DEVELOPING SUSTAINABLE PRACTICES FOR CBM-PRODUCED WATER IRRIGATION

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BIOGRAPHICAL SKETCH

Aaron DeJoia is a soil scientist specializing in managed irrigation of CBM water for Cascade Earth Sciences. Aaron has a BS in Agronomy and a Masters in Soil Science both from Kansas State University. Mr. DeJoia specializes in vadose zone solute transport and monitoring changes in soil physical properties. At Cascade Earth Sciences Mr. DeJoia is responsible for monitoring soil chemistry changes at CBM managed irrigation sites to ensure applied amendments are appropriate to maintain soil physical quality. Mr. DeJoia has evaluated managed irrigation as a beneficial use option for CBM produced water and determined its effects on soil physical quality.

Abstract

Coal bed methane (CBM) produced water chemistry limits its use for long-term agricultural irrigation. CBM production creates a water resource that is high in sodium and bicarbonate but low in minerals such as calcium. Without soil or water conditioning, irrigation results in destruction of soil structure. In 2001 CES along with a leading gas producer established a feasibility and demonstration project that was initiated to identify the most appropriate methods to treat the soil and produced water to sustain irrigation for grass production on rangeland as an alternative to National Pollutant Discharge Elimination System (NPDES) discharge. Four center pivot irrigation systems, constructed on about 95 acres, were divided into 11 different treatments for soil amendments to prevent soil degradation. In 2002, the best amendments are now being applied to the entire site in a full-scale operational managed irrigation system. The thriving grass crop growing under the current irrigation system will be considered for hay or limited cattle grazing once the final best management practices are selected and refined. The results of this study from both the fall of 2001 and the 2002 operating year demonstrate that CBM produced water irrigation can be managed effectively without causing soil degradation. These cost-effective irrigation techniques and soil amendments can be applied to additional sites and refined even more over a wider area for hay, cattle-grazing and wildlife habitat enhancement without an NPDES discharge.

INTRODUCTION

Cascade Earth Sciences (CES) along with a leading gas producer established a feasibility and demonstration site to identify possible alternatives to direct discharge for Coal Bed Methane (CBM) produced water. CBM production is a constantly growing industry in the Powder River Basin. During the dewatering phases of methane gas production in this area, large quantities of highly sodic water are pumped out of the coal seams and frequently cannot be directly discharged into streams. This highly sodic and sometimes saline water has traditionally been directly discharged into surrounding streams through the use of NPDES discharge permits. Currently NPDES discharge permits have not been granted or have been granted as winter discharge only permits. Therefore the CBM producers in the Powder River Basin are looking for alternatives ways to manage and use this water that would not require an NPDES discharge permit. An alternative to the NPDES discharge permit is to use the produced water for beneficial uses such as irrigation. However, the produced water throughout much of the Powder River Basin usually has an elevated sodium adsorption ratio (SAR) and total dissolved solids (TDS) concentrations. These elevated SAR and TDS concentrations are known to negatively affect soil structure and plant growth if not managed and irrigated properly. To complicate matters the produced water also has high bicarbonate concentrations, which in effect raise the water's SAR even more due to precipitation calcium in the produced water.

This paper relays how, if designed and monitored properly, CBM produced water can become a beneficial resource through the use of managed irrigation. Furthermore, a case study example shows how managed irrigation, if performed properly, can be a sustainable solution to this water management problem.

During the first year, CES evaluated the soil impacts that CBM-produced water irrigation had on 11 different treatment units. As was expected the produced water from the Powder River Basin exhibits relatively high TDS, and bicarbonate concentrations and SARs. These elevated levels create problems when this water is used for irrigation because of the impacts it can have on crop growth and soil physical properties.

The primary objectives during the initial year of operations were to monitor the changes in soil conditions and to determine the most economically feasible management strategies. Specific objectives of the feasibility and demonstration project were to:

1) Manage irrigation to promote beneficial re-use of CBM produced water

2) Manage irrigation to maintain soil infiltration and permeability

3) Monitor the effects of produced water irrigation on soil quality

4) Evaluate the ability of different soil amendments to mitigate the effects of CBM produced water irrigation

5) Apply produced water to avoid surface discharge.

During the second year of operation (2002), CES implemented the management strategy that was deemed most effective and economical and began to operate the system as a fully managed irrigation site. Monitoring of the site decreased throughout the year as CES became more comfortable with the soil chemistry reactions occurring and could better predict changes.

METHODOLOGY

CES conducted a feasibility and demonstration project to assess the impacts that managed irrigation with CBM produced water would have on soil quality. Managed irrigation was studied as an alternative to direct surface water discharge during the highest evapotranspiration months (April through October). The demonstration site utilized water from CBM extraction wells that target the Big George coal seam in the Powder River Basin of Wyoming. As was expected, the water extracted from the Big George coal seam exhibits relatively high SARs and TDS concentrations. The feasibility and demonstration site was established to evaluate soil and water conditioning alternatives to mitigate the negative impacts associated with CBM produced water irrigation.

CES evaluated the impacts that produced water irrigation had on 11 different treatment units. Treatments are categorized into two approaches soil applied and water applied plus a “proprietary” electric static precipitator treatment system requested by the site owner. The electric static precipitator results are not discussed because of electrical problems that did not allow this device to work to the manufacturer’s specifications. Soil applied amendments consisted of sulfur only, gypsum only, one-month supply of sulfur and gypsum, three-month supply of sulfur and gypsum, and a soil-applied polyacrylamide product (PAM). Water-applied amendments consisted of water-soluble polyacrylamide (PAM), calcium polysulfide (CPS), and polyacrylamide and calcium polysulfide (Pam+CPS). The application rates for each treatment were based on either geochemical model results or the manufacturer’s suggested application rates. The overall goal was to provide a beneficial use of the produced water by increasing forage and overall plant community production while maintaining soil tilth.

The field demonstration site schedule was from late July through October 2001. Construction delays and the lack of produced water to be applied resulted in a delay of the demonstration project start date until September 21, 2001. The application of water at the demonstration site began on September 21 and was completed on November 26, 2001. During that period 26,323,700 gallons of water (626,755 barrels) were applied across 95 acres.

Soil samples were obtained on a weekly basis throughout the duration of the feasibility and demonstration project. Samples were obtained at the 0 to 6 and 6 to 18-inch depth from each test unit. All soil samples were sent to a certified laboratory and analyzed for pH, electrical conductivity (EC) and SAR.

Water samples were obtained prior to the start of irrigation and then three times during the demonstration period. Samples collected prior to irrigation were collected at individual wellheads and analyzed for pH, EC, major cations and anions, and metals. Samples collected during the irrigation season were collected at the surge pond outfall, irrigation system pump inlet, and at the pivot spray nozzles. These samples were analyzed for pH, EC, and all major cations and anions. Samples were collected using standard water sampling methodology, and enough water was collected to ensure that no headspace was available in the sampling container.

During the second year of the project the site switched from being a feasibility and demonstration site to a full-scale managed irrigation project. Prior to irrigation in 2002 all previous treatment areas that were deemed unsuccessful had a treatment of gypsum applied to bring the soil exchangeable sodium percent (ESP) back to acceptable levels. In other words all fields were set to manageable soil ESP levels. In 2002 CBM produced water irrigation began on April 1 and will be operated through the end of October. An average of 11.1 million gallons (MG)/month (264,285 bbl/month) of produced water has been applied to approximately 95 acres of rangeland during the 2002 irrigation season. The site was seeded to native rangeland grass species in the spring of 2002 to assist with recovery from past overgrazing and system installation impacts.

Soil samples were collected every six weeks during the irrigation season to monitor soil chemistry changes. Samples were collected and analyzed the same way as during the previous year. CBM produced water samples were collected quarterly to ensure that the chemistry was not changing and that the amendment application rates were still appropriate.

2001 RESULTS

Water Sample Analysis

During the irrigation season, water quality remained fairly consistent at each sampling point. However, CBM produced water quality changed dramatically between sampling locations at each sampling event. Water quality at the spray nozzle, based on irrigation parameters, was the worst among the sample points while surge pond outfall water quality was the best. Between these two points the pH and SAR increased, while the EC of the water decreased. This change in water quality between the outfall and spray nozzles was expected due to the water equilibrating with the atmosphere. As the water equilibrates with the atmosphere it degasses, which begins to increase the pH. The increased pH increases the SAR and lowers the EC due to the precipitation of calcite.

This change in water quality as it moves through the system decreases the water quality of CBM produced water for irrigation. As the SAR of the water increases and the EC decreases, the possible effects on soil infiltration increases. It should be noted, however, that the calcium that is lost to precipitation can be recovered as the pH of the water is lowered. The lowering of the water pH will also allow for the further degassing, while at the same time prevent the precipitation of calcite. Therefore, the recovery and addition of more calcium into this water system will lower the SAR and raise the EC of the water and allow for the use of this water for irrigation purposes.

Soil Results for Soil Applied Amendments

Soil pH

Surface soil pH (0-6 inch) on all soil-applied treatments increased as the volume of water applied increased. The soil treated with PAM exhibited the greatest rate of increase in soil pH, increasing from 7.3 to greater than 8.6 within the first 5.6 inches of application. Soil pH remained stable and even slightly decreased during the next 2.8 inches of application. The greatest total increase in soil pH was observed in the soil treated with sulfur only where pH increased from 7.3 to 9.0, after 8.4 inches of irrigation. After an initial increase in soil pH the soil pH remained stable as the irrigation quantity increased in samples from the other soil-applied treatments (one-month supply of gypsum, one-month supply of sulfur and gypsum, and three-month supply of sulfur and gypsum). At these treatments pH increased to 8.1, 8.2 and 8.0, respectively.

Electrical Conductivity (EC)

The change in soil EC (0-6 inch) was vastly different, as expected, for treatments that received the different soil applied treatments. The treatments that received additions of gypsum exhibited the greatest increases in soil EC regardless of irrigation quantity. Soil EC within the soil applied PAM treatment increased from 0.4 to 0.8 mmhos/cm during the first 8.4 inches of irrigation. The soils that received a three-month supply of gypsum and sulfur and gypsum only exhibited an increase from 0.4 to 2.0 mmhos/cm. This is likely due to the application of the gypsum. However, soil EC declined to 1.5 and 1.0 mmhos/cm by the time the application of produced water reached 6.3 and 7.5 inches on the treatments receiving the three-month supply of gypsum and sulfur and the gypsum only, respectively. Final EC was elevated over “background” soil conditions after 6.4 inches of water application; however, it appears that a majority of this increase occurred within the initial week of operations. Because of this rapid increase in soil EC, it appears this increase is an artifact of amendment application not produced water application. However, this increase in soil EC is not expected to significantly impact the grass species at the site since a majority are classified as moderately salt tolerant species.

Sodium Adsorption Ratio (SAR)

The SAR (0-6 inch) increased the greatest in the sulfur only treatment. The SAR in soil samples collected within this treatment increased from 0.8 to 16.3 as irrigation quantity increased from 0 to 8.4 inches. However, SAR in this treatment never increased above 7.0 until irrigation exceeded 6.5 inches. The treatment receiving a one-month supply of gypsum and sulfur appeared to control SAR the best of all soil applied amendments. The soil SAR in this treatment increased from 0.8 to 7.9 as irrigation quantity approached 7.3 inches. All other soil applied treatments appeared to control soil SAR equally as well. In all treatments it appeared that SAR increased the greatest after approximately 6.5 inches of water was applied. This was expected since the amendment application rates were designed only to treat approximately 7.0 inches of CBM produced water. Although the effectiveness of the treatments appeared to decline prior to the theorized irrigation amount, the timing of application could have caused these minor differences.

Water applied amendments

Water applied amendments were designed to be delivered through the irrigation system. The CPS treatment was the only treatment in this group that was designed to chemically mitigate (by adding calcium and sulfur) the elevated sodium in the produced water. The PAM treatment was designed only to mitigate the anticipated soil dispersion and not to alleviate the build up of sodium in the soil surface.

pH
Soil pH (0-6 inch) increased relatively equally in all water applied amendment treatments. After 8.4 inches of CBM water irrigation the soil pH was approximately 8.2, 8.2, and 8.5 for the water applied PAM, PAM+CPS, and CPS, respectively. The greatest pH reading (8.8) observed for all water applied treatments occurred in the PAM+CPS treatments after 5.0 inches of application, however as stated above pH readings observed at the end of the demonstration project was 8.2. This demonstrates that the water-applied treatments had little effect on controlling soil pH.

EC
Soil EC (0-6 inch) increased from 0.6 to 1.1, 1.2, and 1.2 mmhos/cm for the water applied PAM, PAM+CPS, and CPS treatments, respectively, as irrigation with produced water increased from 0 to 8.4 inches. This increase in soil EC was expected since the produced water has elevated levels of TDS associated with it. However, the soil EC is still below levels that would negatively impact plant growth.

SAR
Soil SAR (0-6 inch) increased the greatest in the CPS treatment. Soil SAR increased from 0.7 to 10.1, 11.1 and 13.0 for the water applied PAM, PAM+CPS, and CPS treatments, respectively. The increase in soil SAR appeared to be linear throughout the duration of the demonstration project. It is expected that SAR will continue to increase until equilibrium is reached between the soil and the applied produced water. The increase in SAR at these treatments was greater than three of the five soil applied amendments increases. Greater soil SAR levels in the water applied treatment were expected since no or limited amounts of calcium were applied to mitigate the sodium applications through produced water.

2001 CONCLUSIONS
The results of the feasibility and demonstration project indicate that the use of soil applied amendments was successful at mitigating the high bicarbonate and sodium concentrations in CBM produced water. The addition of gypsum and sulfur appeared to work the best out of all of the treatments applied. These amendments appeared to work best when a one-month application was applied versus the use of a three-month application. Gypsum alone also appears to be an option; however, because of the larger amounts required to treat this water with gypsum alone, the treatment costs are higher. Therefore the addition of sulfur was able to reduce the total amendment cost while not impacting the effectiveness of the amendments. No other treatments appeared to effectively control soil SAR at the site.

The use of soil PAM did not appear to control soil pH or sodicity. However, the infiltration rate at this treatment did remain relatively high (data not shown). The infiltration rate was actually as good as the gypsum and sulfur site. Therefore, it appears that the use of soil PAM could help to increase infiltration rates on soils that are adversely affected by low infiltration. The actual implementation of soil PAM for this practice was not evaluated so its actual place in managing CBM produced water is not known at this time.

2002 RESULTS
In 2002 the feasibility and demonstration site was converted to a full-scale managed irrigation site. In preparation for this, CES applied a single application of gypsum to the treatments that did not effectively control SAR to lower the SAR levels to levels that would not negatively impact soil structure. After the single application of gypsum the selected treatment, gypsum and sulfur, was applied on predetermined intervals to maintain soil structure.

<u>Soil pH</u>
Average soil pH ranged from 7.7 to 8.0 with an average of 7.9. These pH levels are approximately where we predicted based on the results of the initial year’s study. Although these are not optimum pH values they are being maintained and are sufficiently low enough to inhibit the formation of calcite. By inhibiting the formation of

calcite in the soil, the applied gypsum should be soluble and effectively compete against the sodium ions for exchange sites and limit clay swelling and dispersion.

Soil SAR

The SAR of the soil ranged from 8.6 to 14.6 with an average SAR of 12.0. Although these levels are elevated they do not appear to impacting soil infiltration rates. One reason for the higher than expected SAR readings is that most of the soil samples were taken immediately after application of amendments. The timing of the sampling events could cause an elevated SAR reading since the gypsum may not have had enough time to become soluble prior to the sampling event. CES has taken measures to address this sample timing theory, however those results are not available at this time. However, based on the water chemistry and amendment application rates we predicted that the soil SAR would be raised to approximately 10. Therefore, the soil sample results are not excessive compared to the predicted results, even if the sample timing does not affect our results.

Soil EC

As stated above maintaining an adequate EC in the soil is necessary when managing CBM produced water a high SAR. The average soil EC in 2002 for all sites was approximately 4.2 mmhos/cm with a range of 2.4 to 4.9. This EC should not affect the grass species at the site and is needed to maintain appropriate infiltration rates.

CONCLUSION

This feasibility and demonstration study showed that a source of calcium is needed to effectively amend CBM produced water. This was expected since the soil system had very little calcium available in the surface soil and the applied water sodium concentration was relatively high compared to the calcium concentration. The addition of sulfur reduced the total amendment by decreasing the quantity of gypsum needed to maintain the soil structure. The addition of sulfur maintained the soil pH and allowed for the calcium additions to be utilized completely. The actual application rates of gypsum and sulfur are site specific due to the differences in produced water chemistry and soils at each irrigation site. The use of gypsum and sulfur as amendment sources was the best treatment option that was evaluated for CBM produced water irrigation.

The use of CBM produced water for irrigation can negatively impact soil quality if not properly managed. With proper management and monitoring, the irrigation of CBM produced water has shown to be a successful alternative to direct discharge to surrounding streams. The additional crop growth realized through managed irrigation results in the ability to revitalize overgrazed rangeland, provide habitat for wildlife, and produce high price commodities. During the two years of managed irrigation, a site with poor range growth has been converted to a highly productive ecosystem for both livestock and wildlife. Although soil SAR and EC have increased this was expected and they are being managed at levels where soil tilth and crop growth will not be negatively impacted. This managed irrigation site demonstrates that if managed appropriately CBM produced water can be beneficially used for crop production and wildlife enhancement. As this site continues to operate, changes will need to be made to ensure that the results obtained during the first two years of operations are continued. The additional growth realized through the use of CBM produced water for managed irrigation can generate income that could offset some of the costs for operating the system.