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Appendix E

Phytoremediation of Saline Seeps by Hydrologic Modification

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Abstract

Saline seeps are a growing concern in south-central Kansas. To remediate salt-affected seep areas, site hydrology must be modified to reduce seep recharge. A hydrologic model, POTYLDR, was used to estimate the water balance in a saline seep recharge area, and to estimate the effectiveness of various acreages of alfalfa treatments in reducing seep recharge. Practical applicability of this modeling procedure was encouraged by using only readily-available published data. Percentage of recharge area to be shifted from current wheat cropping to alfalfa was determined for a given target percentage reduction in total recharge or in number of months contributing to recharge. A 50% reduction in total recharge required 14 to 32% alfalfa acreage, while a 50% reduction in the number of contributing months required 27 to 41%. The major limitation in application of these results is in selection of the percentage seepage reduction needed to effect seep control.

Keywords: bioremediation, hydrologic balance, modeling, alfalfa, wheat

Introduction

Seeps are intermittent or continuous ground water discharges fed from upslope recharge areas. Excess rainfall, after evaporation, transpiration, and runoff losses, percolates into the soil profile. If a relatively impermeable layer occurs below the surface, the water accumulates leading to local ground water flow. This local ground water flow emerges downslope as a seep. Saline seeps occur in response to three factors: hydrogeology, climate, and land management (Doering and Sandoval, 1976; Halvorson, 1988). Saline seeps occur when water mixes with salts in the substrata as it travels through the soil profile. When this seep water emerges and evaporates at the soil surface, it leaves behind the transported salts. Over time, salinization of the seep continues until once-productive soils can no longer support crops. The impact of saline seeps are compounded due to their distributed nature. Seeps often receive full inputs of tillage, fertilizer, and seed, even though no crop is produced. In addition, the salt-affected areas are subject to serious wind and water erosion due to the total absence of vegetation under current management.

Once established, seep areas can grow at an average rate of about 10% a year, taking large areas out of production (Doering and Sandoval, 1976; Miller et al., 1981). Saline seeps range in size from a few square meters to 20 hectares and are growing in number, area, and severity. Seeps in the Dakotas, Wyoming, and Montana have removed 162,000 ha (400,000 acres) from production (Doering and Sandoval, 1976). Within one county in north-central Oklahoma, 1,300 of 65,000 ha of wheatland was known to be affected by seeps, and the extent was estimated to be similar in south-central Kansas (Berg et al., 1991). Approximately 65,000 ha (160,000 acres) of south-central Kansas soils mapped as saline/sodic are particularly susceptible to seep development. Saline seeps are an increasing concern in the dryland crop production areas of Kansas.

Two general methods have been used to remediate seep areas (Halvorson, 1988). Subsurface drains installed up-gradient from the seep can intercept the lateral water movement and reduce the salt loading to the seep area (Berg et al., 1987). Further adoption of this control practice is limited by the high initial cost and the environmental and developmental problems associated with locating an acceptable outlet for the drainage discharge. Alternatively, a form of phytoremediation could be employed. Phytoremediation, or the use of plants to remove pollutants from the environment, often begins with hydrologic control of the site. In this case, hydrologic control with agronomic cropping systems allows and encourages the removal of the salt pollutants by natural processes. Agronomic practices can be modified to use the water while it is a relatively non-saline resource before it percolates below the root zone, thus controlling seep recharge and arresting seep development and expansion. Berg et al. (1991) recommend warm-season, deep-rooted crops (sunflower, safflower, etc.) or perennial species (alfalfa, grasses, etc.) that use more water than does wheat. While annual warm-season grasses root to depths of 1.8 m or less (Berg et al., 1991; Halvorson, 1988), sunflower and safflower root 2.0 to 2.2 m deep (Halvorson, 1988), and alfalfa may extract soil water from as deep as 5.5 m after several seasons of development (Berg et al., 1991; Halvorson, 1988). Alfalfa was found to extract 6.1 cm year^{-1} in excess of annual precipitation, causing soil

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beneath alfalfa stands to contain less water than adjacent crop-fallow fields. Because of its deep rooting and high water use, alfalfa has been identified as the best species for gaining hydraulic control in recharge areas (Black et al., 1981).

In order for bioremediation to be successful, the recharge area must be clearly identified and farmers must be willing and able to implement management practices which maximize water use and minimize percolation past the root zone (Halvorson, 1988). Alfalfa has been successfully used to control seep recharge (Halvorson and Reule, 1980; Miller et al., 1981). Halvorson and Reule (1980) found that when alfalfa was grown on 80% of the recharge area, the decrease in deep percolation of soil water provided hydrologic control within one year after establishment. However, an upslope buffer strip of alfalfa grown on 20% of the recharge area did not provide hydrologic control.

Once the hydrology is controlled, salts will naturally leach from the surface in the saline seep. Reclamation has often proceeded swiftly. Once recharge was arrested, Halvorson (1984) found salinity of seep areas (0-30 cm) was reduced enough to allow successful crop growth after 2 years, and average yields after 3-4 years of hydrologic control. In another example, a farmer in Colorado established alfalfa in the seep recharge zone in 1984, which dried the seep area sufficiently to allow machinery crossing in fall of 1985 and three cuttings of alfalfa in 1987 (Halvorson, 1988).

The extent and nature of saline seeps varies from farm to farm due to different combinations of soils, climate, and cultural practices. As a general rule, cropping practices alone will control or reclaim only about 60 to 70% of the saline seeps (Miller et al., 1981). This indicates the need for a design methodology to assist in selecting where biological remediation is possible and to determine the extent of treatment required.

Objectives

1. Demonstrate the use a basic hydrologic balance model with readily available data to analyze saline seep bioremediation treatments.
2. Determine the feasibility of saline seep phytoremediation using alfalfa at five south-central Kansas sites.
3. Estimate the reductions in saline seep recharge at each site in response to a range of recharge area treatments.

Methods

POTYLDR Hydrologic Model

The Potential Yield Revised (POTYLDR) model is a water budget simulation model designed to estimate water yield on a daily basis (Koelliker, 1994). Precipitation, from daily weather station data, that is not evaporated, intercepted, or removed by surface runoff is allowed to infiltrate the surface. The subsurface is divided into two zones: the upper zone, 0.3 m (1 ft) deep, and the lower zone, the next 0.9 m (3 ft) or less according to soil profile characteristics.

The POTYLDR model was further revised to accommodate the objectives of designing seep remediation treatments. First, alfalfa was allowed to access soil moisture in up to 0.3 m (1 ft) greater soil depth than wheat. To accomplish this, available soil water in the lower zone was decreased by 33% for wheat compared to alfalfa. Second, each site was divided into two land uses, one upslope from the other. Deep percolation from Land Use 1 was directly input to the lower zone of Land Use 2 to simulate seep-water transport in the vadose zone. This allowed the downslope crop (Land Use 2) to access the shallow groundwater which would be transported through its root zone on route to the discharge (seep) area. Deep percolation from Land Use 2 was interpreted as ground water discharge available for seep development. For saline seep remediation, the wheat was selected to be grown upslope (in Land Use 1) from the alfalfa (Land Use 2) to take advantage of alfalfa's higher water-use capacity hydraulically closer to the seep.

This model was selected for several reasons. Model inputs are minimal and readily available, as will be seen in the following section. This would allow ready adoption of the procedures developed here to the preliminary assessment and design of other saline seep remediations without costly, time-consuming, and often unavailable site-specific data. Nonetheless, the model includes the important hydrologic-balance parameters necessary for a reasonable accounting of water fluxes in the seep recharge/discharge system.

Model Inputs

Inputs to the POTLYDR model were purposely taken from readily available sources. A site reconnaissance was used to determine current cropping and land use characteristics. Five saline seep sites were studied: three in Rice

County (R1, R2, and R3) and two in Harper County (H1 and H2). All fields were cropped to wheat. The R2 and H2 fields were terraced. Seep recharge areas were estimated to follow the surface contour: all land upslope of the existing seep was assumed to be contributing. Runoff curve numbers were estimated from standard SCS Curve Number tables based on site assessments of land use and conditions. Soil hydrologic groups were estimated from county soil surveys, and soil irrigation classes were found from the Kansas Irrigation Guide (SCS, 1975). A 41-year record (1948-1988) of climatic files, daily precipitation and daily maximum and minimum temperatures, were taken from a nearby weather station in Great Bend, KS. Model defaults were used for Blaney-Criddle evapotranspiration crop coefficients for wheat and alfalfa, the two primary crops being studied.

Results and Discussion

The POTYLDR model was used to simulate daily deep percolation on each field for a 41-year period. A variety of wheat-alfalfa combinations were used to explore the effects of a range of potential remediation treatments. Average annual recharge to the saline seep, expressed as an average depth for the entire recharge area, decreased as the areal percentage of alfalfa increased (Table 1). A similar trend was seen in the number of months that contributed deep percolation (Table 1); as the percentage of alfalfa cropping area increased, the number of months contributing to recharge decreased.

Table 1. Effects of each remediation treatment on saline seep recharge.

Land Use 1 *wheat* (% area)	Land Use 2 *alfalfa* (% area)	Saline Seep Recharge: Months with Contributing Recharge (% of total)					Avg. Annual Recharge Depth (in)				
		R1	**R2**	**R3**	**H1**	**H2**	**R1**	**R2**	**R3**	**H1**	**H2**
100	**0**	3.3	13.4	11.6	7.3	7.3	0.32	1.08	1.06	0.83	1.30
80	**20**	2.2	8.1	7.3	5.3	5.7	0.10	0.61	0.71	0.43	0.50
60	**40**	1.6	4.1	4.7	3.7	3.3	0.06	0.27	0.40	0.29	0.31
50	**50**	1.4	2.8	3.7	3.0	2.8	0.05	0.18	0.32	0.25	0.25
40	**60**	1.0	2.0	3.0	2.4	2.4	0.04	0.12	0.25	0.22	0.20
20	**80**	0.8	0.8	1.8	2.0	1.6	0.02	0.04	0.16	0.17	0.14
0	**100**	0.4	0.2	1.2	1.6	1.2	0.02	0.01	0.11	0.14	0.09

Several factors contributed to the reduction in deep percolation for alfalfa compared to wheat. Alfalfa was modeled to have a 25% greater root-zone depth than wheat, which increased both storage capacity and available water for evapotranspiration. Also, the growing season for alfalfa (April to October) covers a different portion of the high-rainfall period than wheat (October to June); typically, 30% of annual precipitation falls during May and June, and 45% occurs between July and September in south-central Kansas. Timing of the period of active crop water use to rainfall events affects the likelihood of deep percolation. Rainfall that occurs between July and September is more likely to contribute to deep percolation on a field with wheat stubble than actively transpiring alfalfa.

This information can be helpful in preliminary design of saline seep phytoremediation treatments. Figure 1 shows data from Table 1 expressed as a percentage of the maximum value for each field. From this graph, the percentage of alfalfa area needed to achieve a certain percentage reduction in seep recharge can be determined directly. For instance, to achieve 50% reduction in the number of months contributing to recharge would require 38% (R1), 27% (R2), 31% (R3), 41% (H1), or 37% (H2) of the recharge area to be converted to alfalfa production, depending on the field. Similarly, to achieve a 50% reduction in average annual recharge would require 14% (R1), 24% (R2), 32% (R3), 22% (H1), or 17% (H2) of the recharge area to be converted to alfalfa production. This graph also shows the maximum percentage reduction possible using alfalfa at each site. With alfalfa on 100% of the recharge area, average annual recharge volume was reduced by values ranging from 83% for H1 to 99% for R2.

This simple modeling approach has several important limitations. First, selection of the target percentage recharge reduction necessary would require more information to determine accurately. Such information would include: mass fluxes and total accumulation of salts in the seep, history of the seep development, soil hydrogeologic characteristics, etc. Second, it is important to note that not all seeps are formed exclusively by local recharge, as was assumed for this analysis. Such seeps tap into ground water flows from non-connected recharge areas and are

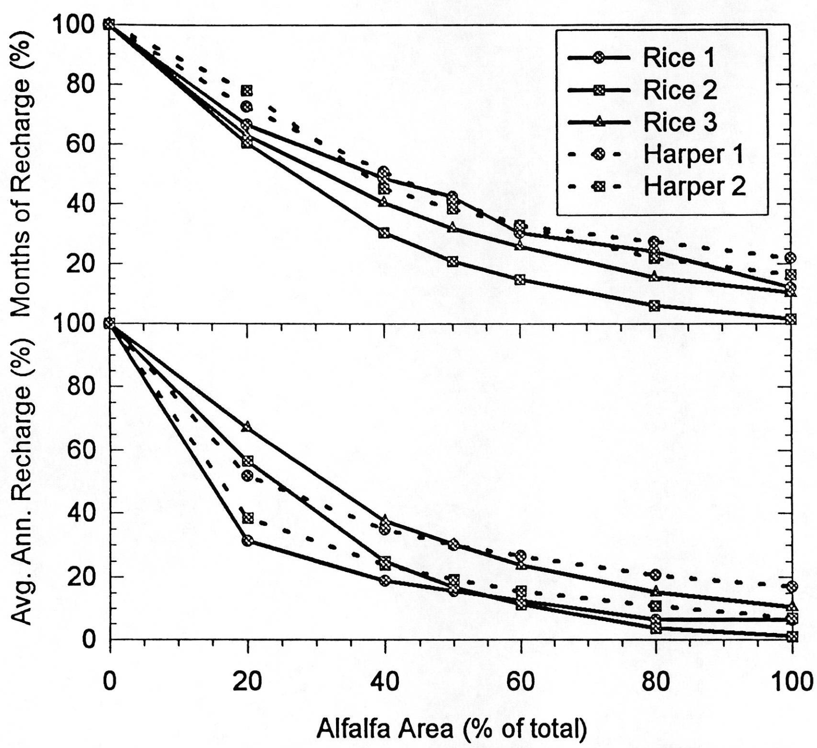

Figure 1—Months contributing to seep recharge and average annual recharge depth. Values are expressed as a percentage of the peak value for each treatment.

more difficult to control. Third, the model demonstrated that seep development is very sensitive to soil depth and texture; more accurate results would be obtained with actual data on depth to impermeable layer, crop rooting depths, and available water capacity. Finally, this modeling process focused on hydrology and made a basic assumption that solute concentration was not affected by recharge rate. The implied goal of controlling recharge is to reduce mass influx of salts to the saline seep. If solute concentration increased with decreasing recharge rates, further refinements would need to be made to account for solute mass flux directly.

Conclusions

A simple hydrologic balance model was used to provide useful information to design saline seep remediation treatments. Percentage of recharge area requiring a shift to alfalfa production was determined for a given target percentage reduction in total recharge or number of months contributing to recharge. Final selection of remediation treatments will be made in collaboration with the land owner and operator at each of the five sites discussed in this paper. Remediation treatments will be monitored to assess the accuracy of model predictions and the effectiveness of the chosen remediation treatments.

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