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Agricultural Salinity Assessment and Management

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CHAPTER 17

MANAGEMENT OF DRYLAND SALINE SEEPS[a]

INTRODUCTION

Discussed in this chapter are the diagnosis, control, and reclamation of dryland saline seep problems.

A saline seep results from a salinization process, often accelerated by dryland farming, which allows water to move through salt-laden substrata below the root zone. It refers to intermittent or continuous saline water discharge at or near the surface of the soil, downslope from recharge areas under dryland conditions. It reduces or eliminates the growth of crops in the discharge area due to increased soluble concentrations of salt in the root zone. 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 (Brown et al. 1983).

Saline seeps occur frequently in dryland farming areas throughout the Great Plains (Ballantyne 1963; Berg et al. 1986; Brown et al. 1987; Colburn 1983; Doering and Sandoval 1976b; Halvorson and Black 1974; Neffendorf 1978; Vander Pluym 1978). Miller et al. (1981) estimated that nearly 1 million ha of productive cropland has been salinized in the northern Great Plains. Saline seep problems also exist in Australia (Malcolm 1982; Matheson 1968), India, Iran, Turkey, and Latin America (Olson 1978). Saline seeps result from a combination of geologic, climatic, hydrologic, and cultural (land-use) conditions. The primary cause is a change from grassland or forest to a cropping system, such as crop-summerfallow rotation, that allows rainfall in watershed recharge areas to move below the root zone and provide seepage water.

Factors Contributing to Saline Seep Development

The characteristics and causes of saline seeps in the Great Plains are similar (Berg et al. 1986; Brown et al. 1983; Doering and Sandoval 1976a; Doering and Sandoval 1976b, Halvorson and Black 1974; Vander Pluym 1978). Typically, native grasses or naturally occurring vegetation have been replaced with agricultural fields and cropping systems with lower potential evapotranspiration requirements. Precipitation that exceeds the root zone's storage capacity, which takes place primarily during summerfallow periods, is the source of water.

The crop-summerfallow system of dryland farming has contributed significantly to the development of saline seep problems in the

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northern Great Plains but is not the sole cause (Brown et al. 1983; Christie et al. 1985; Halvorson and Black 1974). Also contributing to the development of seeps are periods of above-normal precipitation, restricted surface and subsurface drainage due to the building of roads and pipelines, large snowdrifts, gravelly and sandy soils, obstructions across natural drainageways (e.g., roads), uncapped or poorly cased artesian water wells, leaky ponds and dugouts, and crop failures. These factors, combined with the right geologic conditions, can result in saline seeps years after vegetation has changed. Water conservation practices in the southern Great Plains, such as level bench terraces, have contributed to the development of saline seeps (Berg et al. 1986; Naney et al. 1986).

Types of Saline Seeps

Miller et al. (1981) discussed geologic formations of the northern Great Plains. Materials in the soil profile vary from glacial till deposited over shales to highly stratified, water-deposited geologic materials. Brown et al. (1983) diagrammed several geologic conditions that can result in seeps in the northern Great Plains (Fig. 17.1). Seeps generally develop on sidehills or toe slopes of rolling to undulating topography, where permeable material lies above less permeable strata that are conducive to the development of perched water tables. Characteristics of different types of seep are as follows:

1. *Geologic outcrop seep.* The recharge area lies above material of low hydraulic conductivity (HC) such as shale, dense till, or clay. Soil above the low HC layer varies in texture and depth. Most of the seeps expand laterally and downslope. Only limited expansions occur upslope.
2. *Coal seam seep.* The recharge area lies above coal, which, in turn, lies above clay of low HC. Soil above the coal seam varies in texture. Water moves laterally through the coal-related material at a rapid rate. Seepage occurs where outcropping and truncated coal beds exist. Coal seeps typically expand laterally and downslope.
3. *Glaciated Fort Union seep.* The recharge area of glacial till lies above sandstone, siltstone, lignite, and clay strata of the Fort Union Formation. Water in the recharge area enters permeable strata to form a water table above a zone of low HC. Seepage water moves downslope to glacial till. The till is of lower HC and truncates the permeable zone, causing the water table to rise. Seep expansion is generally upslope, with some downslope and lateral expansion.
4. *Textural change seep.* The recharge area lies above material with a low HC. The soil above the zone of low HC has a coarse or medium texture. Water moves through the root zone to a zone of low HC, then laterally downslope until it encounters a zone of lower HC, which slows movement and causes the water table to rise to the surface of the soil. Seep expansion is lateral and downslope.
5. *Slope change seep.* The recharge area lies above geologic material of low HC. Soil above the zone of low HC varies in texture. Water moves through the root zone to the zone of low HC, then laterally downslope to where the slope decreases. The reduced gradient at that location

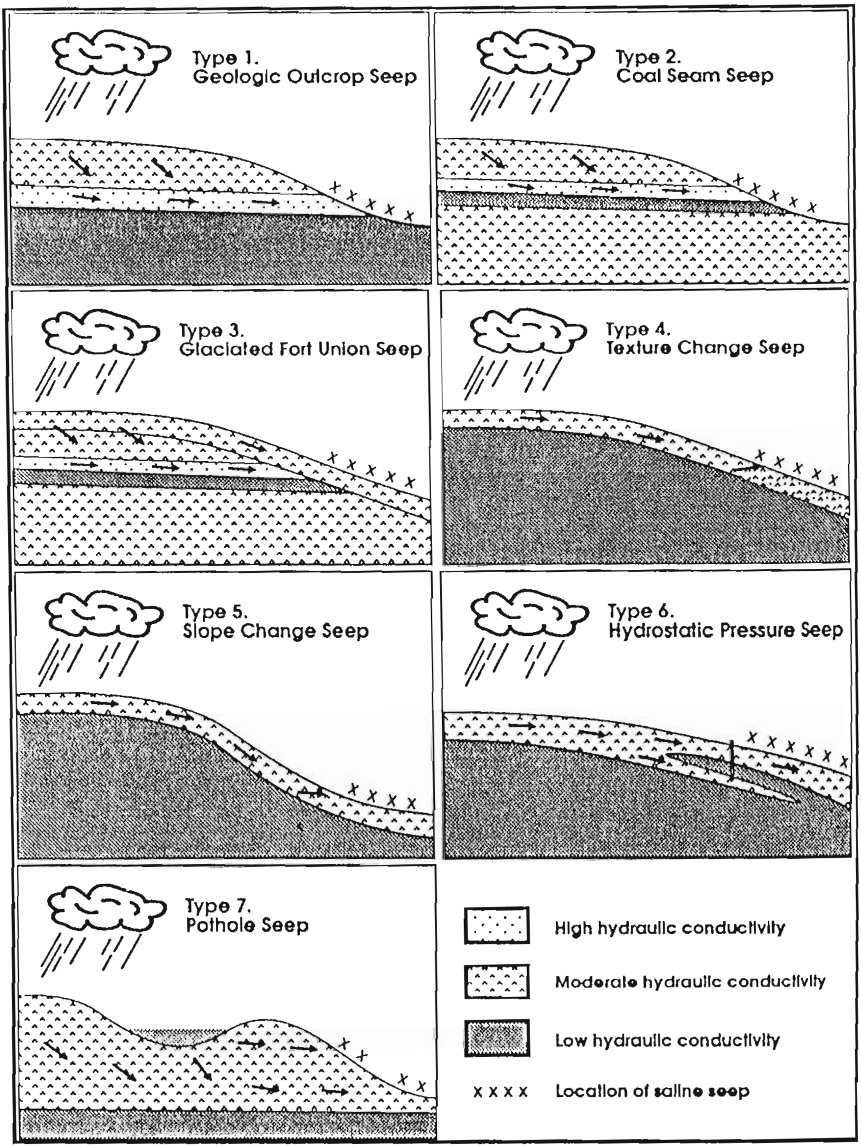

Fig. 17.1 Schematic Diagrams Illustrating Seven Geologic Conditions for Saline-Seep Development (Brown et al. 1983)

causes water to move slower and the water table rises, forming a seep. Seep expansion is mostly lateral and downslope with some upslope expansion.

6. *Hydrostatic pressure seep.* The recharge area lies above geologic material of low HC. Soil above the dense layer varies in texture. Water moves through the root zone to the zone of low HC and then laterally downslope to a zone of low HC located above the saturated zone. The confined water is under hydrostatic pressure. This often forces water through fractures to the surface of the soil and causes a saline seep. The

seep expands mostly laterally and downslope. The recharge area may be located at a greater distance and at a higher elevation than for other types of seeps.

7. *Pothole seep.* The recharge area has potholes or poorly drained areas that lie above material of low HC. Water moves through slowly permeable material in a pothole to a zone of low HC, then downslope, where it may encounter a zone of higher HC that outcrops at or near the surface of the soil to form a saline seep. The seep primarily expands laterally and downslope. The rate of seepage increases rapidly during periods of high precipitation, when ponded water volumes are greatest, and contracts during dry periods.

The above types of seeps vary in the field. Understanding the geology and circumstances that cause a saline seep to form will help in designing ways to control or prevent them. Agronomic practices generally work well for some types of seeps: geologic outcrop, coal seam, glaciated Fort Union, texture change, and slope change. They need to be combined with drainage and land leveling for hydrostatic pressure seeps and pothole seeps.

WATER QUALITY ASSOCIATED WITH SALINE SEEPS

As water passes through the soil profile toward the perched or permanent water table, salts dissolve and move downward. Hydrologic studies show that seeps are generally sustained by local recharge areas (Doering and Sandoval 1976a; Halvorson and Black 1974; Halvorson and Reule 1980; Hendry and Schwartz 1982; Naney et al. 1986).

Numerous studies document the movement of soluble salts and NO_3-N toward and into shallow water tables. Ferguson and Batteridge (1982) have estimated that as much as 90 Mg/ha of salt has migrated toward the ground-water table in glacial till soils of north-central Montana after several decades of grain production. Christie et al. (1985) reported that the soil-profile salinity of cultivated land decreased more than that of an adjacent native non-cultivated area, indicating movement of salt to lower depths. Doering and Sandoval (1981) reported that a drained seep area had lost salt and 50 kg NO_3-N/ha.

The data in Table 17.1 show the chemical composition of waters associated with several saline seeps in the northern and southern Great Plains. The shallow ground water often associated with saline seeps is unsuitable for consumption by humans and livestock due to high levels of salt and NO_3 (>0.7 mmol/l) and unsuitable for irrigation due to total salt concentration. Calcium, magnesium, and sodium are the dominant cations and sulfate is the dominant anion in most of the shallow ground water associated with saline seeps. Compared to sulfates, chlorides exist in water and soil at relatively low concentrations in the northern Great Plains. They occur at slightly higher concentrations in the southern Great Plains. Soils in seep areas are generally in equilibrium with gypsum, lime, and other types of Ca-Mg sulfate minerals (Brun and Deutch 1979; Doering and Sandoval 1981; Oster and Halvorson 1978; Timpson et al. 1986).

TABLE 17.1 Chemical Composition of Waters Associated with Saline Seeps in the Great Plains

Location (1)	pH (2)	EC (dS/m) (3)	Ca[a] (4)	Mg[a] (5)	N[a] (6)	HCO_3[a] (7)	NO_3[a] (8)	Cl[a] (9)	SO_4[a] (10)	Reference (11)
MT recharge	8.4	5	7	11	18	3.8	4.3	0.7	21	Halvorson and Black (1974)
MT seep	8.2	9	8	21	66	9.8	0.4	0.8	52	Halvorson and Black (1974)
MT seep	7.9	14	10	37	109	8.1	29.5	2.6	80	Halvorson and Black (1974)
MT seep	8.4	26	1	108	211	4.0	5.4	7.6	225	Miller (1971)
MT recharge	8.2	7	3	21	39	2.4	6.2	11.2	44	Miller (1971)
ND seep	3.7	10	9	36	59	—	5.7	2.1	70	Doering and Sandoval (1981)
ND seep	4.6	8	9	30	40	—	4.7	2.5	55	Doering and Sandoval (1981)
OK seep	8.1	5	15	16	26	—	0.6	12.3	27	Berg et al. (1986)
OK seep	8.2	3	3	17	13	—	—	16.0	15	Naney et al. (1986)

[a] Chemical elements in mmol/l.

Researchers in the northern Great Plains have concluded that the NO_3 in ground water originates mainly from exchangeable NH_4 of geologic origin located deep in the profile and from NO_3 that comes from mineralized organic matter and is leached from the root zone during periods of summerfallow (Doering and Sandoval 1981; Hendry et al. 1984; Power et al. 1974). The NH_4 is oxidized to NO_3. Little, if any, of the NO_3 had its origin as fertilizer N because little fertilizer N was used by dryland farmers in the northern Great Plains before the early 1970's, when saline seeps became a problem.

IDENTIFICATION OF RECHARGE AND DISCHARGE (SEEP) AREAS

Early detection and diagnosis of a saline-seep problem may allow a farmer to change current cropping systems to minimize the damage. Postponing the use of control practices obviously leads to a problem that is more difficult to control.

Visual Assessment

Brown (1976) described several visual symptoms of the impending development of saline seeps: vigorous growth of kochia (*Kochia scoparia* L.) or other weeds after the harvest of grain in areas where the soil normally would be too dry to support the growth of weeds; the presence of salt crystals on the surface of the soil; prolonged wetness of the surface in localized areas after rainfall; the slipping of tractor wheels or

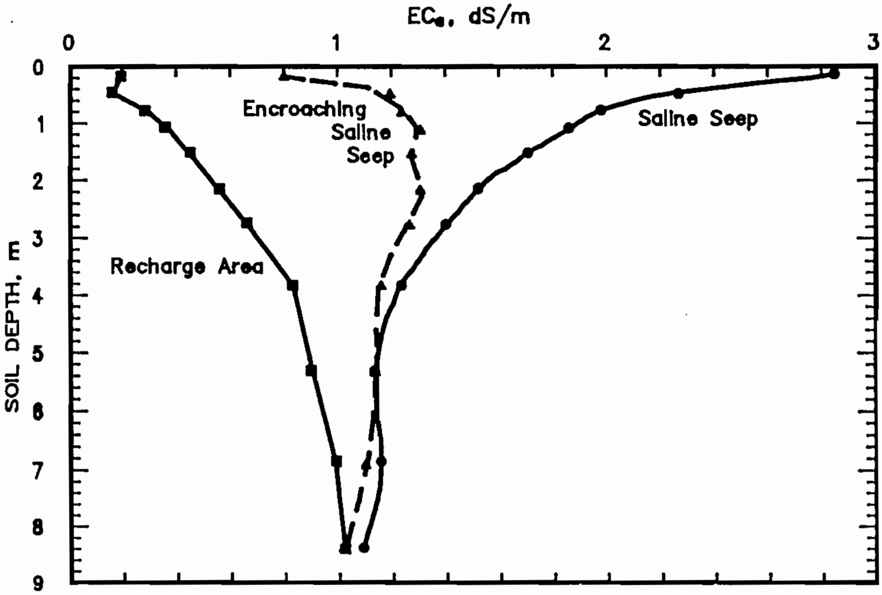

Fig. 17.2 Typical Four-Probe Electrical Conductivity (EC_a) Readings as a Function of Soil Depth in Saline-Seep Recharge Area, Encroaching Saline-Seep Area, and Saline Seep Itself (Halvorson and Rhoades 1974)

the bogging down of equipment in areas of a field, or the seepage of water into the tracks of wheels, with salt crystals becoming visible as the soil dries; crop growth accompanied by lodging in areas of the field that previously produced normal growth; increased infestations of foxtail barley (*Hordeum jubatum* L.); stunted or dying trees in a shelterbelt or windbreak; and poor seed germination.

Field Assessment of Soil Salinity

Electrical conductivity (EC) methods for measuring soil salinity have been developed to identify areas where saline seeps may develop. Halvorson and Rhoades (1974, 1976) and Halvorson et al. (1977) used a four-electrode resistivity technique to characterize the salinity levels of the soil profile and to identify recharge areas and incipient and existing saline seep areas (Fig. 17.2). Rhoades and Halvorson (1977) also used electrical conductivity methods to delineate saline seep areas and map soil salinity.

Saline seeps generally have high levels of salinity at the surface of the soil, decreasing with depth. Developing seep areas generally have low to medium levels of salinity at the surface of the soil, with higher salinity at a depth of 30 cm to 90 cm and lower salinity at deeper depths. Salinity generally increases gradually with increasing depth in recharge area.

Cameron et al. (1981) described the use of electromagnetic inductive techniques for measuring and mapping soil salinity in the field. This method can also be used to verify areas of high and low salinity in the field without laboratory analyses.

Locating Recharge Areas

The size of recharge areas must be delineated and estimated before treatments for controlling saline seeps can be designed. Generally, recharge areas are located a short distance (180 m–600 m) upslope from the discharge or seep area. If gravel beds and sandy soils are involved, recharge areas may be within 30 m. The recharge area usually is located directly upslope or at an angle across the slope from the discharge area (Brown et al. 1983). The following methods may be useful for determining the location and size of recharge areas.

Soil Maps and Geologic Information. Soil survey maps can be used to locate sandy or gravelly soils located upslope from the discharge area, as well as poorly drained areas, such as potholes. Geologic maps can provide information on subsurface stratification, the type of saline seep, and depths to permanent ground-water tables.

Soil Moisture Probes and Test Holes. If a seep is surrounded by elevated topography on several sides, a soil moisture probe (Brown 1958) can be used to identify the location of recharge area relative to the seep by locating abnormally wet soil in one general direction. Augering or coring machines can be used to examine and sample soil profiles to greater depths. Each drilled hole should be carefully logged during drilling. The depths at which dense materials, such as clay and shale, or highly permeable materials, such as sand, gravel, silt, and lignite, are encountered should be recorded. The depth to the water table should be noted and the hole cased with perforated pipe so that depths of the water table can be periodically monitored and water samples can be collected. Information collected from the test holes, including well log data, water depth, and salinity measurements, can be combined with visual observations and topography to delineate the recharge area. Often, soil moisture probes and a few well-placed test holes will provide the most economical way to locate a recharge area.

Visual Inspection. When soil survey maps, drill rigs, and equipment for measuring soil salinity in the field are unavailable, visually locate the upslope area, direction of seep expansion, and upslope factors that may contribute water to the discharge area. Bear in mind that: 1) The recharge area is higher in elevation than the seep area; 2) the recharge area is generally within 600 m of the seep area; 3) saline seeps in glacial till areas generally expand laterally and upslope toward the recharge area; 4) saline seeps in nonglaciated areas tend to expand laterally and downslope away from the recharge area; and 5) if the seep does not begin to dry up within two to three years of implementing control measures, such as planting alfalfa or grasses or annually cropping the suspected recharge area, the boundary of the recharge area was incorrectly identified, or the recharge area was larger than anticipated, or the seepage water may be coming from an artesian source.

METHODS FOR CONTROLLING SALINE SEEPS

Since seeps are caused by water moving below the root zone in the recharge area, the saline seep problem will not be permanently solved unless control measures are applied to the recharge area. Two procedures for managing seeps are: 1) Mechanically drain ponded surface water before it infiltrates, and intercept lateral flow of subsurface water with drains before the water reaches the discharge area; and 2) agronomically use the water before it percolates below the root zone.

Drainage

Undulating, near-level land with poor surface drainage (potholes) can create recharge areas for saline seeps. Runoff takes place after rainfall and snowmelt, causing these areas to fill with water temporarily. Where possible, surface drains are installed to prevent the temporary ponding of surface water. Drainageways under roadbeds should be cleared of debris and sediment so that they do not temporarily pond surface water. In the central Great Plains, level bench terraces serve as temporary water impoundments that may be contributing water to saline seeps (Berg et al. 1986; Naney et al. 1986). Their use may need to be evaluated if saline seepage is a problem.

Drainage studies have shown that hydraulic control can be accomplished quickly with subsurface interceptor drains located on the upslope side of the seep area (Doering and Sandoval 1976a; Sommerfeldt et al. 1978). However, a suitable outlet for disposal of the saline water must be available. Outlet considerations include easement for transport of drainage water across intervening lands and the effect of drainage waters on the quality of receiving streams or reservoirs. Because seep waters are saline and typically high in nitrate, disposal into downstream surface waters or ground waters is difficult due to physical and legal constraints and costs. Therefore, subsurface drainage is generally not a satisfactory solution to the problem. The best approach is to use the soil water for growing crops when the soil water is in the root zone of the recharge area and relatively nonsaline.

Mole drains have been used in Alberta, Canada, to maintain water tables at a sufficient depth to prevent the accumulation of salts on the surface of the soil (Sommerfeldt et al. 1978). Procedures for using mole-type drains are specific to the site. With moist, cohesive, fine-textured soils and shallow water tables (<100 cm), drains installed on proper grade work well. Such drains may not work in noncohesive soils and with a water table that is >100 cm below the surface of the soil (Sommerfeldt 1976).

Oosterveld (1978) used seep discharge water to irrigate the recharge area, thus, recycling the salts. Limited water supplies for irrigation, the cost of an irrigation system to deliver the water, and the buildup of soil salinity in the recharge area may reduce the usefulness of this technique.

Agronomic Practices

Hydraulic control of saline seep areas can be achieved by planting crops that use available soil water supplies in the root zone of the re-

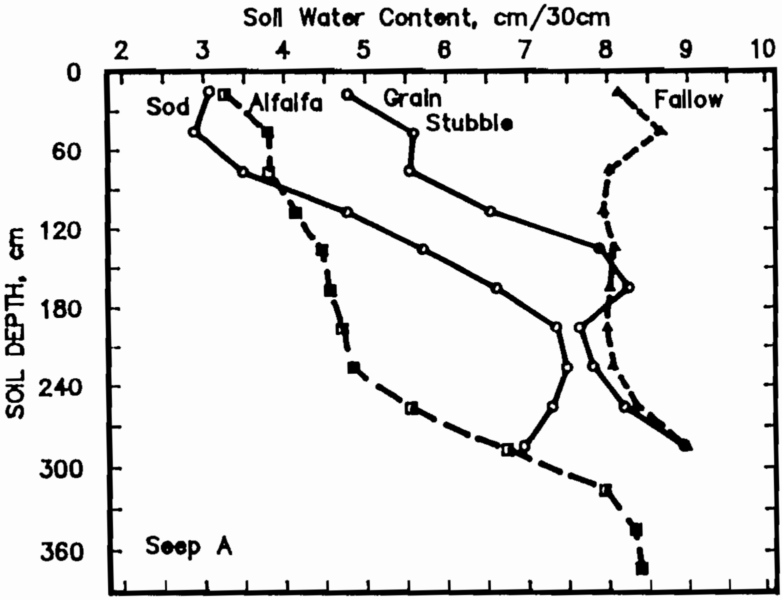

Fig. 17.3. September 1976 Soil Water Profiles of a Saline-Seep Recharge Area in Native Range Sod, Alfalfa (Seeded in 1973), Spring Wheat Stubble, and Summerfallow (Halvorson and Reule 1980)

charge area. To do so, the recharge area must be delineated; and practices that maximize the use of soil-water and minimize deep percolation must be adopted.

Alfalfa (*Medicago sativa* L.), seeded in recharge areas, is one crop that helps to control seep discharge areas hydraulically (Brown et al. 1983; Brun and Worcester 1975; Halvorson and Reule 1980). In Montana, Halvorson and Reule (1980) found that alfalfa extracted more water from the soil profile than native grass sod or small grain crops (Fig. 17.3). Alfalfa depleted more soil water to a depth of 3.0 m than did other crops. This created a larger reservoir in the soil to store precipitation more effectively, thus, reducing the potential loss of water via deep percolation. With the upslope recharge area in alfalfa, the saline seep area dried sufficiently to once again obtain normal yields (Halvorson 1984). In Colorado, alfalfa established in a terraced recharge area in 1984 hydrologically controlled an active saline seep (Halvorson 1988). By the autumn of 1985, the seep had dried sufficiently to allow the seep area, once again, to be worked with farm machinery. In 1987, three cuttings of alfalfa were harvested from the discharge area, where only salt-tolerant weeds had grown in 1984.

Brown and Miller (1978) and Miller et al. (1981) showed that alfalfa controlled saline seeps effectively, while Brown (1983) further showed that it took seven to eight years to recharge the dried soil profile to field-capacity water content, when a summerfallow-winter wheat-barley rotation followed three years of alfalfa (Table 17.2). Halvorson and Reule (1980) reported a rise in the level of the water table where a farmer

TABLE 17.2 Total Soil-Water Content (0.0 m–4.6 m) at the End of Each Growing Season Following Three Years of Alfalfa (Brown 1983)

Year (1)	Crop/ summerfallow (2)	Fall Soil Water ($mm\ H_2O/4.6\ m$) (3)	Annual Precipitation (mm) (4)
1973	Alfalfa (3rd yr)	217	—
1974	Summerfallow (no crop)	342	278
1975	Winter wheat	330	563
1976	Barley	393	371
1977	Summerfallow (no crop)	448	363
1978	Winter wheat	461	418
1979	Barley	461	208
1980	Summerfallow (no crop)	524	380
1980	Estimated field capacity	573	—

reverted to a crop-summerfallow system of farming in the recharge area after several years of alfalfa production, during which hydraulic control of the seep area had been achieved and the seep area supported near normal crop production. These studies indicate that once a saline seep area has been controlled, reclaimed, and returned to normal crop production, a farmer cannot permanently return to a conventional crop-summerfallow system of farming in the recharge area. The soil water needs to be managed continually to prevent the recurrence of saline seep.

Other work has shown that small grain crops can be used to control saline seep areas (Alberta Agric. 1986; Bramlette 1971; Halvorson and Reule 1976; Holm 1983; Steppuhn and Jenson 1984). Using annual small-grain cropping systems to control seep discharge areas hydraulically is slower than using alfalfa because less soil water is used, and rooting depths are shallower. Oil-seed crops that are deeper-rooted than small grains, such as safflower and sunflower (Table 17.3), can help to deplete the stored soil water to greater depths, thereby increasing the capacity of the soil to store precipitation between crops or during periods of summerfallow.

Black et al. (1981) describe several dryland cropping strategies for controlling saline seeps in the northern Great Plains. They suggest using intensive, flexible cropping systems with adapted crops and soil, water, and crop management practices to improve the crop-production-water-use relationship enough to eliminate or reduce the need for summerfallow.

Flexible cropping involves planting a crop only in years when soil-water and precipitation are expected to be sufficient to produce an economic crop yield. Each year, based on data regarding soil water and expected precipitation during the growing season, the farmer decides to crop or summerfallow the area where the seep occurs (Alberta Agric. 1986; Brown et al. 1981; Naney et al. 1986). Re-cropping or annual crop

TABLE 17.3 Rooting Depth and Soil-Water Use by 11 Dryland-Grown Crops (Black et al. 1981)

	Fort Benton, Montana		Culbertson, Montana	
Crop (1)	Rooting Depth (m) (2)	Soil Water Use (mm) (3)	Rooting Depth (m) (4)	Soil Water Use (mm) (5)
Alfalfa (1st yr)	2.1	178	—	—
Alfalfa (4th yr)	5.5	666	—	—
Sanfoin (1st yr)	1.5	150	—	—
Sanfoin (4th yr)	4.0	561	—	—
Russian wild rye (1st yr)	2.1	318	—	—
Russian wild rye (4th yr)	3.0	475	—	—
Sweet clover (1st yr)	1.8	276	—	—
Sweet clover (2nd yr)	2.7	403	—	—
Safflower	2.2	249	2.1	229
Sunflower	2.0	206	—	—
Winter wheat	1.8	200	1.6	190
Rapeseed	1.5	170	—	—
Spring wheat	—	—	1.2	152
Barley	1.4	190	1.1	135
Corn	1.2	94	—	—

ping is ill-advised when less than about 76 mm of soil water is available at planting time (Alberta Agric. 1986; Black and Ford 1976).

Farmers can use a moisture probe to determine soil moisture profiles (Brown 1958), or they may determine soil water content in another way. Halvorson and Kresge (1982) have developed a computer model, FLEXCROP, to help farmers select the best cropping and soil management strategies for wheat (*Triticum aestivum* L.), barley (*hordeum sativum*, Jess.), oats (*Avena sativa* L.), and safflower based on stored soil water and expected precipitation (the program is available from the author). Weed control and soil fertility are also critical factors in developing flexible dryland cropping systems.

Black et al. (1981) reported that crops grown under annual cropping systems used an average of 75% to 81% of the precipitation received between crop harvests within a grass barrier system. Conventional spring wheat-summerfallow systems used only 40% (Table 17.4). The amount of unused available water between crops, a portion of which may contribute to the development of saline seeps, averaged 473 mm for spring wheat-summerfallow systems and only 72 mm to 98 mm for annual cropping systems. These data show that more water, nitrates, and dissolved salts can be moved below the root zone with a spring wheat-summerfallow system than with an annual cropping system. Adequate fertility is essential for optimizing yields with annual cropping systems (Black et al. 1982, deJong and Halstead 1986, Halvorson et al. 1976, Schneider et al. 1980).

If intensive, flexible cropping systems are to succeed, more effi-

TABLE 17.4 Average Precipitation-Use Efficiency (PUE) per Cropping Sequence, as Influenced by Cropping System Within a Tall Wheat Grass Barrier System over a 12-Year Period (Black et al. 1981)

Cropping system (1)	Number of crops per year (2)	Total precipitation per crop (mm) (3)	Total[a] water use per crop (mm) (4)	PUE[b] (%) (5)	Annual grain yield[c]		WUE[c,d]	
					Without Nitrogen (kg/ha) (6)	With Nitrogen (kg/ha) (7)	Without Nitrogen (kg/ha-mm) (8)	With Nitrogen (kg/ha-mm) (9)
Annual cropping								
1. 6WW-B-S-B-WW-S-B	1.00	396	322	81	1328	1794	3.4	4.5
2. 5SW-S-B-WW-B-WW-B-WW	1.00	394	296	75	993	1822	2.5	4.6
3. 4SW-S-B-WW-S-SW-B-WW-B	1.00	390	318	82	969	1590	2.5	41
Three-year rotation								
1. SW-WW-F	0.66	569	333	59	997	1416	2.6	3.7
Crop-summerfallow								
1. WW-F	0.50	788	404	51	1019	1247	2.6	3.1
2. SW-F	0.50	786	313	40	853	1065	2.2	2.7

WW = winter wheat; SW = spring wheat; B = spring barley; S = safflower; F = Summerfallow.

[a] Water-use per crop is based on soil water use to 120-cm depth plus precipitation received from seeding to harvest.

[b] PUE = [(total water use/crop)/(total precipitation received/crop)] × 100.

[c] Applied nitrogen of 34 kg N per ha each crop year.

[d] WUE = water use efficiency = [(grain yield/ha)/(total precipitation/crop rotation)] × 100.

cient methods for storing soil water during fallow periods must be found. In the northern and central Great Plains, supplies of soil water can be increased by controlling the growth of weeds and volunteer grain after harvest, leaving standing stubble to trap snow, using annual or perennial barriers or windbreaks for snow trapping and using reduced- or no-tillage cropping systems (Black and Siddoway 1976; Nicholaichuk and Gray 1986; Smika and Whitfield 1966). All of these practices enhance the efficiency of soil water storage. However, more intensive cropping systems than the conventional crop-summerfallow system must be used. Otherwise, the development of saline seep will intensify.

Cropping Strategies

Crops need different amounts of water to produce an economical yield because they have different rooting depths and water extraction patterns. Black et al. (1981) reported that safflower in Montana used more soil water and withdrew water from greater depths in one year than any other annual dryland crop (Table 17.3). Alfalfa used only slightly less water the first year than safflower and sweet clover (*Melilotus officinalis* L.), but its ability to use precipitation plus soil water from progressively deeper depths in successive years makes it the best crop to use first to hydrologically control seep recharge areas. Crops listed in order of decreasing rooting depth and soil water use are alfalfa, sweet clover, safflower, sunflower, winter wheat, rapeseed (*Brassica napus* L.), spring wheat, barley, and corn (*Zea mays* L.).

To decide which crop should succeed another, knowledge of the amount and depth of soil water depleted by the previous crop is needed. Crops should be grown in sequential order with increasing rooting depths, until the depth and amount of soil water removed exceeds soil water recharge during fallow periods (Black et al. 1982). Summerfallow should be used only when needed, e.g., after planting alfalfa or safflower, or when less than 76 mm of soil water exists at planting.

Crops must be rotated in a sequence that avoids weeds, diseases, and insect infestations. Rotating oilseed crops and small grain crops allows grass herbicides to be used, helping to control the buildup of grassy weeds in the small grain crops (Berg et al. 1979; Naney et al. 1986).

Soil fertility is almost as important as water in an annual cropping system. As cropping frequency increases, the need for N increases and responses to P fertilizer depend on the level of soil P and crop N's needs (Halvorson and Black 1985). Nitrogen needs should be balanced carefully with expected water supplies and the potential yield of the crop.

Strict adherence to a crop-summerfallow rotation restricts farmers to a fixed cropping system with limited flexibility to adjust cropping patterns to fit available water supplies. Selection of alternate cropping strategies to use available water supplies effectively requires a knowledge of the amount of water available at any given time, potential evapotranspiration requirements and rooting depths of adapted crops, and expected growing-season precipitation. A knowledge of the depth to some restricting or impermeable geologic strata and water table is

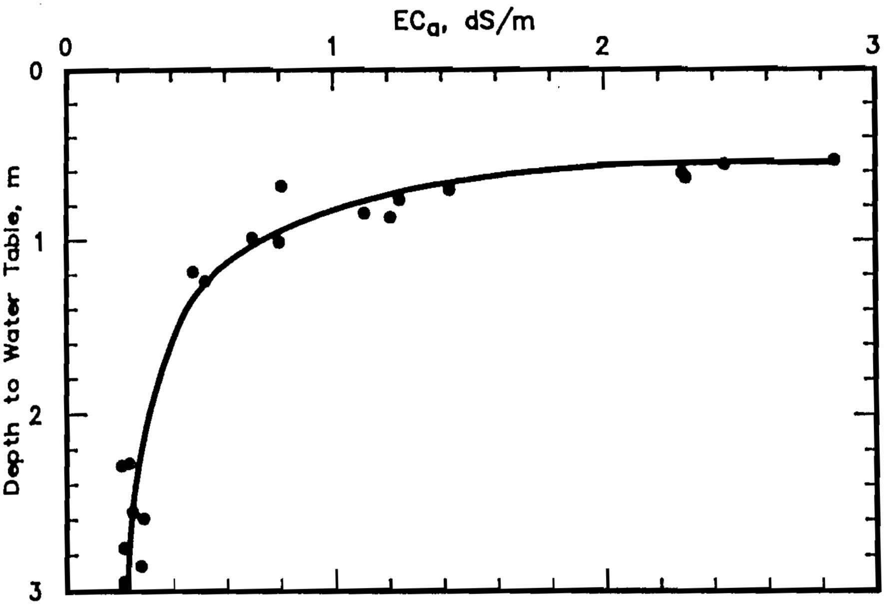

Fig. 17.4 Four-Probe Soil Electrical Conductivity (EC_a) Readings as a Function of Water Table Depth in a Saline Seep Area (Halvorson and Rhoades 1974)

essential if a cropping strategy to control or prevent saline seeps is to be developed.

RECLAMATION OF CONTROLLED SALINE SEEP AREAS

Before reclaiming a saline seep area, the flow of water from the recharge area must be reduced so that the depth of the water table in the area of the seep is low enough to prevent salts from moving up by capillary action into the root zone. If a saline water table is less than 90 cm below the surface, salts can move to the surface by capillary action. The depth of the water table often varies during the year and are shallower in spring and early summer than during the rest of the year. Fig. 17.4 illustrates the relationship between the depth of the water table and soil salinity in the upper 30 cm of soil.

Observation wells should be installed at strategic locations in recharge and seep areas to monitor water tables. A drill rig is needed to install deep wells in recharge areas, but a tractor-mounted post-hole auger or bucket auger can be used to install wells that are less than 180 cm deep. The level of the water table should be monitored monthly. A rising water table that persists into the summer months indicates that cropping practices should be intensified to increase the use of soil water.

The results of research and the experiences of farmers indicate that reclamation occurs quite rapidly (Brown and Miller 1978; Halvorson 1988; Halvorson 1984; Halvorson and Reule 1976 and 1980). If the depth of the water table in the seep area exceeds 150 cm, reclamation procedures to remove salts from the root zone can proceed. The rate of rec-

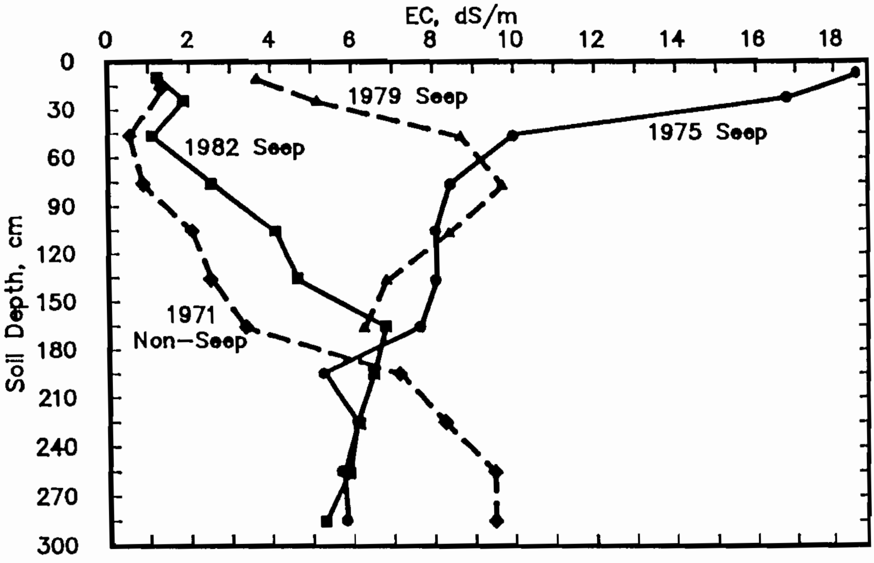

Fig. 17.5 Electrical Conductivity (EC) of Saturated Soil Extracts as a Function of Soil Depth and Time, for a Saline Seep Area that Was Brought Under Hydrologic Control and an Adjacent Non-Seep-Affected Soil (Halvorson 1984)

lamation depends on the amount of precipitation available to leach salts. Therefore, practices that enhance the downward movement of water in the salt-affected area, such as snow trapping or summerfallowing, accelerate reclamation. Summerfallowing can be used during reclamation to help increase downward leaching of salts from the soil profile. None of these practices will be effective, however, until hydrologic control is achieved in the recharge area and the water table is significantly lowered in the seepage area.

Halvorson (1984) reported that soil salinity at the 0-cm to 30-cm depth was markedly reduced two years after a seep was arrested, and various crops could be grown. Adding straw mulch to reduce loss through evaporation from the fallow area helped to accelerate the removal of salt from the 0-cm to 90-cm depth. The application of gypsum did not accelerate reclamation, probably because sufficient naturally occurring gypsum had been precipitated in the soil profile during the formation of saline seep. Because the salts present were Ca, Mg, and Na sulfates, neither the permeability nor the structure of the soil deteriorated during reclamation. Seven years after hydrologic control was achieved, soil salinity was still higher in the area of arrested saline seep than in adjacent areas (Fig. 17.5).

Miller et al. (1981) reported the control of a serious saline seep problem (4 ha in size) located in an 32-ha field near Fort Benton, Mont. "Ladak 65" alfalfa was seeded over the entire field in 1971, when the water table was 0.3 m below the surface in the seep area and 5.8 m below the surface in the recharge area. Six years later, the water table had dropped to 3 m below the surface in the seep area and to 8.5 m below the surface in the recharge area. Alfalfa roots had penetrated to a depth

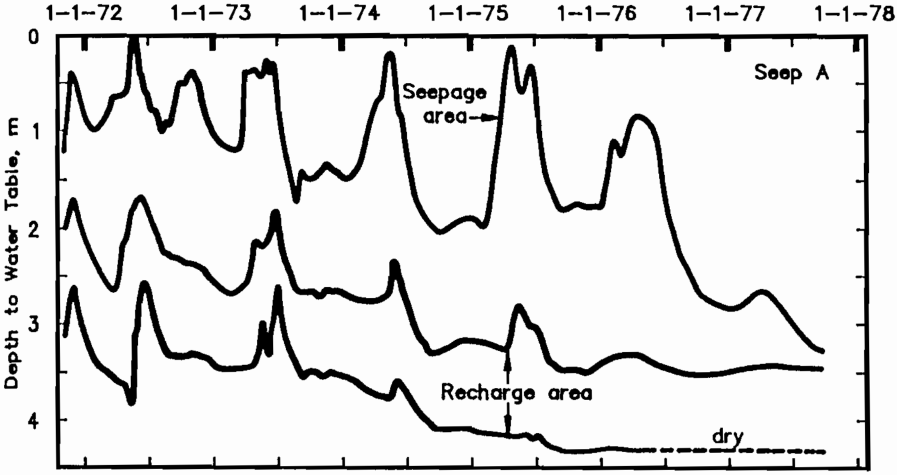

Fig. 17.6 Effect of Alfalfa, Seeded in Summer of 1973, on Water Table Depths in Recharge and Seep Areas on a Farm in Northeast Montana (Halvorson and Reule 1980)

of 4.6 m and had depleted 48 cm of water from the soil profile in the recharge area. The receding water table in the seep area was caused by the reduced flow from the recharge area. Soil salinity in the seep area was 21.3 dS/m and 13.9 dS/m for the 0-cm to 30-cm and 30-cm to 60-cm depths, respectively, in 1971, and 4.3 dS/m and 6.3 dS/m in 1977. With the drop in the level of the water table in the seep, salts had been leached below 60 cm, and the land once again supported economical crop production. In 1977, winter wheat yield in the area of the arrested saline seep was 70% of the surrounding area; in 1978, it was 100%.

Halvorson and Reule (1980) controlled a saline seep that developed in 1971 near Sidney, Mont., where the land was farmed in a crop-summerfallow system. "Ladak 65" alfalfa was seeded on about 80% of the recharge area in 1973. Fig. 17.6 shows changes in the level of the water table before, during, and after the alfalfa was established. The water table in the recharge and seepage areas began to recede shortly after the alfalfa was seeded. By 1975, the surface of the seepage area was dry enough to cross with farm machinery. By 1977, the water table had receded to about 2.4 m below the surface of the soil in the seepage area. In the recharge area, one of two observation wells was dry by 1977. The level of water in the other well had receded from 1.8 m to 3.3 m. Salinity in the top 30 cm of soil in the seep area decreased from 20 dS/m in 1972 to about 5 dS/m in 1978 (Fig. 17.5). Crop yields in the area of the arrested saline seep equalled average county yields after three to four years of hydrologic control (Table 17.5).

Saline seeps would reappear if the crop-summerfallow system were resumed. Halvorson (1984) reports that when a saline seep recharge area that had been hydraulically controlled was converted from alfalfa production back to a crop-summerfallow cropping system in 1979, soil salinity had within three years begun to increase at the 30-cm to 60-cm depths in the saline seep area. Data from the site of the Fort

TABLE 17.5 Yields of Several Crops Grown in Two Reclaimed Saline Seeps in 1978 and 1979, Compared to County Yields in Northeastern Montana (Halvorson 1984)

Crop	Yield (kg/ha)			Average County Yield (kg/ha)	
(1)	1978 (2)	1979 (3)	Average (4)	1978 (5)	1979 (6)
		Seep A		Richland County	
Spring wheat	2,462	1,586	2,024	2,184	1,398
Barley	4,547	2,135	3,341	2,382	1,333
Oats	3,385	1,577	2,481	1,971	1,247
Alfalfa	5,708	9,834	7,771	4,346	3,360
		Seep B		Roosevelt County	
Spring wheat	2,426	1,781	2,104	1,848	1,270
Barley	3,861	3,279	3,570	2,091	1,409
Oats	5,273	2,175	3,724	1,756	1,247
Corn (silage)	16,948	3,474	10,211	17,920	11,200

Benton seep indicated that six years of crop-summerfallow rotation had recharged the 4.6-m soil profile to field capacity and that continued crop-summerfallowing in the recharge area would reactivate the former saline seep area.

SOCIOECONOMIC CONCERNS

Saline seeps do not respect property lines. A recharge area on one farmer's property can supply water to a discharge area on a neighbor's farm, or the seep discharge can contaminate a stream, natural drainageway, or farm pond. Except for small, uncomplicated seeps, such as geologic outcrop and coal seam seeps, most farmers need help in diagnosing their saline seep problem and in developing cropping systems or other control measures. When a recharge area is on an adjacent farm, landowners need to cooperate. Knowledgeable individuals or agencies can help by characterizing the problem and recommending control measures. Legislation could provide ways for farmers to form salinity control districts and achieve collectively what cannot be done individually.

A saline seep is not just one farmer's problem. Any loss of farmland decreases the nation's food and tax base. Unless saline seeps are controlled, salty water from seeps can pollute fresh surface waters and add to the salinity of ground water. The problem of saline seep has political implications, involving such questions as subsidies, crop-acreage allotments, and landowner rights. Federal farm programs sometimes have inadvertently adversely affected the progress of saline seep control programs by restricting the acreage that can be planted with small grains or other crops to provide economic control of a saline seep problem. Hectares of summerfallow are often increased, magnifying the saline seep problem.

REFERENCES

Alberta Agriculture. 1986. "Dryland saline seep control." *Alberta Agriculture* AGDEX 518-11, Edmonton, Alberta, Canada. 12p.

Ballantyne, A.K. 1963. "Recent accumulation of salts in the soils of southeastern Saskatchewan." *Can. J. Soil Sci.* 43: 52-58.

Benz, L.C., F.M. Sandoval, E.J. Doering, and W.O. Willis. 1976. *Managing saline soils in the Red River of the North.* U.S. Dept. Agric. ARS-NC-42, 54p.

Berg, W.A., C.R. Cail, D.M. Hungerford, J.W. Naney, and G.A. Sample. 1986. "Saline seep on wheatland in northwest Oklahoma." *Proc. National Conference on Ground Water Quality and Agricultural Practices.* Lewis Publ. Co., Chelsea, Mich. pp. 265-271.

Black, A.L., P.L. Brown, A.D. Halvorson, and F.H. Siddoway. 1981. "Dryland cropping strategies for efficient water use to control saline seeps in the northern Great Plains, U.S.A." *Agricultural Water Management* 4: 295-311.

Black, A.L., and Ford, R.H. 1976. "Available water and soil fertility relationships for annual cropping systems." *Proc. Regional Saline Seep Control Symposium.* Montana State Univ., Bozeman, Coop. Ext. Serv. Bull. 1132.

Black, A.L., and F.H. Siddoway. 1976. "Dryland cropping sequences within a tall wheatgrass barrier system." *J. Soil Water Conserv.* 31: 101-105.

Black, A.L., F.H. Siddoway, and J.K. Aase. 1982. "Soil moisture use and crop management-(DRYLAND)." *Proc. Soil Salinity Conference.* Lethbridge, Alberta, Canada, Nov. 29-Dec. 2, 1982.

Bramlette, G. 1971. "Control of saline seeps by continuous cropping." *Proc. Saline Seep-Fallow Workshop*, Feb. 22-23, 1971, Great Falls, Mont. Highwood Alkali Control Association, Highwood, Mont.

Brown, P.L. 1958. Soil moisture probe. U.S. Patent No. 2,860,515.

Brown, P.L. 1976. *Saline seep detection by visual observation.* Montana Coop. Ext. Serv. Bull. No. 1132: 59-61.

Brown, P.L. 1983. "Saline seep control and soil water recharge under three rotations following alfalfa." Paper presented at Montana Chapter Soil Conservation Society of America meeting, Feb. 4-5, 1983, Bozeman, Mont.

Brown, P.L., A.L. Black, C.M. Smith, J.W. Enz, and J.M. Caprio. 1981. *Soil-water guidelines and precipitation probabilities for growing barley, spring wheat, and winter wheat in flexible cropping systems in Montana and North Dakota.* Montana Coop. Ext. Serv. Bull. No. 356.

Brown, P.L., H. Ferguson, and J. Holzer. 1987. "Saline seep development and control in Montana." *A Century of Action, Natural Resource Development and Conservation in Montana,* J.W. Bauder, ed. Montana Chapter of Soil Conservation Soc. of Am., Bozeman.

Brown, P.L., A.D. Halvorson, F.H. Siddoway, H.F. Mayland, and M.R.

Miller. 1983. *Saline-seep diagnosis, control and reclamation*. U.S. Dept. Agric. Cons. Res. Rpt. No. 30.

Brown, P.L. and M.R. Miller. 1978. "Soil and crop management practices to control saline seeps in the U.S. Northern Plains." Proc. of Meeting of Sub-commission on Salt-Affected Soils, 11th International Soil Sci. Soc. Congress, Edmonton, Alberta, Canada, June 21-24.

Brun, L.J., and R.L. Deutch. 1979. *Chemical composition of salts associated with saline seeps in Stark and Hettinger Counties, North Dakota*. North Dakota Agric. Exp. Sta. Farm Res. 37(1): 3-6.

Brun, L.J., and B.K. Worcester. 1975. "Soil-water extraction by alfalfa." *Agron. J.* 67: 586-589.

Cairns, R.R., and W.E. Bowser. 1977. *Solonetzic soils and their management*. Agric. Canada Public. No. 1391.

Cameron, D.R., E. DeJong, D.W.L. Read, and M. Oosterveld. 1981. "Mapping salinity using resistivity and electromagnetic inductive techniques." *Can. J. Soil Sci.* 61: 67-78.

Christie, H.W., D.N. Graveland, and C.J. Palmer. 1985. "Soil and subsoil moisture accumulation due to dryland agriculture in southern Alberta." *Can. J. Soil Sci.* 65: 805-810.

Colburn, E. 1983. "Salt buildup in soil, slicing Texas yields." *Crops and Soil Magazine* 35(4): 26.

de Jong, E., and E.H. Halstead. 1986. "Field crop management and innovative acres." Proc. Moisture Management in Crop Production Conference, Nov. 18-20, 1986, Calgary, Alberta. Alberta Agriculture, Edmonton, Alberta.

Doering, E.J., and F.M. Sandoval. 1976a. "Hydrology of saline seeps in the northern Great Plains." *Trans. ASAE* 19: 856-861, 865.

Doering, E.J., and F.M. Sandoval. 1976b. "Saline-seep development on upland sites in the northern Great Plains." U.S. Dept. Agric. ARS-NC-32; 26p.

Doering, E.J. and F.M. Sandoval. 1981. "Chemistry of seep drainage in southwestern North Dakota." *Soil Science* 132:142-149.

Ferguson, H., and T. Batteridge. 1982. "Salt status of glacial till soils of north-central Montana as affected by the crop-fallow system of dryland farming." *Soil Sci. Soc. Am. J.* 46: 807-810.

Halvorson, A.D. 1984. "Saline-seep reclamation in the northern Great Plains." *Trans. ASAE* 27: 773-778.

Halvorson, A.D. 1988. "Role of cropping systems in environmental quality: Saline seep control." *Cropping Strategies for Efficient Use of Water and Nitrogen*. Spec. Pub. no. 51, ASA-CSSA-SSSA, Madison, Wisc.

Halvorson, A.D., and A.L. Black. 1974. "Saline seep development in dryland soils of northeastern Montana." *J. Soil and Water Conservation* 29: 77-81.

Halvorson, A.D., and A.L. Black. 1985. "Long-term dryland crop responses to residual phosphorus fertilizer." *Soil Sci. Soc. Am. J.* 49: 928-933.

Halvorson, A.D., A.L. Black, F. Sobolik, and N. Riveland. 1976. "Proper management: Key to successful winter wheat recropping in Northern Great Plains." *North Dakota Agric. Exp. Sta. Farm Res.* 33 (4): 3-9.

Halvorson, A.D., and P.O. Kresge. 1982. "FLEXCROP: A dryland cropping systems model." U.S. Dept. Agric. Production Research Report No. 180; 49p.

Halvorson, A.D., and C.A. Reule. 1976. "Controlling saline seeps by intensive cropping of recharge areas." Proc. Regional Saline Seep Control Symposium. Montana State Univ., Coop. Ext. Serv. Bull. 1132.

Halvorson, A.D., and C.A. Reule. 1980. "Alfalfa for hydrologic control of saline seep." *Soil Sci. Soc. Am. J.* 44: 370-373.

Halvorson, A.D., and J.D. Rhoades. 1974. "Assessing soil salinity in identifying potential saline-seep areas with field soil resistance measurements." *Soil Sci. Soc. Am. Proc.* 38: 576-581.

Halvorson, A.D., and J.D. Rhoades. 1976. "Field mapping soil conductivity to delineate dryland saline seeps with four electrode technique." *Soil Sci. Soc. Am. J.* 40: 571-575.

Halvorson, A.D., J.D. Rhoades, and C.A. Reule. 1977. "Soil salinity—four-electrode conductivity relationships for soils of the northern Great Plains." *Soil Sci. Soc. Am. J.* 41: 966-971.

Hendry, M.J., R.G.L. McCready, and W.D. Gould. 1984. "Distribution, source and evolution of nitrate in a glacial till of southern Alberta, Canada." *J. Hydrology* 70: 177-198.

Hendry, M.J., and F. Schwartz. 1982. "Hydrogeology of saline seeps." *Proc. Soil Salinity Conference.* Lethbridge, Alberta, Canada, Nov. 29-Dec. 2, 1982.

Henry, J.L., P.R. Bullock, T.J. Hogg, and L.D. Luba. 1985. "Groundwater discharge from glacial and bedrock aquifers as a soil salinization factor in Saskatchewan." *Can. J. Soil Sci.* 65: 749-768.

Holm, H.M. 1983. "Soil salinity: A study in crop tolerances and cropping practices." Saskatchewan Agriculture, Plant Industry Branch, Regina, Saskatchewan. 17p.

Malcolm, C.V. 1982. "Wheat Belt salinity: a review of the salt land problem in southwestern Australia." Western Australian Dept. of Agric. Technical Bull. No. 52, 65p.

Matheson, W.E. 1968. "When salt takes over." *J. of Agric., South Australia,* 71: 266-272.

Miller, M.R. 1971. "Hydrology of saline-seep spots in dryland farm areas, a preliminary evaluation." Proc. Saline Seep-Fallow Workshop. Feb. 22-23, 1971, Great Falls, Mont. Highwood Alkali Control Association, Highwood, Mont.

Miller, M.R., P.L. Brown, J.J. Donovan, R.N. Bergatino, J.L. Sonderegger, and F.A. Schmidt. 1981. "Saline seep development and control in the North American Great Plains—hydrologic aspects." *Agric. Water Management* 4: 115-141.

Naney, J.W., W.A. Berg, S.J. Smith, and G.A. Sample. 1986. "Assessment of ground-water quality in saline seeps." *Proc. Agricultural Impacts on Ground water,* Aug. 11-13, 1986, Omaha, Neb. National Water Well Association, Dublin, Ohio.

Neffendorf, D.W. 1978. "Statewide saline seep survey of Texas." M.S. Thesis, Texas A&M University, College Station, Texas.

Nicholaichuk, W., and D.M. Gray. 1986. "Snow trapping and moisture infiltration enhancement." Proc. Moisture Management In Crop Production Conference, Nov. 18-20, 1986, Calgary, Alberta. Alberta Agriculture, Edmonton, Alberta.

Olson, G.W. 1978. "Some observations on dryland saline seepage in several countries and some comments on causes, effects, and cures." *Proc. Sub-Commission on Salt-Affected Soils*, 11th International Soil Sci. Soc., Congress, Edmonton, Alberta, Canada, Sec. 2: 7-29.

Oosterveld, M. 1978. "Disposal of saline drain water by crop irrigation." *Proc. of Meeting of Sub-commission of Salt-Affected Soils*, 11th International Soil Sci. Soc. Congress, Edmonton, Alberta, Canada, June 21-24.

Oster, J.D., and A.D. Halvorson. 1978. "Saline seep chemistry." *Proc. of Meeting of Sub-commission of Salt-Affected Soils*, 11th International Soil Sci. Soc. Congress, Edmonton, Alberta, Canada, June 21-24.

Power, J.F., J.J. Bond, F.M. Sandoval, and W.O. Willis. 1974. "Nitrification in paleocene shale." *Science* 183: 1077-1079.

Rasmussen, W.W., G.C. Lewis, and M.A. Fosberg. 1964. "Improvement of the Chilcott-Sebree (solodized-solonetz) slick spot spoils in southwestern Idaho." U.S. Dept. Agric., Agric. Res. Serv., ARS 41-91, 39p.

Rhoades, J.D. and A.D. Halvorson. 1977. "Electrical conductivity methods for detecting and delineating saline seeps and measuring salinity in northern Great Plains soils." U.S. Dept. of Agric., Agric. Res. Serv., Western Region, ARS W-42. 45p.

Schneider, R.P., B.E. Johnson, and F. Sobolik. 1980. "Saline seep management: Is continuous cropping an alternative? North Dakota Agric. Exp. Sta. Farm Res. 37(5): 29-31.

Smika, D.E., and C.J. Whitfield. 1966. "Effect of standing wheat stubble on storage of winter precipitation." *J. Soil Water Conserv.* 21: 138-141.

Sommerfeldt, T.G. 1976. "Mole drains for saline seep control." Montana Coop. Ext. Serv. Bull. 1132, p. 296-302.

Sommerfeldt, T.G., H. Vander Pluym, H. Christie. 1978. "Drainage of dryland saline seeps in Alberta." *Proc. of Meeting of Subcommission of Salt-Affected Soils*, 11th International Soil Sci. Soc. Congress, Edmonton, Alberta, Canada, June 21-24.

Steppuhn, H. and D. Jenson. 1984. "Barley can help control dryland salinity." *Crops and Soils Magazine* 36(8): 22-23.

Timpson, M.E., J.L. Richardson, L.P. Keller, and G.J. McCarthy. 1986. "Evaporite mineralogy associated with saline seeps in southwestern North Dakota." *Soil Sci. Soc. Am. J.* 50: 490-493.

Vander Pluym, H.S.A. 1978. "Extent, causes and control of dryland saline seepage in the Northern Great Plains of North America." *Proc., Sub-commission on Salt-Affected Soils*, 11th International Soil Sci. Soc. Congress, Edmonton, Alberta, Canada, June 21-24.