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Soil

A saline seep results from a soil salinization process, often accelerated by dryland farming, that allows water to move through salt-laden substrata below the root zone (**Fig. 1**). Saline seep refers to intermittent or continuous saline water discharge at or near the surface of the soil, downslope from recharge areas under dryland (rain-fed) conditions. This process reduces or eliminates the growth of crops in the discharge area because of increased soluble concentrations of salt in

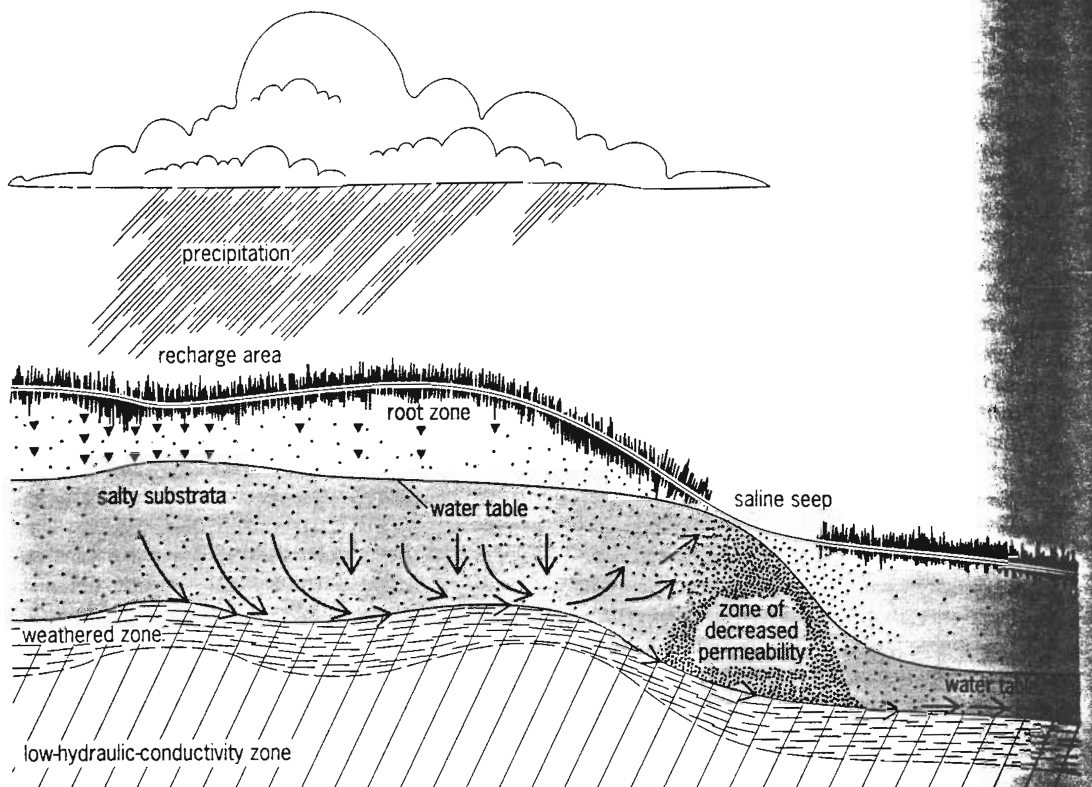

Fig. 1. Schematic diagram illustrating typical geologic conditions that contribute to development of saline seep. The triangles indicate downward movement of water through the soil profile. (*After P. L. Brown et al., Saline-Seep Diagnosis, Control and Reclamation, USDA Cons. Res. Rep. 30, 1983*)

the root zone (**Fig. 2**). Saline seeps can be differentiated from other saline soil conditions by their recent and local origin, saturated root-zone profile, shallow water table, and sensitivity (short-term response) to precipitation and cropping systems.

Occurrence of saline seeps. Saline seeps occur frequently in dryland farming areas throughout the North American Great Plains, with an estimate of nearly 10^6 hectares (2.5×10^6 acres) of productive cropland salinized. Saline seep problems are present in Australia, India, Iran, Turkey, and Latin America. Saline seeps result from a combination of geologic, climatic, hydrologic, and cultural (land-use) conditions. The primary cause is a change in vegetation from grassland or forest to a cropping system that is less efficient in water use, such as a crop–summer fallow rotation, which allows precipitation in the recharge areas to move below the root zone and provide seepage water. The characteristics, hydrology, and causes of most saline seeps are similar regardless of geographic location.

Fig. 2. Typical saline seep discharge area in Montana.

In the United States, the crop–summer fallow system of dryland farming has contributed significantly to the development of the saline seep problem in the Great Plains but is not the only cause. Seep development is encouraged by periods of above-normal precipitation; restricted surface and subsurface drainage due to construction of roads or pipelines; large snow drifts at windbreaks, roadways, and such; gravelly and sandy soils; obstructions (such as roads) across natural drainageways; unplugged or poorly cased artesian water wells; leaky ponds and dugouts; and crop failures. Water conservation practices, such as forming level bench terraces, have contributed to saline seep development.

Seep development generally occurs on sidehills or toe slopes (bottom part of a sidehill) of rolling-to-undulating topography, where permeable material is underlain by less permeable strata, a circumstance conducive to development of perched water tables. An understanding of the geology and circumstances that cause a particular saline seep to form will help in designing effective control or prevention measures. In general, while agronomic practices work well to control most seeps, some may require additional drainage and land leveling to achieve hydrologic control.

ble 1. Chemical composition of waters associated with saline seeps in the Great Plains*

Location	pH	Electrical conductivity, dS/m†	Ion concentration, mmol/liter						
			Calcium (Ca^{2+})	Magnesium (Mg^{2+})	Sodium (Na^{+})	Bicarbonate (HCO_3^-)	Nitrate (NO_3^-)	Chloride (Cl^-)	Sulfalte (SO_4^{2-})
ntana recharge	8.4	5	7	11	18	3.8	4.3	0.7	21
ntana seep	8.2	9	8	21	66	9.8	0.4	0.8	52
ntana seep	7.9	14	10	37	109	8.1	29.5	2.6	80
ntana seep	8.4	26	1	108	211	4.0	5.4	7.6	225
ntana recharge	8.2	7	3	21	39	2.4	6.2	11.2	44
rth Dakota seep	3.7	10	9	36	59	—	5.7	2.1	70
rth Dakota seep	4.6	8	9	30	40	—	4.7	2.5	55
lahoma seep	8.1	5	15	16	26	—	0.6	12.3	27
lahoma seep	8.2	3	3	17	13	—	—	16.0	15

*From A. D. Halvorson, Management of dryland saline seeps, in K. K. Tanji (ed.), *Agricultural Salinity Assessment and Management*, ASCE Man. Rep. Eng. Prac. 71, American Society Civil Engineers, 1990.
† Decisiemens per meter.

Water quality and saline seeps. As the ater passes through the soil profile toward the rched or permanent water table, salts are dissolved d moved downward. Often the shallow groundwater sociated with saline seeps is unsuitable for human livestock consumption because of high levels of trate (NO_3; >0.7 mmol/liter) and other salts, and for rigation because of total salt concentration. Calcium (Ca^{2+}), magnesium (Mg^{2+}), and sodium (Na^{+}) are the minant cations and sulfate (SO_4^{2-}) is the dominant nion in most of the shallow groundwater associated ith saline seeps. Sulfates are the dominant anion in e water and soil system in the Great Plains, while hlorides are generally low in the northern Great Plains ut tend to be slightly higher in the southern Great lains (**Table 1**). Little, if any, of the nitrate in the ater originated from nitrogen fertilization practices, ecause little, if any, nitrogen fertilizer was used by ryland farmers in the Great Plains prior to the early 970s, when the saline seep problem was first re- earched. Much of the nitrate was of geologic origin.

Identification. Early detection and diagnosis of saline seep problem is important in designing and im- plementing control and reclamation practices in order o prevent further damage. Early detection may allow farmer to minimize the damage by changing current ropping systems.

Visual symptoms of impending saline seep develop- ment are (1) vigorous growth of kochia (*Kochia sco- paria*) or other weeds after grain harvest in areas where normally the soil should be too dry to support weed growth; (2) presence of salt crystals on soil surface; (3) prolonged wetness in small areas of the soil surface following rain; (4) tractor wheel slippage or equipment bog-down in isolated areas of a particular field or water seepage into wheel tracks, with salt crystals visible as soil dries: (5) rank crop growth accompanied by lodg- ing (stem breaking) in localized areas that previously produced normal crop growth, which may indicate a rising water table where soil salinity is not yet high enough to reduce crop growth and yield: (6) increased infestations of salt-tolerant weeds; (7) stunted or dying trees in a shelterbelt or windbreak: and (8) poor seed germination.

Methods for measuring soil salinity based on the electrical conductivity of the soil have been developed for identifying potential saline seep areas. Four-electrode resistivity and electromagnetic inductive techniques have been used to characterize soil-profile salinity levels of saline seep areas and to identify recharge areas. These electrical conductivity methods can be used for detecting and delineating saline seeps, for measuring and mapping field soil salinity, and for verifying areas of high and low salinity in the field without need for laboratory analyses. Thus, salinity in suspected saline seep areas can be monitored in comparison to surrounding nonseep areas. Existing saline seeps generally have high levels of salinity at the soil surface, and these levels decrease with soil depth. Developing seep areas generally have low-to-medium levels of salinity at the soil surface, with higher salinity at shallow (1–2 m or 3–6 ft) soil depths and lower salinity at greater depths. Soil salinity generally increases gradually with increasing soil depth in the recharge area (**Fig. 3**).

Delineating the location and approximate size of recharge areas is essential to designing successful control treatments. Generally, recharge areas are located a

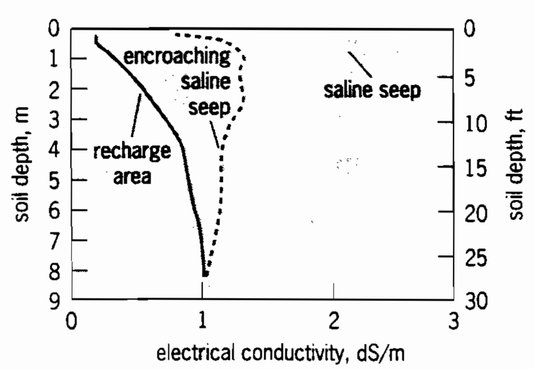

Fig. 3. Typical four-probe electrical conductivity readings as a function of soil depth in a saline seep recharge area, encroaching saline seep area, and saline seep area. (*After A. D. Halvorson and J. D. Rhoades, Assessing soil salinity and identifying potential saline-seep areas with field soil resistance measurements, Soil Sci. Soc. Amer. J., 38:576–581, 1974*)

Table 2. Yields, in metric tons/hectare,* of several crops grown in two reclaimed saline seeps in 1978 and 1979 co... to average county yields in northeastern Montana†

Crop	1978	1979	Average	1978	1979
		Seep A			Richland County
Spring wheat	2.5	1.6	2.1	2.2	1.4
Barley	4.5	2.1	3.3	2.4	1.3
Oats	3.4	1.6	2.5	2.0	1.2
Alfalfa	5.7	9.8	7.8	4.3	3.4
		Seep B			Roosevelt County
Spring wheat	2.4	1.8	2.1	1.8	1.3
Barley	3.9	3.3	3.6	2.1	1.4
Oats	5.3	2.2	3.8	1.8	1.2
Corn (silage)	16.9	3.5	10.2	17.9	11.2

* 1 metric ton/ha = 0.45 ton/acre.
† From A. D. Halvorson, Saline-seep reclamation in northern Great Plains, *Trans. ASAE*, 27:773–778, 1984.

short distance upslope from the discharge or seep area. Information from test holes, water table levels, salinity measurements, visual observations, and topography can be used to delineate the approximate recharge-area location. A combination of probing, mapping field salinity levels, and drilling test holes is an effective way to locate recharge areas.

Control. Since seeps are caused by water moving below the root zone in the recharge area, there will be no permanent solution to the saline seep problem unless control measures are applied to the recharge area. There are two general procedures for managing seeps. In the first, ponded surface water is drained mechanically before it infiltrates, and the lateral flow of subsurface water is intercepted with drains before it reaches the discharge area. The second method is to let crops use the water before it percolates below the root zone.

Hydraulic control can be quickly and effectively accomplished with subsurface interceptor drains located on the upslope side of the seep area. However, a suitable outlet for disposal of the saline water needs to be available. Outlet considerations must include not only an easement for transport of drainage water across intervening lands but also the effect of drainage waters on the quality of the receiving streams or reservoirs. The water is saline, usually high in both sulfate and nitrate, and disposal is difficult because of environmental, physical, and legal constraints. Therefore, subsurface drainage is generally not satisfactory because of disposal problems and the economics of dryland crop production. The best approach is to use the soil water for crop growth before the water becomes saline.

Hydraulic control of saline seep areas can be accomplished by planting crops and employing cropping systems that will effectively use soil water in the recharge area. This approach requires identification of the recharge area, followed by adoption of appropriate cultural practices to minimize deep percolation. Any delay in implementing control practices can lead to a larger problem that is more difficult to manage. Alfalfa (*Medicago sativa*), seeded in recharge areas, effectively controls or stops excessive percolation. ... seep areas have dried sufficiently with alfalfa to ... normal grain and forage crop yields (**Table 2**) ... a saline seep area has been controlled, reclaimed ... returned to normal crop production, soil water ... recharge area must be continually managed to pr... recurrence.

Flexible cropping systems, which involve ... ing a crop in years when stored soil water a... pected growing-season precipitation are suffic... produce an economic crop yield, have been ... to control saline seeps. Using flexible, small ... cropping systems to gain hydraulic control o... discharge areas is a slower process than usi... falfa. Inclusion of safflower (*Carthamus tinctori...*) ... sunflower (*Halianthus annuus*), which are norm... deeper-rooted than small grains, will help deple... stored soil water to greater depths.

Reclamation. Before reclamation of a ... seep area can proceed, the flow of water from ... recharge area must be reduced to the extent th... water table depth in the saline seep has been ... ered sufficiently (to more than 150 cm or 59 ...) ... prevent movement of salts by capillary action ... the water table into the root zone. Both research ... farmer experiences show that reclamation occurs ... rapidly. With a water table depth in the seep area ... is more than 150 cm (59 in.), reclamation proced... to remove salts from the root zone can proceed. R... of reclamation depends on the amount of precipita... received to leach the salts. Therefore, practices such ... snow trapping or fallowing in the summer in the ... affected area will enhance water movement throu... the profile and hasten the reclamation process.

Socioeconomic concerns. Saline seeps ... not respect property lines. A recharge area on ... farmer's property can supply water to a discharge are... on a neighbor's farm, or the seep discharge can co... taminate a stream, natural drainageway, or farm pond. ... Except for small, uncomplicated seeps, most farmer... need help in diagnosing their saline seep problem and ... in developing cropping systems or other control mea... sures. When a recharge area is on an adjacent farm, ...

operation of landowners is needed. Knowledgeable ividuals or agencies can assist by characterizing the oblem and recommending control measures. Legation may provide procedures for farmers to form linity control districts to achieve collectively what nnot be done individually.

Saline seep is not just a farming problem. Any loss farmland decreases a nation's food and tax base. lty water from seeps can pollute fresh surface waters d add to the salinity of groundwater. The saline ep problem has political implications, involving such estions as subsidies, crop acreage allotments, and ndowner rights. In the United States, federal farm ograms have sometimes adversely affected progress controlling saline seeps by restricting the acreage at can be planted to small grains or other seep control ops.

For background information SEE AGRICULTURAL SOIL ND CROP PRACTICES; GROUNDWATER HYDROLOGY in the McGraw-Hill Encyclopedia of Science & Technology.

Ardell D. Halvorson

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Soil ecology

The traditional view of ecosystems suggests that the importance of animals derives from their consumption of energy and materials. In contrast, recent studies suggest that terrestrial animals do not consume a great percentage of the material produced by green plants in most ecosystems. Instead, the importance of animals to the structuring and functioning of ecosystems is related to activities other than consumption. For example, both pollination and disease can control the structure and functioning of ecosystems, yet the importance of animals as pollinators of plants is not related to the quantity of energy or materials that the animals consume; nor does their important role as agents in the transmission of disease relate directly to their involvement in the energy dynamics of ecosystems.

Another animal activity that significantly affects the composition and functioning of ecosystems is burrowing by fossorial species. The term fossorial (adapted to a burrowing mode of life) is often restricted to burrowing organisms that rely on the resources that they extract belowground.

Only the direct effects of an animal's digging activities on soil properties and the subsequent influences on the ecosystem will be considered in this article. Such an approach ignores effects of fossorial animals that are related to removing whole plants or their parts during feeding, and effects of fertilization due to the production of feces.

Fossorial species. Numerous animals dig in soil. Often this digging involves merely scratching through the soil surface to obtain food. Many large mammals obtain consumable plant parts in this manner. Obviously, this digging can have some effect on ecosystem properties; however, the more intense, subterranean burrowing activities of the fossorial organisms have a more pronounced effect. Burrowing is a common activity in taxonomic groups, ranging from minute insects to large mammals. Species that are especially familiar as burrowers include moles, prairie dogs, a variety of rodents, badgers, foxes, some rabbits, armadillos, a host of insect species (especially ants, wasps, beetles, termites, and cicadas), some tortoises, a few birds, and frogs. Fossorial species occur worldwide in most ecosystem types. However, they are most common in areas that are not heavily forested, and they are generally small. Among the largest is the aardvark (*Orycteropus afer*) of Africa.

While some burrowers exhibit few adaptations to a subterranean life and spend only part of their time belowground, others are highly specialized. A prime example of specialization is a family of rodents confined to the New World—the Geomyidae, usually called pocket gophers. This family consists of 5 genera and about 35 species that occur from British Columbia, Canada, to Colombia, South America. Pocket gophers are familiar in many areas of North America because of characteristic mounds that are created during the burrowing process and linear casts of soil that appear on the ground surface following the melting of winter snow. All members of the family spend their lives in burrows, where they forage, mate, give birth, and die; they seldom come to the surface. Their feet, teeth, muscles, sense organs, and respiratory characteristics are adapted to a subterranean life.

Effects of burrowing animals. As animals burrow or dig, they can alter the physical, chemical, or biological properties of the soils. These changes affect the soil's properties and its inhabitants. This observation was described by Charles Darwin in 1888 in a work that detailed the effects of burrowing by earthworms.

Physical effects in soils result from merely turning the material over—changing its bulk density, mixing different combinations of particle sizes in soil, or aerating soils by burrow creation. The changes in bulk density (how compacted the soil is) are similar to those caused by a person digging in a yard. When a hole is dug and then refilled with the removed material, there will be an excess of soil that forms a mound because the soil volume has increased. As burrowers dig, the increased volume of soil must be recompacted, used to fill an existing tunnel, or moved to the surface to keep the burrow system clear. Soil moved to the surface covers the existing soil and plants; because of its lesser bulk density, this excavated soil is more