11 Role of Cropping Systems in Environmental Quality: Saline Seep Control[1]

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Saline seeps are occurring more 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). They are caused by a combination of geologic, climatic, and cultural conditions. The term *saline seep* describes a salinization process accelerated by dryland-farming practices that utilize water inefficiently, allowing water to move through salt-laden substrata below the root zone. Saline seep is accepted to mean intermittent or continuous saline water discharge, at or near the soil-surface downslope from recharge areas under dryland conditions, which reduces or eliminates crop growth in the discharge area because of increased soluble-salt concentrations 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 to precipitation and cropping systems (Brown et al., 1983).

The characteristics, hydrology, and causes of most saline seeps are similar regardless of geographic location (Berg et al., 1986; Brown et al., 1983; Doering and Sandoval, 1976a, b; Halvorson and Black, 1974; Vander Pluym, 1978). Native or naturally occurring vegetation has been removed and replaced with agricultural crops that have a lower water requirement. Precipitation received in excess of the soil-root zone storage capacity, primarily during fallow or noncrop periods, is the source of water. The crop-fallow system of dryland farming has contributed significantly to the development of the saline-seep problem in the Northern Great Plains, but is not the only cause (Brown et al., 1983; Christie et al., 1985; Halvorson and Black, 1974). Periods of high precipitation, restricted surface and subsurface drainage due to roads and/or pipeline construction, snow accumulations resulting in large drifts (i.e., windbreaks, roadways, etc.), gravelly and sandy soils, drainage ways, leaky ponds and dugouts, and crop failures can contribute to seep develop-

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ment. The above factors combined with the right geologic conditions can result in the development of a saline seep after many years of cropping. Generalized diagrams of geologic conditions resulting in seep development in the Northern Great Plains are shown in Fig. 11-1. Seeps generally develop on sidehills or toe-slopes of rolling to undulating topography common to the Great Plains, where permeable geologic material is underlain by less-

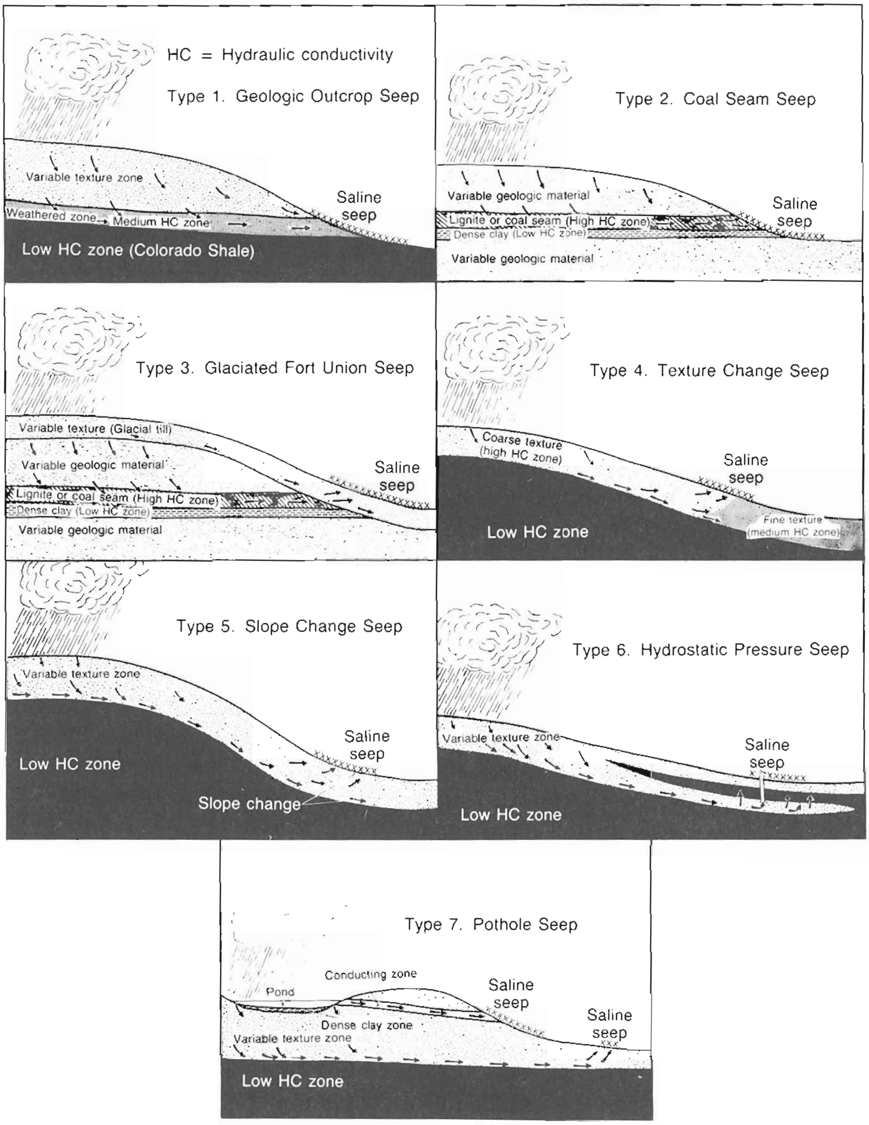

Fig. 11-1. Schematic diagrams illustrating seven geologic conditions for saline seep development (Brown et al., 1983).

permeable geologic strata. These geologic and topographic conditions result in conditions favorable to development of perched water tables.

GROUNDWATER QUALITY ASSOCIATED WITH SALINE SEEP

Hydrologic studies show that seeps are 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). As the water-passes through the soil profile toward the perched or permanent water table, salts are dissolved and moved downward. Ferguson and Batteridge (1982) estimated that up to 90 Mg/ha of salt has been moved in the soil toward (to) the groundwater table in some areas of Montana. Christie et al. (1985) also reported a decrease in soil-profile salinity of cultivated land vs. that of an adjacent native noncultivated area, indicating movement of salt to lower depths. Doering and Sandoval (1981) reported the removal of 6.1 Mg/ha of salt and 50 kg of NO_3-N/ha from a drained seep area. These studies document the movement of soluble salts and NO_3-N toward and into shallow water tables.

Table 11-1 shows the composition of waters associated with several saline seeps in the Northern and Southern Great Plains. Note the high concentrations of NO_3 (>0.7 mmol/L) present in many of the shallow water tables associated with saline seeps. Much of the shallow groundwater associated with saline seeps is unsuitable for human and/or livestock consumption because of high NO_3 and salt levels, and for irrigation because of total salt concentration. Calcium, Mg, and Na sulfates are the dominate cations and anion in most of the shallow groundwater associated with saline seeps in the Great Plains. Chlorides are low compared to sulfates in the water and soil

Table 11-1. Chemical composition of waters associated with saline seeps in the Great Plains.

Location	pH	EC	Ca	Mg	Na	HCO_3	NO_3	Cl	SO_4	Source
		dS m^{-1}				mmol L^{-1}				
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

system of the Northern Great Plains. Chloride tends to be slightly higher in the Southern Great Plains. Soil chemistry studies show that soils in seep areas are generally in equilibrium with gypsum, lime, and other Ca-Mg sulfate-type minerals (Brun and Deutch, 1979; Doering and Sandoval, 1981; Oster and Halvorson, 1978; Timpson et al., 1986).

Studies in the Northern Great Plains have surmised that the NO_3 in the groundwater came primarily from two sources: (i) exchangeable NH_4 of geologic origin located deep in the profile oxidized to NO_3, and (ii) NO_3 leached from the root zone during fallow periods, which originated from mineralization of organic matter near the soil surface (Doering and Sandoval, 1981; Hendry et al., 1984; Power et al., 1974). Little, if any, of the NO_3 had its origin as fertilizer N because little fertilizer N had been used by dryland farmers in the Northern Great Plains prior to the early 1970s when saline seeps were becoming a prominent dryland salinity problem.

CONTROL METHODS

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: (i) mechanically drain-ponded surface water where possible before it infiltrates, and/or intercept lateral flow of subsurface water with drains before it reaches the discharge area, and (ii) agronomically use the water before it percolates below the root zone. Each of these will be discussed in some detail with major emphasis on agronomic control.

Drainage

Undulating, near level land with poor surface drainage (potholes) can be recharge areas for saline seeps (Brown et al., 1983). Following heavy rain and rapid snowmelt, these potholes may fill with water temporarily. Where possible, surface drains should be installed to prevent the temporary ponding of surface water. Drainageways under roadbeds should be kept clear of debris and sediment so that they do not serve as sources of temporarily ponded surface water that infiltrates and contributes water to a saline seep. 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). Use of such water conservation practices may need to be evaluated if saline seep is a problem.

Drainage studies have shown that hydraulic control can be quickly accomplished 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 needs to be available. Outlet considerations must include not only easement for transport of drainage water across intervening lands, but also the effect of drainage waters on the quality of streams or reservoirs that they might subsequently enter. The water is salt contaminated, usually high in NO_3, and disposal without downstream surface or groundwater pollution is difficult because of physical and legal constraints. Therefore, although effective, subsurface drainage is generally not satisfactory because of disposal problems and costs in the dryland crop areas of the Great Plains. Doering and Sandoval (1981) concluded that the best approach is to use the soil water for crop growth while it is a relatively nonsaline resource in the root zone of the recharge area.

Oosterveld (1978) used seep discharge water to irrigate the recharge area, thus recycling the salts back to the land. In general, the concept was successful, but limited water supplies for irrigation, cost of an irrigation system to deliver the water, and buildup of soil salinity in recharge area may reduce the practical application of this technique for saline seep control.

Agronomic Practices

Hydraulic control of saline seep areas can be effected agronomically by planting crops and utilizing cropping systems that will use available soil water in the root zone where it is a relatively nonsaline resource. This requires that recharge areas be distinctly identified and that farmers be willing and able to adopt the cultural practices needed for maximum soil water use and minimum percolation. Techniques for identifying recharge and potential saline seep areas have been developed (Alberta Agriculture, 1986; Brown et al., 1983; Halvorson and Rhoades, 1974; Halvorson and Rhoades, 1976). Early detection and diagnosis of a saline seep problem are important in designing and implementing effective crop management practices to prevent further damage or salinization. Any delay in implementing control practices can lead to a much larger and more difficult-to-manage problem. By early detection, a farmer may be able to change cropping systems to minimize the damage. Techniques for identifying potential seep and recharge areas include: (i) visual observations, (ii) field measurement of soil electrical conductivity, (iii) soil survey and geologic information, and (iv) auger or core-drilling procedures (Brown et al., 1983).

Alfalfa (*Medicago sativa* L.), seeded in recharge areas, is an effective crop for gaining hydraulic control of seep discharge areas (Brown et al., 1983; Brun and Worcester, 1975; Halvorson and Reule, 1980). Halvorson and Reule (1980) found that alfalfa extracted more water from the soil profile than native grass sod or small grain crops (Fig. 11-2). Land that had been fallowed was at or near field-capacity water content, creating a potential for any additional precipitation to percolate below the root zone. Alfalfa depleted the soil water more than the other crops, creating a larger effective reservoir to store annual precipiation by using more water during the growing season, thus reducing the potential for water loss to deep percolation. This resulted in the saline seep or discharge area drying sufficiently to once again grow normal grain and forage crops (Halvorson, 1984). Similar results were observed by the author in Colorado, when a farmer near Akron established alfalfa in a seep recharge area in 1984 to bring an active saline seep area under

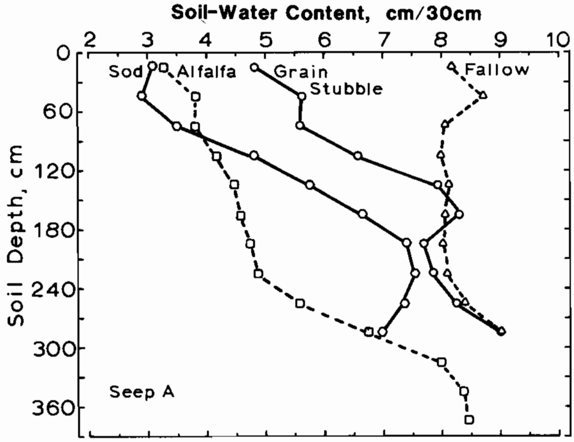

Fig. 11-2. Soil water profiles in September 1976 in the recharge area under native range (sod), alfalfa (seeded in 1973), spring wheat stubble, and fallow (Halvorson and Reule, 1980).

control. By the fall of 1985, the seep had dried sufficiently to allow the seep area to once again be crossed with farm machinery. In 1987, three cuttings of alfalfa were harvested from the discharge area where only salt-tolerant weeds grew in 1984.

Brown and Miller (1978) and Miller et al. (1981) also showed that alfalfa was effective for controlling saline seeps, while Brown (1983) further showed that it took 7 to 8 yr to recharge the dried soil profile to field-capacity water content when a fallow-winter wheat (*Triticum aestivum* L.)-barley (*Hordeum vulgare* L.) rotation followed 3 yr of alfalfa (Table 11-2). Similarly, Halvorson and Reule (1980) reported a rise in water table level where a farmer reverted back to a crop-fallow system of farming in the recharge area following several years of alfalfa production, during which hydraulic control of the seep area was achieved and the seep area was supporting near-normal crop production. These studies indicate that once a saline seep area has been

Table 11-2. Total soil water content (0-4.6 m) at the end of each growing season following 3 yr of alfalfa (Brown, 1983).

Year	Crop/fallow	Fall soil water	Annual precipitation
		mm 4.6 m^{-1}	mm
1973	Alfalfa, 3rd yr	217	--
1974	Fallow, no crop	342	278
1975	Winter wheat	330	563
1976	Barley	393	371
1977	Fallow, no crop	448	363
1978	Winter wheat	461	418
1979	Barley	461	208
1980	Fallow, no crop	524	380
1980	Estimated field capacity	573	--

controlled, reclaimed, and returned to normal crop production, a farmer cannot return to a conventional crop-fallow system of farming in the recharge area on a permanent basis. Soil water in the recharge area will need to be continually managed to prevent the recurrence of the saline seep.

Other work has shown that use of annual cropping systems with small-grain crops has resulted in control of seep areas (Alberta Agriculture, 1986; Bramlette, 1971; Halvorson and Reule, 1976; Holm, 1983; Steppuhn and Jenson, 1984). Use of annual, small-grain cropping systems to gain hydraulic control of seep discharge areas is a slower process than using alfalfa because of less soil water use and shallower rooting depths. Inclusion of oil seed crops such as safflower (*Carthamus tinctorius* L.) or sunflower (*Helianthus annuus* L.), which are normally deeper rooted than small grains (Table 11-3), will help deplete the stored soil water to greater depths, thereby increasing the capacity of the soil to store precipitation between crops or during fallow periods.

Black et al. (1981) describe several dryland cropping strategies for efficient water use to control saline seeps in the Northern Great Plains. They suggest using intensive, flexible cropping systems with adapted crops in combination with proper soil, water, and crop management practices to improve crop production-water-use relationships sufficiently to reduce the frequency or eliminate the need for summer fallow.

Flexible cropping involves planting a crop in years when stored soil water and expected growing season precipitation are sufficient to produce an economic crop yield. Summer fallowing is employed only when soil water and expected growing-season precipitation are not sufficient to produce a reasonable or economic crop yield. A farmer can assess the soil water supply by having a knowledge of soil texture and using a soil moisture probe to physically determine moist soil depth (Brown, 1958) or by any other method

Table 11-3. Rooting depth and soil water use by 11 dryland crops (Black et al., 1981).

	Fort Benton, MT		Culbertson, MT	
Crop	Rooting depth	Soil water use	Rooting depth	Soil water use
	m	mm	m	mm
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 wildrye, 1st yr	2.1	318	--	--
Russian wildrye, 4th yr	3.0	475	--	--
Sweetclover, 1st yr	1.8	276	--	--
Sweetclover, 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
Dryland corn	1.2	94	--	--

of determining soil water. Based on available soil water and expected growing-season precipitation, a decision to crop or fallow can be made (Alberta Agriculture, 1986; Brown et al., 1981). Recropping or annual cropping is not recommended whenever plant-available soil water stored at planting time is less than about 76 mm (Alberta Agriculture, 1986; Black and Ford, 1976). Therefore, determining the soil water status of the root zone just before planting is essential if more intensive crop-management systems are to be successful. Halvorson and Kresge (1982) developed a computer model (FLEX-CROP) to help farmers decide the best cropping and soil-management options for wheat, barley (*H. sativum* Jess.), oat (*Avena sativa* L.), and safflower (*Carthamus tinctorius* L.) based on stored soil water and expected growing-season precipitation (program available from author). Weed control and soil fertility are also critical management factors in developing successful, flexible, dryland-cropping systems.

Black et al. (1974) and Halvorson and Black (1974) reported that 72 to 83% of the total water stored during the 84-week fallow period in the Northern Great Plains was stored during the first 36 weeks of the fallow period. Therefore, saving an additional 20 to 30 mm of water during the first overwinter period may eliminate the need for a summer-fallow period. Snow-management studies indicate that saving this much additional water during the first over-winter period is possible (Black et al., 1981; Black and Siddoway, 1976; Nicholaichuk and Gray, 1986).

Black and Siddoway (1976) found that precipitation use efficiency was 80% for a continuous cropping system vs. 50% for a spring wheat-winter wheat-fallow and 30% for a spring wheat-fallow rotation. Thus, with more intensive cropping, the potential for water loss to deep percolation in the Northern Great Plains is reduced.

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; whereas, conventional spring wheat-fallow used only 40% (Table 11-4). The average amount of unused plant-available water between crops, a portion of which may contribute to saline seep development, averaged 473 mm for spring wheat-fallow and only 72 to 98 mm for annual cropping. These data demonstrate the potential of moving water, NO_3, and dissolved salts below the root zone in a spring wheat-fallow system compared with an annual cropping system. Adequate fertility is essential for optimizing yields in annual cropping systems (Black et al., 1982; de Jong and Halstead, 1986; Halvorson et al., 1976; Schneider et al., 1980).

If more intensive, flexible-cropping systems are to be successful, more efficient methods of storing soil water during noncrop periods is needed. In the Northern and Central Great Plains, soil water supplies can be increased by controlling weed growth and volunteer grain after harvest, leaving standing stubble to trap snow, utilizing annual or perennial barriers or windbreaks for snow trapping, and utilizing reduced and no-tillage systems (Black and Siddoway, 1976; Nicholaichuk and Gray, 1986; Smika and Whitfield, 1966). All of these practices will enhance the efficiency of soil water storage.

Table 11-4. Average precipitation-use efficiency per cropping sequence as influenced by cropping system within a tall wheatgrass barrier system over a 12-yr period (Black et al., 1981).

Cropping system	No. crops yr^{-1}	Total PPT $crop^{-1}$	Total water use $crop^{-1}$†	PUE‡	Annual grain yield No N	Annual grain yield +N	WUE No N	WUE +N
		——mm——		%	—kg ha^{-1}—		kg ha^{-1} mm^{-1}	
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	4.1
Three-yr rotation								
1. SW-WW-F	0.66	569	333	59	997	1416	2.6	3.7
Crop-fallow								
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

† Crop water-use per crop is based on soil water use plus precipitation received from seeding to harvest.

‡ Symbols: +N = 34 kg of N ha^{-1} each crop year; PPT = precipitation; PUE = [(total water use/crop)/(total precipitation received/crop)] × 100; WUE = [(grain yield/ha)/(total precipitation/crop rotation)] × 100; WW = winter wheat; SW = spring wheat; B = spring barley; S = safflower; F = fallow.

However, if these practices are used, a more intensive cropping system than the conventional crop-fallow system must be employed or saline seep development will intensify.

CROPPING STRATEGIES FOR SALINE SEEP CONTROL

Crops differ in the amount of water required to produce an economical yield because of rooting depths and extraction patterns. Black et al. (1981) reported that safflower used more soil water to greater soil depths in 1 yr than any other annual dryland crop grown in Montana (Table 11-3). Alfalfa used only slightly less water the 1st yr than safflower or sweetclover (*Melilotus officinalis* L.), but alfalfa's ability to use growing-season precipitation plus existing-soil water supplies from progressively deeper soil depths in successive years marks alfalfa as the best crop for initial use to gain hydraulic control in recharge areas (Table 11-4). Sanfoin (*Onobrychio viriaefolia* Scop.) and Russian wildrye (*Elymus junceus* Fisch.) depleted soil water to a depth of 4 and 3 m, respectively, after 3 yr. Biennial sweetclover used more soil water than safflower the 1st yr and about equal to alfalfa the 2nd yr. Following alfalfa, sweetclover, and safflower, the ranking of crop water use in order of decreasing rooting depth and soil water use was sunflower (*Helianthus annuus* L.), winter wheat, rapeseed (*Brassica napus* L.), spring wheat, barley, and corn (*Zea mays* L.). Fallow becomes a viable option in flexible cropping systems once the soil water has been depleted from the root zone.

Selecting the best crop sequence requires knowledge of the amount and depth of soil water depletion by the previous crop. Crops should be grown in sequential order with increasing rooting depths until the depth and amount of soil water removal exceeds soil water recharge during noncrop periods (Black et al., 1982). An example would be the use of a spring wheat-winter wheat-fallow rotation, where the deeper rooted winter wheat follows spring wheat. A fallow period then follows winter wheat because of greater soil water depletion by this crop. Ideally, fallow should only be used when needed, such as following alfalfa, or when there is <76 mm of plant-available soil water at planting in the upper part of the root zone.

Successful recropping will require that crops be rotated in sequence to avoid specific weed, disease, and insect problems. Inclusion of oilseed crops in rotation with small grain allows the opportunity to use grass herbicides, helping control build-up of grassy weeds in the small grain crops (Bergman et al., 1979).

Soil fertility follows water in importance in a successful annual cropping system (Black et al., 1981; Black and Siddoway, 1976; de Jong and Halstead, 1986; Halvorson et al., 1976; Halvorson and Kresge, 1982; Schneider et al., 1980). As cropping frequency increases, the need for additional N increases proportionately (Fig. 11-3) and responses to P fertilizer become dependent upon soil-test P level and first satisfying crop N needs (Halvorson and Black, 1985). Nitrogen needs should be carefully balanced with expected plant-available water supplies and crop-yield potential.

The practice of a strict crop-fallow 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 effectively use available water supplies requires a knowledge of the amount of water available at any given time, specific water requirements and rooting

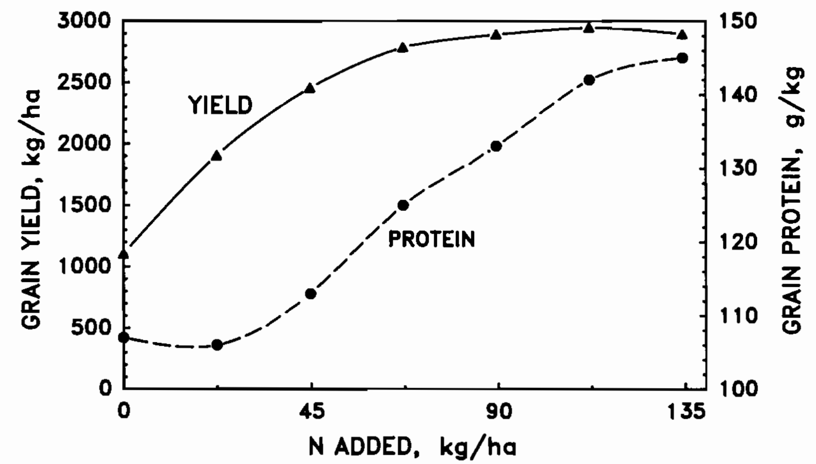

Fig. 11-3. Average recrop grain yield and protein content of winter wheat as affected by N-fertilization rate (Halvorson et al., 1976).

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 essential if an effective cropping strategy to control or prevent the development of saline seeps is to be developed. Berg et al. (1986) and Naney et al. (1986) suggest that this type of strategy will also work in the Central and Southern Great Plains area to control saline seeps.

CONCLUSION

Based on the information presented in this chapter, the importance of cropping systems in controlling the dryland saline seep problem in the Great Plains has been shown. However, if more intensive cropping systems than the conventional crop-fallow system are to be used successfully, farmers need to know the soil water status at planting, an estimate of growing-season precipitation, crop-rooting depths and soil water-use characteristics, soil fertility, weed and pest control practices, water conservation strategies (i.e., snow management), yield and disease characteristics of crop varieties, crop rotations, and other soil and crop-management factors. Timely farm operations will be essential along with soil-test information and a knowledge of the depth to impermeable geologic strata and water tables to make a flexible, intensive crop-management system work. Cropping restrictions under the current federal farm program complicate the picture and make developing effective and economical cropping strategies difficult.

By developing and employing cropping systems that use water more efficiently, environmental quality will be preserved or improved in areas where dryland saline seeps exist as well as in areas where their potential for development occurs. Limiting the percolation of water below the root zone of dryland crops will reduce the movement of soluble salts and nitrates toward and into the groundwater, thus preserving its quality.

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