Spatial Nutrient Distribution of VTA Pilot Sites in Iowa

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Abstract Cattle feeding operators are interested in alternative runoff control and treatment systems that eliminate the need for long-term liquid storage; however, the feasibility and sustainability of these systems is yet to be determined. Five demonstration sites in Iowa utilizing vegetative treatment areas (VTAs) have been constructed to determine their sustainability for feedlot runoff control. These sites represent an array of climate, site considerations (i.e. topography, soil texture, management, etc.), and design. A geospatial statistical method using multi-linear regression (MLR) models combined with soil analysis was used to predict nutrient distributions and mean concentrations. The over-all objective was to report the preliminary chloride, total nitrogen (TN), and total phosphorus (TP) nutrient distribution and mean concentrations in the VTAs for two sites. Some of the VTAs appear to have a history of feedlot runoff; however, the extensiveness of this history is complicated by site construction. Mean concentrations for chloride, TN, and TP were either calculated by MLR model or by actual soil analysis. The determined concentrations for each of these nutrients were at the lower end expected from VTAs that have been in operation for many years. When MLR model fit was sufficient for determining predicted nutrient distributions, these distributions were predominately clustered at the low end expected by VTAs with many years of operation. Preliminary analysis appears to have provided sufficient base-line understanding as to the status of these VTAs at the on-set of their operation. This information will be used with similar analyses after subsequent years of operation to determine over-all VTA feasibility and sustainability for controlling feedlot runoff.

Keywords: VTA, EMI, Multilinear regression, feedlot, nutrients

Introduction

Livestock producers have expressed interest in feedlot runoff control and treatment systems that eliminate the need for long-term liquid storage. This interest stems from complaints about runoff storage ponds that include costs, unpleasant odors, contaminant leakage to groundwater, maintenance difficulties, and environmental unsightliness. For more than twenty years, researchers have investigated runoff contaminant reduction through the use of vegetative treatment areas (VTA) (Koelsch et al., 2006; Woodbury et al., 2005 and 2003; Lim et al., 1998; Dickey and Vanderholm 1981; Young et al., 1980). This research has documented the potential feasibility of these types for runoff control, but has not documented their sustainability on production-sized operations.

Five demonstration sites in Iowa utilizing VTAs have been constructed to demonstrate their feasibility for feedlot runoff control. These five sites represent an array of climate, site considerations (i.e. topography, soil texture, management, etc.), and designs for application in the U.S. Midwest. A method using electromagnetic induction (EMI), apparent soil electrical conductivity (ECa) measures, and soil analyses were combined with a geospatial statistical method using multi-linear regression (MLR) models to predict site nutrient distribution (Eigenberg et al., 2006). These predictions will establish initial conditions prior to system operation. Annual evaluations using this technique will be collected to evaluate the nutrient distribution changes and to elucidate system sustainability. This paper will report the spatial nutrient distribution preliminary analysis and baseline estimates of chloride, total nitrogen (TN) and total phosphorus (TP) concentrations contained in the VTAs for two of the five sites.

Material and Methods

Site Descriptions

The five sites across Iowa represent different climates, soil types, topography, feedlot size, feedlot to VTA area ratio, and management approaches. Each site utilized some kind of solid separation system,
usually a sediment basin before releasing the discharge to a vegetative infiltration basin (VIB) or directly to a VTA. These solid separation basins varied in size from large enough to contain all runoff from a 24-hour, 25-year storm to just large enough to allow sediment separation. The specific purpose for the vegetative infiltration basins is to attenuate the runoff going to the VTA thereby reducing the required size of the VTA. Vegetative treatment area design utilized topography and ranged in complexity from a simple single upland distribution system to a complex multiple distribution systems discharging to multiple terraced VTAs. Two sites were selected to illustrate a variety of site topographies and designs. Feedlot A is located near Inwood, IA, and Feedlot B is located near Hawarden, IA. Both feedlot runoff control systems were put into operation during the summer of 2006.

Feedlot A is a 4000 head capacity beef cattle feedlot. Feedlot A utilizes a VIB that was planted to a hay mixture of brome and reeds canary grass. Following solid separation, runoff water from Feedlot A enters the infiltration basin where it is collected and allowed to infiltrate to drain tile approximately 1 m beneath the soil surface (Figure 1). Water is transferred from the drain tile to a collection well where it is pumped to the up-gradient end of a 0.9 ha VTA (VTA A-2) (Figure 1). The ratio of VIB and VTA to feedlot surface was approximately 0.4 and 0.35:1, respectively. Water was uniformly distributed across the 4% slope of the VTA through perforated pipe with 16 mm holes every 0.78 m. Water is used to irrigate a brome and reed canary grass hay mixture. Any excess water was collected at the down-gradient end of the VTA, and returned to the VIB drain tile collection well to be reapplied to the up-gradient end of the VTA. For the remainder of this paper the VIB will be referred to as A-1 and the VTA will be referred to as A-2.

Feedlot B is a 3400 head capacity beef cattle feedlot with pens located on the curved slope of a hill. There are three separate solid separation basins that discharge to five terraced VTAs (VTA B-1 through 5) (Figure 2). The solids separation basins were sized to contain the volume of runoff from a 25-year, 24-hour design storm. Basin drainage was designed to release the entire design storm volume to the VTAs over a 72-hour period. All five terraced VTAs are connected together at their down-gradient ends to a common discharge point at the end of VTA B-5 (Figure 2). The ratio of VTA to feedlot surface is approximately 1:1. There is an average slope along each VTA of approximately 0.5 to 1% and each VTA is planted to reed canary and brome grass. Vegetative treatment areas B-1 through 4 are approximately 180 m in length, while VTA B-5 is approximately 500 m in length. Sedimentation basin discharge was achieved using shallow concrete spreaders which uniformly distributed the water across the VTA.

Site Assessment

Measurements used to assess each site included EC$_a$ and soil samples to a depth of 30 cm. Each site required specific adjustments to the over-all assessment protocol because of topography and system design features. Either 6- or 12-grid soil samples were collected from each VTA. The number was based on VTA size, shape, and number of VTAs for each runoff control system. An initial site survey was done to determine the overall length (i.e. distance from runoff entry point to the VTA) and width of each VTA to identify grid sampling locations. A GPS guidance system was used to establish an A-B line on the VTA edge that was perpendicular to the runoff entry point. The guidance system was programmed to create a path to follow on 6 m intervals. The total number of 6 m intervals across the VTA was determined and

Figure 1. Feedlot A GPS guided EMI instrument track illustrating the layout and elevations. Note the location on the drain tile collection well and VTA A-2 inlet location.
divided by the number of segments necessary to create two or four transects perpendicular to the distribution system in the middle of the VTA, and perpendicular to the entry point. These transects were generated so that soil samples could be collected in the same path measured by the EMI instrument. Regardless of the number of grid soil samples collected, three rows of grid points were established parallel to the distribution system on the 6 m intervals that approximated 20, 40 and 80% of the distance from the runoff entry point to the down-gradient end of each VTA.

In addition to the grid samples, soil samples were collected to calibrate the MLR model estimations as discussed in a companion paper (Eigenberg et al., 2007). The number of samples required for calibration was based on the number of grid samples collected on each VTA. For example, if six grid samples were collected, then six calibration samples were collected. Calibration sample site selection used ECa survey data in an algorithm that spatially represented the entire survey area, and simultaneously facilitated model parameter estimations (Lesch, 2004; Lesch et al., 1995a; and Lesch et al., 1995b). Calibration site location coordinates were ascertained from ECa GPS data. These coordinates were transferred to a GPS system for navigating to the selected locations in the field. Sites were sampled to a depth of 30 cm. Soil samples were returned to the laboratory, air-dried, and analyzed for chloride, TN, and TP using methods described in Methods of Soil Analysis (1996).

Apparent soil electrical conductivity maps were generated at the VTA sites to be used as a co-variant with soils data. This data was co-located with EMI data to reduce the geospatial cokrigging method to simple MLR. A program, ESAP, developed by the Soil Salinity Lab at Riverside, CA was used to: 1) determine sampling locations based on high density ECa data, which optimized the prediction model, 2) generate nutrient specific predictive maps using MLR models.

Results and Discussion

The ECa survey with grid and model selected soil sample locations for Feedlot A, VIB A-1, and VTA A-2 are included in figure 3. Vegetative infiltration basin A-1 is located just down-gradient from the feedlot and has some history of receiving runoff. This history is illustrated by the relatively elevated ECa values on the west and east end of VIB A-1, with ranges from 55 to 95 mS m⁻¹ (figure 3). The runoff history is also illustrated by MLR models fit for chloride, TN, and TP, with R² values of 0.697, 0.674, and 0.628, respectively (Tables 1, 2, and 3). Generally, higher R² values for these nutrients indicate improved ability to
predict nutrient concentrations in one location based on known concentrations in another and some understanding of the spatial structure (in the x and y directions) driven by feedlot runoff.

The MLR model $R^2$ values for VTA A-2 were 0.064, 0.457, and 0.248 for chloride, TN and TP, respectively (Tables 1, 2, and 3). Vegetative treatment area A-2 is situated upland from the feedlot and has no history of receiving feedlot runoff; however, it may have received animal waste as a soil amendment because of its proximity to the feedlot. It is interesting to note that goodness of model fit for TN and TP was much higher than chloride, even though the $R^2$ values did not exceed the predetermined threshold value of 0.5 for further analyses. This indicates the spatial structure associated with VTA A-2 may be driven by spatial differences rather than impact from feedlot runoff, because spatial chloride structure in soils is typically associated with animal feeding operations.

Overall VIB A-1 means for chloride, TN, and TP are 76.8, 2129.4, and 1096.4 ppm, respectively (Table 1, 2, and 3). Since the model fit was greater than the threshold level, means were determined by predicting nutrient values for each EC survey location, and then averaging across the entire data set. Greater than 85% of the predicted nutrient concentrations are accounted for in just two ranges for each nutrient. No nutrient distribution was predicted for VTA A-2 because the MLR models did not meet the level necessary for further analysis; therefore, the overall mean was determined by averaging the grid site soils data.

The EC survey with grid and model selected soil sample locations for Feedlot B, VTA B-1 through 5, are included in figure 4. It appears that portions of all five VTAs have received feedlot runoff at some time prior to construction; however, site construction has complicated analysis due to the amount of soil moved to build the terraces and creating proper slope (figure 4). The highest EC values were predominately on the northeast ends of VTA B-4 and VTA B-5 (figure 4). These values ranged from 61 to 131 mS m$^{-1}$ (figure 4). The lowest EC values were predominately in the down-gradient southwest ends of VTA B-2, 3, and 5, with values that ranged from 22 to 37 mS m$^{-1}$ (figure 4).

The chloride MLR model $R^2$ values for VTA B-1 through 5 were 0.506, 0.015, 0.767, 0.777, and 0.312, respectively (Table 1). Though three of the five VTAs had sufficient levels of fit to warrant further spatial nutrient analysis, information derived from this must be tempered because of the extensive site construction. Additional problems confounding data interpretation is chloride solubility and mobility. When historical runoff patterns to the VTAs changed due to construction, chloride ions could be leached below the 30 cm soil sampling depth. Leached chloride would still be measured by the EMI instrument, but would not be measured in the soil analysis. This discrepancy in measurements would limit the ability for 2-D, MLR models to fit the data. This illustrates the need to incorporate a depth component to the procedures. It is interesting to note the best models fit were VTA B-3 and 4. Vegetative treatment area B-4 appears to have a strong history of receiving runoff, and that runoff could have continued into area that is now VTA B-3 (figures 2 and 4). This history may still be affecting the spatial chloride structure of these VTAs.

The TN MLR model $R^2$ values for VTA B-1 through 4 were 0.757, 0.442, 0.647, 0.518, and 0.506, respectively (Table 2). Only VTA B-2 $R^2$ value of 0.442 was insufficient to warrant additional analysis, though it was nearly at the threshold value. Approximately 70% of predicted TN values were accounted for in the two lowest concentration categories for VTA B-1, 3, and 4 (Table 2). Over 90% of predicted TN values in VTA B-5 were accounted for in the 1000 to 2000, and 2000 to 3000 ppm categories (Table 2). These high-predicted value percentages are at the lower end of expected values for VTAs that have been in operation for several years (Eigenberg et al., 2005). Overall mean TN values for VTA B-1 through 4 were between 1448 and 1632 ppm, while the overall mean value for VTA B-5 was 1969 ppm. This increased relative overall TN mean may be a result of historical runoff loading at the north east end of VTA B-5.

The TP MLR model $R^2$ values for VTA B-1 through 5 were 0.642, 0.627, 0.447, 0.205, and 0.447, respectively (Table 3). Only VTA B-1 and 2 $R^2$ values were sufficient for further analysis; however, both VTA B-3 and 5 were nearly at this level. Greater than 95% of the predicted TP values for VTA B-1 and 2 are in the 500 to 1000, and 1000 to 1500 ppm concentration ranges. These distributions are also at the lower end expected by VTAs that have been in operation for several years. Overall mean concentrations were between 993.9 and 1139.1 ppm (Table 3).

<table>
<thead>
<tr>
<th>Field ID</th>
<th>$R^2$</th>
<th>&lt;20 ppm</th>
<th>20 to 40 ppm</th>
<th>40 to 80 ppm</th>
<th>80 to 160 ppm</th>
<th>&gt;160 ppm</th>
<th>Mean</th>
<th>Mod. /Soil</th>
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<tbody>
<tr>
<td>A-1</td>
<td>0.697</td>
<td>2.89</td>
<td>8.57</td>
<td>45.4</td>
<td>41.84</td>
<td>1.31</td>
<td>76.8 Model</td>
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<td>A-2</td>
<td>0.064</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A  Soil</td>
<td></td>
</tr>
<tr>
<td>B-1</td>
<td>0.506</td>
<td>35.46</td>
<td>59.10</td>
<td>5.43</td>
<td>0.01</td>
<td>0.00</td>
<td>23.4 Model</td>
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Table 2. Total nitrogen MLR model statistics and nutrient distribution for Feedlot A and B.

<table>
<thead>
<tr>
<th>Field ID</th>
<th>R²</th>
<th>&lt;1000 ppm %</th>
<th>1000 to 2000 ppm %</th>
<th>2000 to 3000 ppm %</th>
<th>3000 to 4000 ppm %</th>
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<th>Mean Mod. /Soil</th>
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<tbody>
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<td>B-2</td>
<td>0.015</td>
<td>N/A</td>
<td>N/A</td>
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<td>N/A</td>
<td>17.0</td>
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<td>B-3</td>
<td>0.767</td>
<td>31.99</td>
<td>38.9</td>
<td>27.57</td>
<td>1.53</td>
<td>0.01</td>
<td>30.0 Model</td>
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<td>B-4</td>
<td>0.777</td>
<td>24.61</td>
<td>23.65</td>
<td>35.98</td>
<td>15.60</td>
<td>0.17</td>
<td>43.7 Model</td>
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<td>B-5</td>
<td>0.312</td>
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<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>69.9</td>
<td>Soil</td>
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Table 3. Total phosphorus MLR model statistics and nutrient distribution for Feedlot A and B.

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<tr>
<th>Field ID</th>
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<th>&lt;500 ppm %</th>
<th>500 to 1000 ppm %</th>
<th>1000 to 1500 ppm %</th>
<th>1500 to 2000 ppm %</th>
<th>&gt;2000 ppm %</th>
<th>Mean Mod. /Soil</th>
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<tr>
<td>A-1</td>
<td>0.674</td>
<td>3.49</td>
<td>38.61</td>
<td>49.49</td>
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<td>A-2</td>
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<td>Soil</td>
</tr>
<tr>
<td>B-1</td>
<td>0.757</td>
<td>19.94</td>
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<td>1466.7</td>
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<td>B-3</td>
<td>0.647</td>
<td>20.15</td>
<td>48.77</td>
<td>26.97</td>
<td>3.83</td>
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<td>1632.3 Model</td>
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<tr>
<td>B-4</td>
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<td>14.67</td>
<td>59.92</td>
<td>24.34</td>
<td>1.03</td>
<td>0.04</td>
<td>1601.6 Model</td>
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<td>3.51</td>
<td>49.67</td>
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<td>0.12</td>
<td>1969.0 Model</td>
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Conclusions

Five demonstration sites in Iowa utilizing VTAs have been constructed to determine their feasibility and sustainability for feedlot runoff control. These five sites represent an array of climate, site considerations (i.e. topography, soil texture, management, etc.), and design complexity. The objective was to report the preliminary analysis of spatial nutrient distribution and baseline estimates of the chloride, TN, and TP concentrations contained in the VTAs for two demonstration sites. The VIB and some of the VTAs appear to have a history of feedlot runoff; however, the extensiveness of this history is complicated by site construction. Mean concentrations for chloride, TN, and TP were either calculated by the MLR model or by averaging grid soil analysis. Determined concentrations for each of these nutrients were at the lower end expected from VTAs that have been in operation for many years (Eigenberg et al., 2005). When MLR model fit was sufficient for determining predicted nutrient distributions, these distributions were predominately clustered at the low end expected by VTAs with many years of operation (Eigenberg et al., 2006). Preliminary analysis appears to have provided sufficient base-line understanding as to the status of the VIB and VTAs at the on-set of their operation. This information will be used with similar analyses after subsequent years of operation to determine overall VIB and VTA feasibility for controlling feedlot runoff.

References


Figure 3. Feedlot A electromagnetic induction soil electrical conductivity (ECa) values with locations of the grid and ESAP soil sampling locations.
Figure 4. Feedlot B electromagnetic induction soil electrical conductivity (ECa) values with locations of the grid and ESAP soil sampling locations.