Reprinted from the *Soil Science Society of America Proceedings*
Volume 36, Number 1, January-February 1972
677 South Segoe Road, Madison, Wisconsin 53711 USA

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Improvement of a Solonetzic (Slick Spot) Soil by Deep Plowing, Subsoiling, and Amendments[1]

W. W. Rasmussen, D. P. Moore and L. A. Alban[2]

ABSTRACT

Soil improvement studies, including deep plowing, subsoiling and gypsum treatments, were conducted on an irrigated solonetzic soil association in southeastern Oregon. The unproductive saline-sodic (solonetz-like) soil tentatively classified as Malheur silt loam (with slick spots) and described as a Nadurargid, occurs in complexes with normally leached soils of the Nyssa and related soil series. The saline-sodic soils were chemically reclaimed in 3 to 4 years by deep plowing 90-cm deep without gypsum and by deep plowing with gypsum at rates of 18 metric tons/ha (8 tons/acre) and 36 metric tons/ha (16 tons/acre). Crop yields, water intake rates, and water and root penetration were greatly increased by deep plowing. The soils were moderately improved by 36 metric tons/ha of gypsum alone and by subsoiling with gypsum. Subsoiling without gypsum was not beneficial. The results over a 4-year period indicate that the salt-affected soils were effectively and most economically reclaimed by deep plowing without gypsum. Deep plowing also improved the productivity and physical conditions of the nonsaline associated soils.

Additional Index Words: **gypsum, saline-sodic soils, natrargid, reclamation, nadurargid.**

More than 55,000 hectares (135,000 acres) of irrigated land in the lower Malheur River Valley in southeastern Oregon and the Boise and Payette River Valleys in Idaho contain small areas of naturally occurring, unproductive, salt-affected soil. These peculiar areas of saline-sodic soil occur in complex patterns with normally leached soils and are commonly known as "slick spots." Affected areas range in size from only a few meters in diameter to ¼ ha, and may comprise from 10% to 50% of the land area in some cultivated fields. The slick spots seriously reduce crop yields and greatly complicate soil and water management.

The problem soils have distinctive B2 or argillic (natric) horizons which are low in soluble salts but contain moderate to high levels of exchangeable Na. The lower soil horizons usually contain both excessive exchangeable Na and soluble salts. Some associated nonsaline soils frequently have silica-calcium carbonate-cemented hardpan (duripan) layers and are underlaid with stratified layers that limit water infiltration and restrict water and root penetration.

The genesis of the slick spot soils in this region is not fully understood. The complex soil associations have developed in silty old alluvium and on, or in, calcareous laminated lake-laid sediments with the surface horizons partially derived from or influenced by loess depositions (1). The slick spot soils occur in intimate association with several related soil series, and while several "kinds" of Na-affected soils are recognized, their mode of formation is considered to be similar. They are probably similar to sodic (solonetz) soils that occur elsewhere in the USA (3, 15),[3] and in other areas of the world (2, 6, 13). Various methods of improving solonetz soils including deep tillage, deep plowing (trenching), and soil mixing for "self-amelioration" have been tested in Russia (2, 4, 7). An extensive review of studies on reclamation of solonetz soils in the USSR has recently been published in English (14).

Previous investigators in Idaho and Oregon concluded that the poor plant growth on the slick spots resulted mainly from the unfavorable physical conditions and extremely low water infiltration rates caused by the high exchangeable Na, particularly in the shallow, clayey Bt horizons (1, 5, 9, 11).[4] Studies on an "alakali" (slick

[1] Contribution from the NW Branch, SWCRD, ARS, USDA, in cooperation with the Oregon Agr. Exp. Sta. Technical Paper no. 2590, Oregon Agr. Exp. Sta., Oregon State Univ. Received Nov. 25, 1970. Approved Oct. 18, 1971.

[2] Soil Scientist, Snake River Conserv. Res. Center, Kimberly, Idaho 83341; Associate Professor of Soils, and former Associate Professor of Soils (deceased), Oregon Agr. Exp. Sta., Oregon State Univ., Corvallis, respectively.

[3] F. F. Peterson, 1961. Solodized solonetz soils occurring on the uplands of the Palouse loess. Ph.D. Thesis. Washington State University, Pullman.

[4] Bower, C. A., and G. Y. Blair. A study of "slick spot" soils found on the Black Canyon Irrigation Project, Idaho. USDA, ARS, US Salinity Laboratory, Riverside, Calif., April 1, 1951. (Mimeo.)

spot) soil in Malheur County, Ore., showed that infiltration rates and productivity of a severe slick spot soil were increased temporarily by applications of gypsum, lime, S, and large quantities of manure (1). A greenhouse study and a limited field plot study in Idaho indicated that infiltration rates and chemical properties of the Sebree series (slick spot soils) in Idaho were improved by mixing the soil profile (8).[4] In other experiments on the Chilcott-Sebree complex soil association in Idaho, mixing the profile layers to simulate deep plowing, subsoiling with gypsum, and actual deep plowing to depths of 60 to 75 cm (24 to 30 inches), with and without gypsum, increased infiltration rates and crop yields severalfold on the Sebree soils (10). These treatments reduced both the excessive soluble salts and exchangeable Na to safe levels for most crops in 2 or 3 cropping years under normal irrigation practices. Subsoiling or applications of gypsum alone did not materially improve these soils. The associated Chilcott (nonsaline-nonsodic) soils were also improved by deep plowing as evidenced by increased crop yields, water intake rates, and depth of water and root penetration.

A preliminary subsoiling and amendment study was initiated on the Nyssa-Malheur (tentative) series (slick spot soil) complex soil association in southeastern Oregon in 1959. The Nyssa series is a nonsodic soil formerly classified as a sierozem and now described as a Haploxerollic Durorthid (coarse, silty, mixed, mesic family). The inclusions of unproductive saline-sodic soil, tentatively classified as the Malheur series (with slick spots), is described as a Nadurargid. In some areas the Malheur or Malheur-like soils occur in complexes with normally leached soils of Greenleaf and related series without duripans and are described as Natrargids.

Subsoiling to a depth of 75 cm with a special subsoil machine (equipped with a 25-cm-diameter fluted, tapered roller, or molelike device drawn behind each shank to increase subsoil shattering) increased moisture penetration directly over the ripper channels, but not between the channels. Application of gypsum at rates from 2.25 to 45 metric tons/ha and ferric sulfate at rates of 450 kg/ha did not improve the soil. Subsoiling in combination with the high rates of gypsum moderately increased water and root penetration within the ripper channels, but large amounts of gypsum remained undissolved in the surface soils for more than 5 years after treatment (unpublished data—W. W. Rasmussen).

This paper summarizes the results of an additional intensive study conducted on the Nyssa-Malheur (slick spot soil) complex soil association in Malheur County, Ore. The augmented study included deep plowing, subsoiling, and amendment treatments, and was conducted on a soil area adjacent to the site of the preliminary subsoiling and amendment study. The objectives of this study were to evaluate the effectiveness of the tillage and amendment treatments, particularly deep plowing, in improving the slick spot-affected soils under irrigation.

PROCEDURE

The field experiment was conducted on an operating farm on land placed under irrigation in 1935. The site was on an intermediate terrace with a uniform slope of 1.5% and was typical of the slick-spot-affected land in the area.

Design of Experiment

The slick spots were randomly distributed within the study area and varied in size from a few meters in diameter to about 0.1 ha. A modified randomized block design with four replications of each treatment was used. The main plots for subsoiling, deep plowing, and check plots were 20 by 100 m. The subplots, located on individual slick spots and selected areas of associated "normal" Nyssa soil within the main plots, were 7 by 8 m.

Treatments were (i) untreated check plots, slick spot, and normal soils; (ii) deep plowing 90-cm deep on slick spot and normal soils; (iii) deep plowing 90-cm deep and adding gypsum at rates of 18 metric tons/ha and 36 metric tons/ha on slick spot soil; (iv) subsoiling alone and subsoiling with several rates of gypsum on the slick spot and normal soil. Deep plowing was done with a 1.2-m (4-foot) moldboard plow pulled by a single 250 HP tractor. Subsoiling was done with the same tractor and a special subsoiling machine having a fluted, molelike device behind each shank.

Treatments were evaluated by determining crop yields, infiltration rates, and changes in chemical and physical properties of the soil.

Methods

Deep plowing and subsoiling treatments were applied in the fall of 1959. Plots were smoothed and gypsum and recommended amounts of N and phosphate fertilizers were applied to the surface of the soils in the spring of 1960. The experiment was seeded to two types of small grain and interseeded with alfalfa in April 1960. Replications 1 and 2 were seeded to spring wheat (*Triticum aesativum* 'Lemhi') and replications three and four were seeded to spring barley (*Hordeum vulgare* 'Bonneville') at recommended rates. Alfalfa (*Medicago sativum*, var. media 'Vernal') was interseeded wtih grain at the rates of 10 kg/ha. The plot areas were harvested for grain in 1960. The usual field cultural and irrigation practices for grain were followed during the season. Grain yields and total straw weights were determined by hand-cutting areas of 3 by 5 m. The established alfalfa on the general farm areas was grown for seed from 1961 through 1963. Total water application was reduced for seed production, with only four irrigations applied during the cropping season.

Irrigation water was applied for approximately 24 hours on the deep-plowed treated areas or until approximately 10- to 12-cm depth of water was added. Irrigations on the non-plowed plots generally were continued for 48 to 72 hours in an effort to wet the soil on the saline-sodic spots. Even with the prolonged irrigations, the depth of water applied to the normal soils was limited to approximately 12 to 14 cm by the restrictive, dense, high silt laminated lenses in the undisturbed soil. Only 4 to 5 cm of water entered the soil on the saline-sodic spots during most irrigations. Alfalfa yield for forage production was determined by hand-cutting samples from 3 by 5-m areas.

Total water intake and soil moisture penetration were evaluated by gravimetric soil moisture determinations before and after two or three mid-season irrigations each year. Samples were taken from four locations and five depths on each plot at each sampling. Intake rates and furrow infiltration rates also were determined with furrow infiltrometers during regular irrigations in midseason and by cylinder infiltrometers following seed harvest in the late fall in 1962 and 1963.

Soil samples for chemical analyses were collected from each plot before treatment in the fall of 1959, after treatment in the spring of 1960, and following harvests in the fall of 1960, 1961, and 1962. Additional soil samples were collected from the deep plowing with gypsum treatments in 1963. Samples were collected by horizons at five depths. The samples were composites from three borings on each plot.

Table 1—Summary of crop yields as influenced by tillage and and amendment treatments, 1960 and 1962

Soils and treatment	Grain, 1960	Alfalfa hay*, 1962 Yield per cutting 1	2	3	Total annual yield
	kg/ha	metric tons/ha			
Nyssa (nonsaline) soil					
Untreated check	3,060	6.6	3.5	2.9	13.0
Subsoiled, 70 cm depth	4,280	6.9	3.9	2.7	13.6
Deep plowed, 90 cm (without gypsum)	5,030	7.4	3.6	2.6	13.6
Malheur (slick spot) soil					
Untreated check	1,290	1.4	.45	.58	2.5
Subsoiled, 70 cm depth	1,020	1.5	.64	.81	2.9
Gypsum, 36 metric tons/ha	1,590	3.8	1.9	1.3	7.1
Deep plowed, 90 cm	5,530	6.3	3.8	1.8	11.9
Deep plowed, 90 cm (with gypsum, 18 metric tons/ha)	5,300	6.1	3.1	1.9	11.2
Deep plowed, 90 cm (with gypsum, 36 metric tons/ha)	4,910	7.1	3.5	2.6	13.1
LSD 5% level	1,140				1.34

* Alfalfa (hay) yields corrected to air-dry hay at 12% moisture (yields are average values of four replications of each treatment).

Table 2—Effect of soil treatments on the total water intake and depth of water penetration during irrigation* †

Soil and treatment	1960 Total water intake	1960 Depth of penetration	1961 Total water intake	1961 Depth of penetration	1963 Total water intake	1963 Depth of penetration
	cm					
Nyssa (Nonsaline) soil	7.9	40-45	7.4	36-40	7.7	40-46
Subsoiled, 70 cm depth	7.1	45-60	8.2	40-46	9.4	46-50
Deep plowed, 90 cm (without gypsum)	9.2	75-90	11.5	75-90	12.0	75-90
Malheur (slick spot) soil						
Untreated check	4.4	5-7	5.2	15-20	3.3	15-20
Subsoiled, 70 cm depth	6.4	28-36	3.6	20-28	2.8	20-28
Gypsum, 36 metric tons/ha	4.6	20-28	5.6	20-28	5.3	20-28
Deep plowed, 90 cm	9.7	70-90	15.0	75-90	10.0	75-90
Deep plowed, 90 cm (with gypsum, 18 metric tons/ha)	6.7	75-90	12.9	80-90	10.7	75-90
Deep plowed, 90 cm (with gypsum, 36 metric tons/ha)	6.4	75-90	12.6	75-90	10.7	75-90

* Total water intake (in equivalent depths in cm) determined by direct soil moisture sampling (gravimetric) methods. Intake values are means for two midseason irrigations (July and August) each year.

† Soil moisture determinations were limited to two replications in 1962 and these data have not been included in this table.

Chemical analyses of the soil samples were made at the Soils Laboratory, Oregon State University, Corvallis, using standard procedures. The bulk densities were determined with a 3-inch Uhland core sampler before and immediately after deep plowing and at the end of the experiment. The water-holding capacity of the various soil horizons at ⅓-atm and 15-atm pressures were determined on disturbed samples.

RESULTS AND DISCUSSION

Crop Yields

Excellent stands of grain and good stands of alfalfa were obtained on all treatments in 1960. Grain yield was increased 330% on the slick spot soils by deep plowing alone, and 280 to 310% by deep plowing with gypsum at rates of 18 metric tons/ha and 36 metric tons/ha, respectively (Table 1). Gypsum alone at 36 metric tons/ha or subsoiling alone did not increase grain yields on the slick spots. On the normal associated soils, grain yields were increased 65% by deep plowing alone to a depth of 90 cm, and 40% by subsoiling alone to a depth of 70 cm on a spacing of 55 cm in two directions.

Alfalfa hay yields on the slick spot soils were increased 380% by deep plowing without gypsum, 350 to 430% by deep plowing with gypsum, and 190% by gypsum alone. Subsoiling alone did not significantly increase hay yields

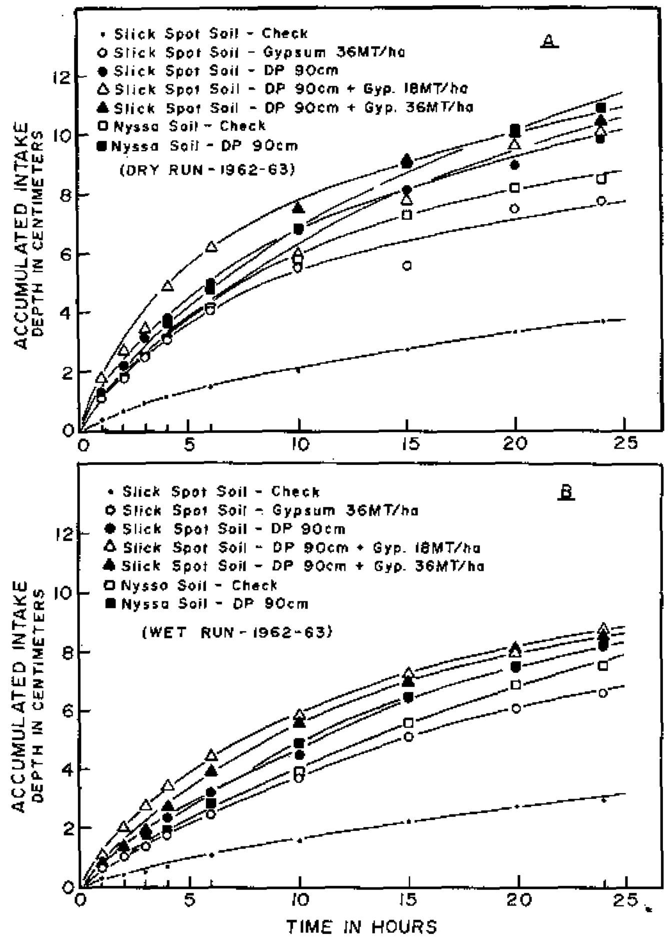


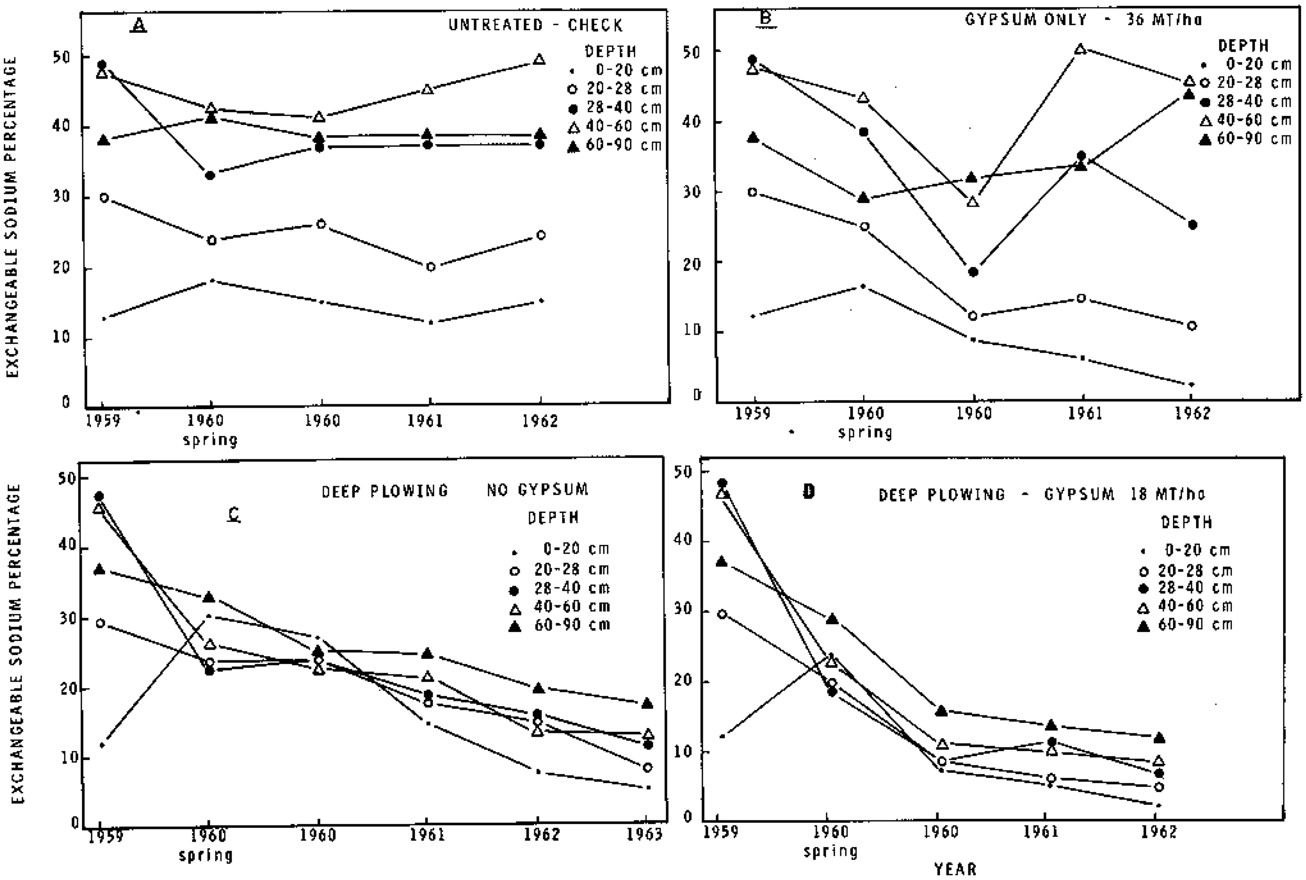
Fig. 1—Accumulated water intake as influenced by the soil treatments on the Nyssa and Malheur (slick spot) soils, values are averages for two mid-season irrigations in 1962 and 1963. Water intake was measured by furrow infiltrometers.

on the slick spot soils. Hay yields on the associated soils were not affected by deep plowing or by subsoiling. The second and third cuttings of alfalfa hay were reduced by severe infestations of green pea aphids in 1962.

The plot areas were cropped to alfalfa for seed production during 1961 through 1963, and irrigation applications were limited. Forage yields were not obtained in 1961 or 1963 because of the limited irrigation and application of toxic insecticides. Observations during these years indicated that plant growth was excellent on the deep-plowed slick spots, while plant growth on the nonplowed slick spots was characteristically very poor. Plant growth was also very limited on the gypsum-treated slick spots and only slightly better than on the untreated slick spots.

Water Infiltration

Total water intake (determined by direct gravimetric soil moisture sampling) on the deep-plowed and deep-plowed plus gypsum treated slick spots was increased 230 to 270%, and water penetration 550 to 600% in comparison to the untreated soils during the 3-year test period (Table 2). The addition of gypsum with the deep plowing did not increase the depth of water penetration or the total water intake over deep plowing alone. Gypsum alone at



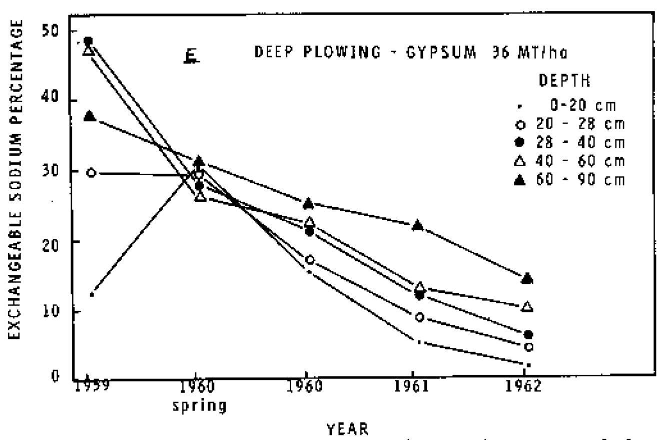


Fig. 2—Effect of gypsum and deep plowing treatments on the average exchangeable sodium percentage (ESP) with depth in the soil profile at various sampling periods. Data for all depths for each treatment are averages of four replications of each treatment.

36 metric tons/ha increased the initial intake rate and the total water intake on the slick spot soils. "Subbing" or the lateral movement of water from the irrigation furrow also was increased by the gypsum treatment, but the depth of water and root penetration was limited to about 28 cm or to the top of the silica-lime-cemented hardpan layer. Since the root zone depth and effective water storage capacity were not increased, the effectiveness of the gypsum treatment was limited.

Intake rates, determined by furrow infiltrometers during regular midseason irrigations, during the cropping seasons in 1962 and 1963 were similar. The average values for 1962 and 1963 are shown in Fig. 1A and 1B. Intake rates on the slick spot areas were greatly increased by the deep plowing and deep plowing with gypsum. Gypsum, applied at rates of 18 and 36 metric tons/ha with deep plowing, did not significantly increase the water intake rates over deep plowing alone. Intake rates on the associated Nyssa silt loam, the nonsaline soil, were increased 12 to 25% by the deep plowing treatments during the 4-year period (Fig. 1A and 1B).

Water and Root Penetration

Observations during the 4 cropping years indicated that water penetrated only 20 to 30 cm on the untreated and subsoiled slick spot soils after 48 to 72 hours of irrigation. After plowing, water penetrated to the full depth of plowing on all the slick spot plots during irrigation periods of 20 to 24 hours (Table 2). Excess water frequently observed at the bottom of the plowed layer indicated that movement of water into the underlying undisturbed, laminated silt lenses was very slow. Water penetration into the

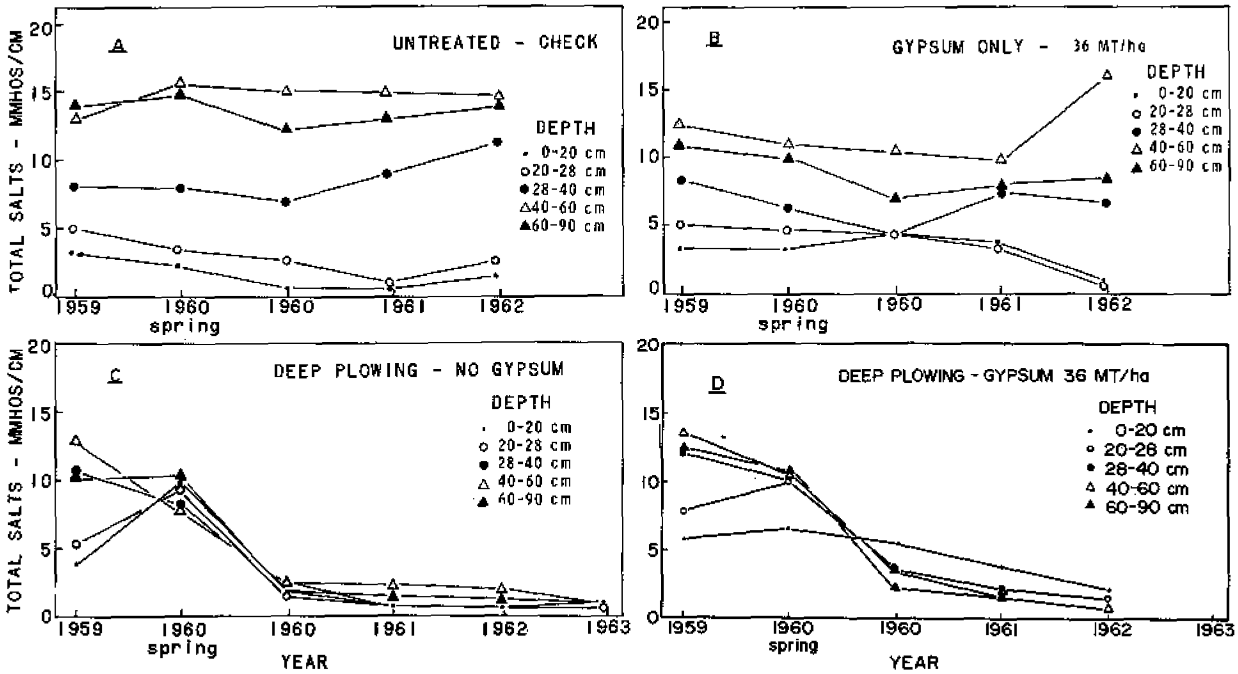


Fig. 3—Effect of gypsum and deep plowing treatments on the distribution of soluble salts in the soil profile as indicated by the electrical conductivity (EC_e) in mmhos/cm of the saturation extracts.

untreated normal soils was restricted by the compact, laminated silt lenses at an average depth of 40 cm. Subsoiling did not increase water penetration, but deep plowing greatly increased the depth of water penetration into the disrupted silt lenses on the Nyssa soils. Root penetration in the undisturbed soils was restricted by the cemented nodular hardpan layers. Depths of root penetration in all other cases were essentially equal to the average depths of water penetration.

Soil Chemical and Physical Changes

Figure 2 and Fig. 3 show that the deep-plowing treatments with 18 metric tons/ha and 36 metric tons/ha of gypsum reduced both soluble salts and exchangeable Na percentage (ESP) to safe levels throughout the plant root zone within 2 or 3 cropping years. Deep plowing without gypsum appeared to be less effective in reducing the soluble salts and the exchangeable Na percentages during the first 3 cropping years. This can be partially attributed to the limited amount of irrigation water applied to alfalfa seed crops during part of the test period. At the end of the 4th cropping year (1963), the soluble salts and exchangeable Na of the soils on the deep plowing treatments without gypsum were essentially at the same levels as on the deep plowing with gypsum treatment plots (compare Fig. 2C, 2D, and 2E and Fig. 3C and 3D).

Reduction in the soluble salt and exchangeable Na appeared to be satisfactory under the irrigation practices used. The lag in the removal of Na from the profile by the deep-plowing treatment may be related to the amount of soluble Ca available in the plots not treated with gypsum. Malheur soils are nongypsiferous and the necessary exchangeable Ca or soluble Ca needed to replace the excessive exchangeable Na was assumed to be derived from the solution of calcium carbonate (soil lime) brought to the surface from the lower soil horizons by deep plowing. Since calcium carbonate is far less soluble than gypsum, a larger quantity of water would have to move through the profile to supply the necessary Ca to replace the considerable exchangeable Na during the reclamation process. More recent studies (not cited) now indicate the value and relative effectiveness of increased leaching volumes on replacement of exchangeable Na in calcareous soils. Results from other studies would indicate the lag in removal of exchangeable Na from the deep-plowed soils without added gypsum probably resulted from the limited leaching resulting from the reduced water application. Data on the level of exchangeable Na and percent of calcium carbonate present in the deep-plowed soils indicate that sufficient soluble Ca is present for complete reclamation of the saline-sodic slick spot areas.

The slick spot soils were not significantly improved by adding gypsum at rates up to 36 metric tons/ha. Although the large amounts of gypsum markedly decreased the ESP in the 0- to 20-cm depth, they had little effect on the ESP below that depth (Fig. 2B). Appreciable quantities of gypsum remained undissolved on the gypsum-treated plots, indicating that water penetration (and hence salt removal) was limited (Fig. 3B). The chemical conditions on the subsoiled treatments and on the untreated slick spot soil remained essentially unchanged during the 4 years of the study. A supplemental deep-plowing study on a soil complex of the Malheur series (with slick spots) in association with soils of the Greenleaf series have substantiated the results from this study (W. W. Rasmussen, unpublished data). These additional studies also have shown that the slick spot soils were completely reclaimed chemically within 2 cropping years with deep plowing alone to a depth of 90 cm under adequate water applications.

Table 3—Physical properties of a representative profile of the Malheur Series (slick spot soil) before deep plowing and 4 years after deep plowing to a depth of 90 cm

Horizon	Soil depth cm	Soil texture (% clay)* before	Soil texture (% clay)* after	Bulk density before	Bulk density after	Water-holding capacity 1/3 Atm. before	Water-holding capacity 1/3 Atm. after	Water-holding capacity 15 Atm. before	Water-holding capacity 15 Atm. after
				g/cm³		% by wt.			
Ap	0-20	Sil (24.4%)	SiCl (28.7%)	1.24	1.22	31.1	32.7	13.1	11.7
B21	20-28	SiCl (34.6%)	SiCl (30.2%)	1.36	1.22	37.4	34.6	20.3	13.8
B22	28-40	SiCl (32.4%)	SiCl (30.7%)	1.41	1.25	34.7	34.0	14.1	12.4
B3ca	40-60	Sil (27.0%)	SiCl (29.2%)	1.38	1.12	38.7	33.0	11.8	10.4
Clca	60-90	Sil	Sil	1.31	1.15	37.1	31.5	11.5	9.8

* Texture of the mixed soil profile for horizons Ap - B3ca exceeded range of clay content (i.e., 27%) for silt loam classification by only 1.7 to 3.7%.

The effect of the subsoiling with added gypsum on the chemical properties of the slick spot soil were erratic and could not be rationally evaluated in the present study. Apparently the method of compositing samples from several borings masked the effect of any differential leaching over the subsoiled channels. However, analyses of samples from individual noncomposited borings within and between channels were also inconsistent. This probably results in part from the variable water penetration and limited dissolution of gypsum in the undisturbed areas between the ripper channels on subsoiled areas. (Similar results have been observed on other hardpan affected soils.) The data obtained generally indicated only a limited benefit from the subsoiling with added gypsum. Results from additional studies on soils similar to the Malheur series (with slick spots) on several other sites indicate that subsoiling in combination with gypsum is not much more effective than treatment with gypsum alone, and subsoiling alone is ineffective for improving the Na-affected soils.

The effects of deep plowing on some physical properties of the slick spot soils are shown in Table 3. Deep plowing slightly increased the clay content of the surface horizon, changing the texture from silt loam to a light silty clay loam, but decreased the clay content in the B2 horizons. Only slightly more mixing of the soil during deep plowing to the 90-cm depth should result in a silt loam soil with a clay content of less than 27%. The bulk densities of all soil horizons were initially reduced by deep plowing. Only moderate recompaction by tillage and irrigation occurred in the upper 40 cm of the soil in 4 years following deep plowing. Observation of the soils on the experimental plots and in other areas indicate that the densities of the lower soil horizons remained low for more than 8 years following deep plowing. The moisture retention properties of the soil horizons evaluated on disturbed samples were only slightly altered by deep plowing. All data from the water intake, water and root penetration, and bulk density measurements indicate that the physical conditions of the highly variable soils were greatly improved by deep plowing.

The overall results of the soil improvement study indicate that Malheur (slick spot) and similar saline-sodic soils with fine-textured, Na-affected (natric) horizons and nodular hardpan layers, but with moderate to highly calcareous medium- to coarse-textured B3ca or Cca horizons, can be effectively reclaimed by deep plowing alone. The productivity of the associated normal soils was also increased by deep plowing. Infiltration rates and crop yields on the nonsaline soils similar to the Nyssa, Greenleaf, and related silt loam soils are moderately increased by deep plowing. Deep plowing of irrigated farmlands affected with unfavorable natric or slick spot soil areas appears to be a feasible and economical practice for general soil improvement and for reclaiming the nonproductive saline-sodic soil areas. Irrigated soils affected with areas of the Malheur-like slick spot soils can be plowed to adequate depths with 1.2-m (4-foot) moldboard plow at costs varying from $35 to $45 per acre.

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