] (Lesch et al., 2000). The ESAP software package represents a more cost-effective alternative to the commonly recommended (and sample intensive) geostatistical modeling techniques for mapping salt and/or nutrient distributions within a VTA, provided the underlying modeling assumptions are met.

OBJECTIVE

The objective of this work is to 1) evaluate a system that will evaluate feedlot surface/subsurface conductivity on a spatial basis, and determine correlations among the conductivity values and soil nutrient analysis. 2) Apply the methodology of the ESAP spatial analysis program with soil sample data and soil conductivity measures to generate a model for Cl^- distribution in a VTA.

MATERIALS AND METHODS

A feedlot surface study was conducted in 2004 and a vegetative treatment system evaluation occurred in 2005. The results of the feedlot study were previously reported as an ASABE proceedings paper (Eigenberg et al., 2005a). The results of the VTA study were presented as an ASABE proceedings paper (Eigenberg et al., 2006).

Feedlot Surface Evaluation

The feedlot surface evaluation was conducted in 2004 at the U.S. Meat Animal Research Center (USMARC), in south-central Nebraska using four

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[1] The ESAP ([E]xchangeable [S]odium [A]nalysis [P]rogram) software package can be used to predict soil salinity (EC_e) and/or other soil property information from bulk soil electrical conductivity survey data. ESAP is shareware software maintained by the U.S. Salinity Laboratory; version 2.35 can be downloaded free of charge from the USDA-ARS website.

consecutive (pens 412-415) feedlot pens (30 m X 90 m each) at the USMARC feedlot. The pens were rebuilt and reshaped in 2000. Cattle populated these pens (75 to 85 per pen), receiving standard feedlot rations; pens received routine maintenance since being resloped. Sequential soil conductivity (EC_a) measurements were taken by EMI and GPS (Trimble Navigation Limited, Sunnyvale, CA). A Dualem-2 (Dualem Inc., Milton, ON, Canada) was mounted on a non-metallic sled and pulled by foot with passes at about 3 m spacing. The Dualem-2 measured soil conductivity for horizontal and vertical orientations (with depths centered at approximately 1.5 and 3 m). Soil conductivity maps were generated for each feedlot pen.

High and low zones were created from the EC_a data in each of the four pens. Sample points were arbitrarily chosen in the ‘High’ EC_a zones and the ‘Low’ zones for each pen. Coordinates were downloaded and GPS navigation was used to locate feedlot surface coordinates for soil sampling. All soil samples were taken from a surface area of 20 X 20 cm, and to a depth of 10 cm. Soil was thoroughly mixed by hand and stored in sealed plastic bags until analysis. All soil samples were analyzed for total P, total N, and volatile solids. Additionally, soil samples were taken on a traverse across a high conductivity region on orthogonal axis in pen 413. These soil samples were also analyzed for total N, total P and volatile solids. Correlation analyses were run to determine associations between horizontal EMI readings and the various soil constituents.

Vegetative Treatment System Evaluation

A vegetative treatment area (VTA) located down slope from the USMARC feedlot (Fig. 1) was chosen as a site for evaluation of the assessment protocols and methodology. This VTA receives precipitation runoff from the eight pens by natural flow that is intercepted by a terrace used as a solids separation basin (Fig. 1). Basin water is passively discharged, by gravity flow, over a 48 to 72 hour period and is distributed relatively evenly across the southern edge of the VTA as the liquid flows through thirteen equal-elevation discharge tubes (Fig. 1). The downslope VTA provides 4.0 ha of bromegrass to utilize nutrients which are than removed during harvest.

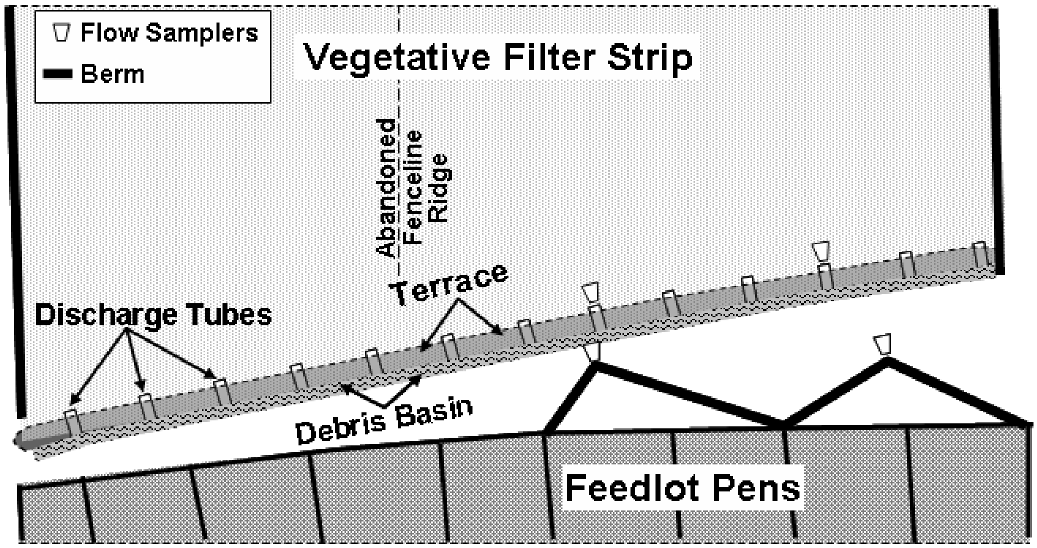

Fig. 1. The VTA receives precipitation runoff from the eight pens; the liquid flows through thirteen equal-elevation discharge tubes to a 4.5 ha field of bromegrass. Nutrients are removed at harvest.

Apparent soil electrical conductivity (EC_a) measurements were collected using a Dualem-1S manufactured by Dualem Inc., Milton, ON, Canada. The Dualem-1S operates in the horizontal and vertical dipole modes simultaneously, but only the horizontal mode (with measurement depth centered at about 0.75 m) was reported in this study. The Dualem-1S was mounted on a non-metallic trailer and pulled by an all-terrain vehicle at about 10 km/hr with passes made every 6 m. Apparent soil electrical conductivity was recorded and stored every second with corresponding GPS coordinates provided by a Trimble EZ-Guide GPS/Guidance system (Trimble Navigation Limited, Sunnyvale, CA).[2]

ESAP Program

EASP was originally developed by Lesch et al., 1995a to serve as the core salinity assessment software package for the Soil Chemistry and Assessment Research Program at the USDA-ARS Salinity Laboratory at Riverside, CA. The statistical methodology and overall software design were developed based on general salinity measurement theories developed by James D. Rhoades (Rhoades et al., 1999). The original version was designed to be the primary support software for member groups of the Lower Colorado Region Salinity Assessment Network (LCRSAN) (Lesch et al. 2002). This software package was implemented at USMARC using data collected from an ongoing study of VTAs for beef cattle feedlots. The ESAP program is a combination of programs that perform specific

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[2] Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

functions. The programs are available on the World Wide Web: http://www.ars.usda.gov/Services/docs.htm?docid=8918. The functions of each program used in this study are described below:

- ESAP-RSSD
  Designed to generate optimal soil sampling designs from bulk EC_a conductivity survey information.
- ESAP-Calibrate
  Designed to estimate both stochastic (regression model) and deterministic (soil theory based) calibration equations; i.e., the equations which will be used to predict spatial values of one or more soil variables from electromagnetic survey data.
- ESAP-SaltMapper
  Used to produce high quality 1-D or 2-D graphical output of EMI survey data and/or predicted soil variables.
- ESAP-SigDPA
  Signal Data pre-processing software for managing raw Conductivity/GPS data file.

Operating Procedures

The EC_a data from the VTA were formatted according to ESAP specifications and provided as input to ESAP-SigDPA. ESAP-SigDPA was then used to import the Dualem-1S sensor file data which also provided options to edit edges and to calculate rows that were output as a transect file. Another program, ESAP-RSSD, input the transect file and provide the option of log transforming the data to provide a normal distribution. In order to facilitate a response surface sampling design, all the conductivity data needed to be centered, scaled, and decorrelated. The decorrelation process detected outliers and provided for removal of those outliers. Response surface methodology has been used extensively to estimate statistical regression models in industrial applications. For this application, soil conductivity survey data represents the controlled input information and the primary variate represents the process output. This process statistically determines optimal sampling sites while dealing with issues of spatial correlation and collinearity. ESAP-RSSD optimized sampling design by selecting sites based on high density EC_a data, which optimized the prediction model. Output of ESAP-RSSD is a set of optimal sample sites (the number is set by the operator, 12 for this test) that are collinear with the ECa data set.

The 12 sample sites were uploaded as a text file for GPS navigation. Those sites were located and soil cores obtained using a hand probe to a depth of 15 cm, on the same day as the EC_a data were collected. Soil cores were then analyzed for Cl^- content. Chloride was chosen as the ion of interest since it tracks well with liquid runoff and can serve as a surrogate for NO_3-N transport in overland flow and soil transport.

Soil core data were then formatted to be compatible with ESAP-Calibrate; this program converted EC_a data to the secondary soil property of interest, in this case Cl^-. The ESAP-Calibrate program used a stochastic model to estimate the theoretical strength of correlations between EC_a and Cl^- or other secondary sample data. It automatically developed the regression modeling, produced an output file predicting field loading estimates and generated a map of the primary parameter, Cl^-.

RESULTS

Feedlot Surface

Surveys of USMARC feedlot pens were conducted on October 18 in 2004. An EC_a map of the soil conductivity survey is shown in Fig. 2.

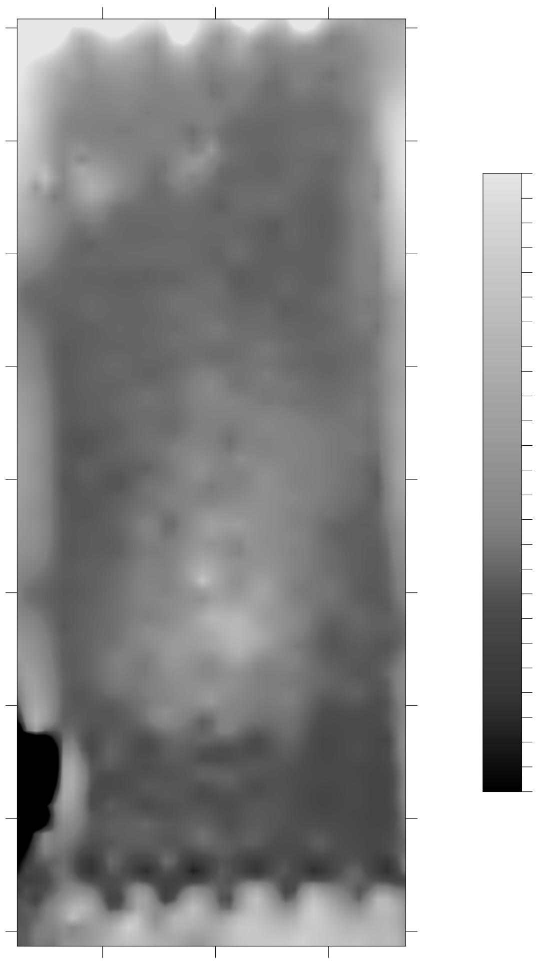

Fig. 2. EC_a maps generated on 10/18/04 for Pen 413 shown in the figure. The bunk is located at the bottom of the map and waterer at the lower left side.The conductivity scale is in mS/m.

The highest EC_a value appears to center on a region defined by the bunk, waterer, and mound. The down-slope portion of the pen (top of figure) also shows higher EC_a values, likely as a result of dissolved solids movement with precipitation events. Surface management of these pens includes the use of manure to build the mound; this is confirmed in the EC_a map with the mound region depicted as lighter gradation representing higher EC_a. Soil samples were taken on a transect in pen 413 on October 18, 2004. The transect included five samples obtained in the north-south direction and five samples east-west across the mound area. Two soil cores were also arbitrarily selected in the high and low conductivity regions (as determined from EC_a files) of pens 412, 413, 414 and 415. Soil cores were also taken at a site near the feedlot where no manure had been applied. Results of soil analysis for soil samples are shown in Figures 3, 4, and 5. Fig. 3 demonstrates the relationship between EC_a and volatile solids (r^2 = 0.77); the elevated salt content of manure contributes to the association. Corollary associations are shown in Fig. 4 and 5; total N (r^2 = 0.92) is linked to volatile solids as is total P (r^2 = 0.80). The combination of Figures 3, 4, and 5 supports the use of EC_a maps to delineate regions of high volatile solids and the associated concentrated N and P nutrients.

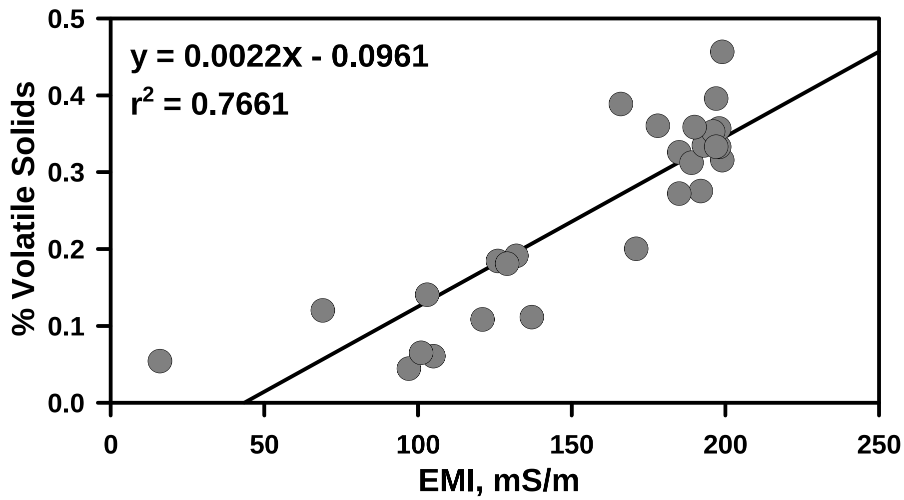

Fig. 3. Association of EC_a values using electromagnetic induction (EMI) to volatile solids for data collected on 10/18/04 from pens 412-415.

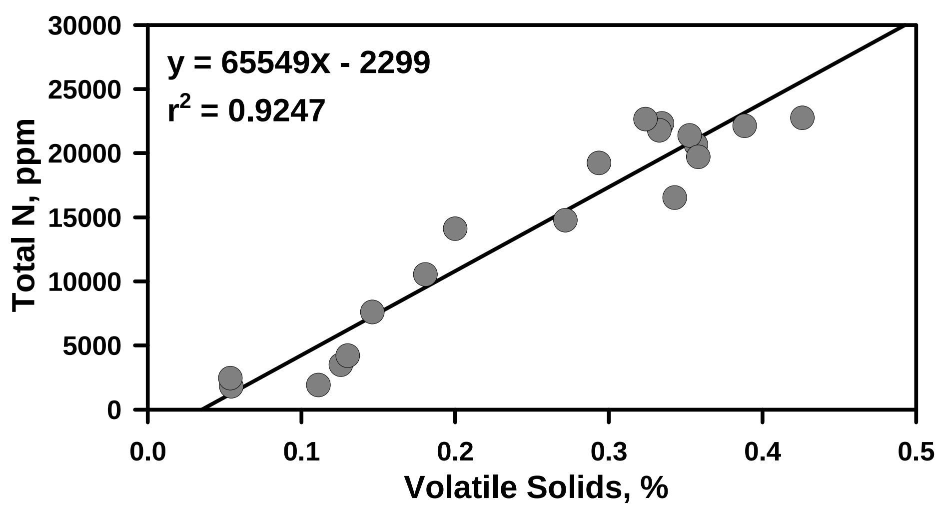

Fig. 4. Association of volatile solids and total N based on cattle feedlot data. Data collected on 10/18/04 from USMARC feedlot pens 412-415.

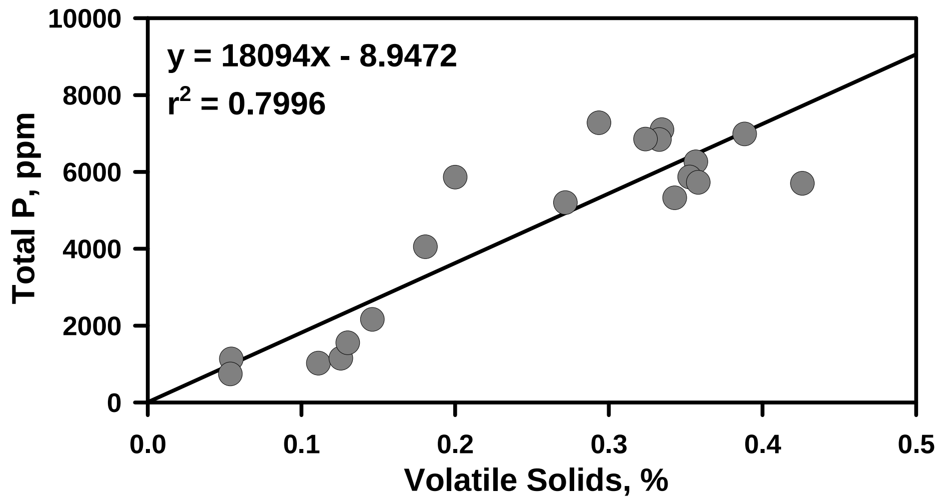

Fig. 5. Association of volatile solids and total P. Data collected on 10/18/04 from USMARC feedlot pens 412-415.

Vegetative Treatment Area

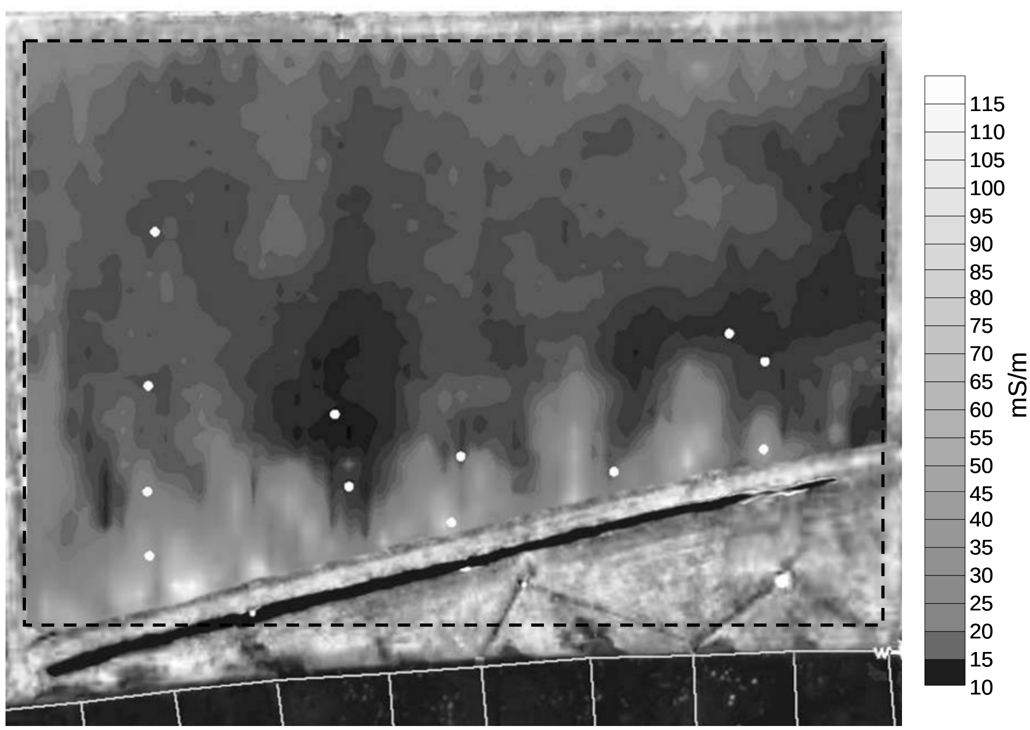

Fig. 6. Map of electromagnetic induction soil conductivity values, EC_a. Also shown on the figure are the sample locations selected by ESAP-RSSD.

The conductivity map is overlaid on an image of the VTA showing the terrace and feedlot pens. The data were collected on August 30, 2005.

A map showing the results of an August 30, 2005 soil EC_a survey of the VTA is shown in Fig. 6. The areas of highest EC_a (lightest shading), in general, are located near the discharge tubes of the VTA and represent the largest salt loads. These patterns have been observed in multiple surveys both at USMARC and at other locations (Eigenberg et al., 2005b), and have been used to demonstrate associations with specific salts associated with waste management (Eigenberg and Nienaber, 2003).

A set of 12 optimal sample points were selected by ESAP-RSSD (Fig. 6). Those sites were identified at the field and soil cores taken to 15 cm. Chloride levels were measured from each of the samples with soil data being fed into ESAP-Calibrate. The ESAP-Calibrate used the soils data and associated EC_a data to generate output files of map coordinates with Cl^- estimates.

The ESAP-RSSD program generated a set of 12 soil sample survey sites; those locations were located via GPS with soil cores taken at the directed sites. The ESAP-Calibrate program produces a model describing the geospatial relation of ECa and Cl^- with the program output containing point estimates of the soil property of interest, (i.e. Cl^-). That dataset has been plotted by Surfer®; Fig. 7 shows estimated Cl^- values across the VTA.

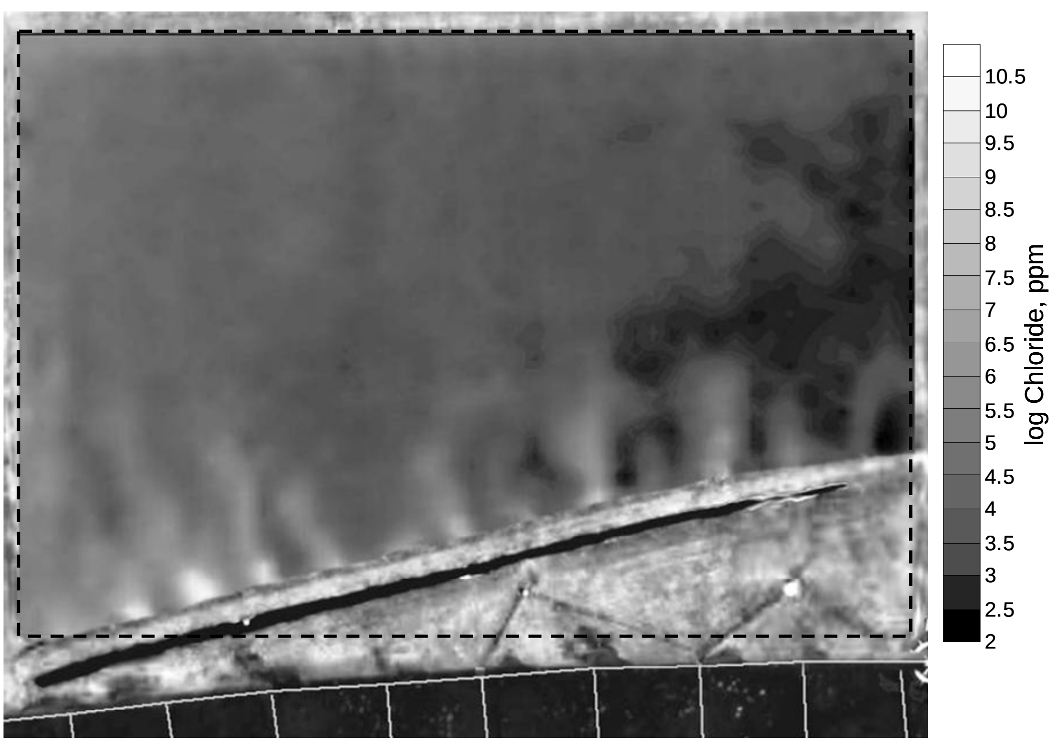

Fig. 7. Predicted levels of Cl^- based on a multiple linear regression model developed in ESAP. The Cl^- prediction map is overlaid on an image of the VTA showing the terrace and feedlot pens.

Comparison of Fig. 7 and Fig. 6. shows a strong resemblance; regions of high conductivity in Fig. 6 result in regions of high Cl^- loading in Fig. 7. Additionally, the program provided range interval estimates and the percent of the study area associated with various Cl^- levels. Table 1 lists the estimates generated by ESAP-Calibrate for four ranges of Cl^- values; the greatest percent of area (46%) has values of Cl^- below 40 ppm.

Table 1. Output data from ESAP showing percent area contribution for each range of Cl^- concentration.

Cl^- range	< 40	40-80	80-160	> 160
% area contribution	46	18	14	22

The 40-80 ppm range is contained in 18% of the area and the 80-160 ppm range is contained in 14% of the area. The highest concentrations (over 160 ppm) are contained in 22% of the area.

A pattern of higher concentrations of Cl^- is clearly visible in the predicted Cl^- maps (Fig. 7) near the discharge tubes and within the VTA. Fig. 7 gives evidence that the liquid discharge concentrations appear to extend only about one third the length of the VTA; demonstrating the conservative nature of the VTA design. The figure is indicative of a sustainable system since much of the field does not show Cl^- buildup; this view is supported by nutrient balances showing more nutrients leave the hayfield in the hay crop than are deposited by the incoming effluent (Woodbury et al., 2005).

CONCLUSIONS

Monitoring methods were applied in two areas of cattle feedlot management; the feedlot surface and a vegetative treatment area receiving feedlot runoff. The EMI methods clearly delineate volatile solid concentrations on the feedlot surface without mechanically disturbing the pens. The application of this method for feedlot management would allow boundaries to be marked and areas harvested without disturbing the entire pen. Harvesting the nutrient rich ‘sweet spots’ would result in a concentrated form of scrapings that could be hauled greater distances and have greater value at the final destination. Additionally, if the ‘sweet spot’ was removed, then runoff, leaching, and volatilization would be reduced. Secondly, methods were examined to monitor an alternative runoff control system for feedlot cattle. The evaluation focused on a software program, ESAP. The ESAP program suite provided a straightforward method of analyzing and estimating a primary data set based on a secondary high density dataset and a small number of primary sample points. The ESAP suite provided an estimate of the primary variable distribution across the VTA based on 12 core sites and the high density EC_a data.

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