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Response of Three Irrigated Crops to Deep Tillage of a Semiarid Silt Loam[1]

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ABSTRACT

The growth and water relations of winter wheat *(Triticum aestivum* L.), sugarbeets (*Beta vulgaris* L.) and corn (*Zea mays* L.) were studied after deepening the root zone in the Portneuf silt loam soil (Durixerollic calciorthid). Roots of annual plants are largely restricted by a hard layer that lies between the 0.4- and 1-m depths. This layer was disrupted to a depth of 1.2 m by complete mixing, by chiseling, or by trenching on 0.6- and 1.2-m centers. The treatments included two irrigation levels to show any advantage in crop water relations due to deeper rooting after deep tillage.

Deeper rooting did develop on the deep-tilled treatments, but the water supplied through net soil moisture depletion below 0.6 m was increased by $<$ 4 cm, even when the crop was stressed for water late in the season. Deep soil water extraction was not always proportional to rooting density. Trenching on 0.6-m centers was the most favorable treatment. Completely mixing the soil decreased yields, due in part to a lighter surface color and lower soil temperatures. Deep tillage seldom had a measurable effect on stomatal resistance or plant water potential. Management of this soil should be concentrated on providing the best possible root environment in the top 0.5 m of soil as this is the basis for maximum production in irrigated agriculture.

Additional Index Words: **corn, sugarbeets, wheat. soil water, plant water, stomatal resistance.**

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Recent papers by Reicosky et al. (1976); Heilmann and Gonzolez (1973); Rasmussen et al. (1972); Eck and Davis (1971); Unger (1970); Burnett and Hauser (1967; James and Wilkins (1972); and Musick and Dusek (1975), show that deep tillage may improve chemical as well as physical conditions, thus creating some benefits whenever there is a logical basis for the tillage. Of interest in this respect is the Portneuf silt loam (coarse-silty, mixed, mesic Durixerollic Calciorthid) in southern Idaho with its lime-cemented layer between the depths of 0.4 m and 1 m. This layer is permeable to water but hard enough to stop most root penetration by annual crops. The silt loam below the hard layer is friable but generally low in P and N.

Robbins (1977) described the physical properties of the soil in some detail. The texture is quite uniform down to 1.2 m (19% sand, 62% silt, 20% clay), below which the sand content gradually increases to 30% as the silt and clay fractions decrease. The saturated hydraulic conductivity of both the surface soil and hard layer is near 1 cm hour^{-1}. The bulk density throughout the profile is about 1.3 g cm^{-3} except in the hard layer, where it rises to 1.4 or 1.5. The available water-holding capacity in the top 1.5 m of soil is about 25 cm.

Some chemical properties of the soil are a surface pH of 7.5 and a cation exchange capacity near 20 meq 100 g^{-1}. Its ESP and SAR values range from 2 to 5%, and the saturation extract conductivity is about 0.6 mmho cm^{-1}. Lime content of the surface 30 cm is near 1%, but rises to 22% in the hard layer.

Studies begun in 1965 by Rasmussen showed that (i) the hard layer can be disrupted by several methods of tillage; (ii) the effects persist for at least 10 years under irrigation; and (iii) deep rooting does increase after deep tillage of the soil. The results reported here are from a study designed to determine the effects of deeper rooting on the water relations of annual plants grown under irrigation in a semiarid climate. The

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hypothesis being: enlargement of the root zone could increase the reservoir of available soil water enough to reduce the number of irrigations required to produce maximum yields. This would save labor, reduce soil loss from water erosion, and improve plant nutrient recovery from the deeper soil.

METHODS

The hard layer was disrupted to 1.2 m by complete mixing with a backhoe, chiseling, or by trenching on 0.6- or 1.2-m centers. The chiseling was done with a vibrating cable-laying machine when the soil was dry. The trenches were dug 15 cm wide and backfilled with the mixed soil profile. The plots were 6 by 18 m and arranged in a complete randomized block with three replications. Two irrigation levels were imposed on each tillage treatment and the control, making a total of 12 plots per replication. A cover crop of corn (*Zea mays* L.) was grown to allow the mixed soil to settle. This was followed by the first test crop, winter wheat (*Triticum aestivum* L.) then sugarbeets (*Beta vulgaris* L.) and corn in the fourth season. The crop rows ran parallel to the trenches and chisel paths but not necessarily directly over them.

The plots were irrigated individually with corrugations on 0.75-m centers for the corn and 0.6-m centers for wheat and sugarbeets. The quantity of water applied was varied by irrigating for 12 or 24 hours in either all or alternate corrugations. The water applied was calculated from infiltration rates measured previously (Rasmussen and Cary 1979). During any given irrigation, all of the plots that received water received it for the same length of time, but the net absorbed by the mixed plots was nearly 30% less than the others due to their lower infiltration rates. All plots were irrigated to provide optimum moisture during pollination of the wheat and corn or until full cover for the beets (i.e., irrigation water was added before the soil matrix potential reached —0.7 bar at the 45-cm depth). At this time the roots in the deep tillage plots had penetrated to at least 0.6 m and the two soil water levels were imposed. For the higher level, the corn and sugarbeets were irrigated when the soil matrix potential at 45 cm reached approximately —1 bar, while the wheat was allowed to become a bit drier. This created more soil water stress during the later part of the growing season than one would normally recommend for optimum growth. The second, or "dry" treatment, was developed by eliminating one or more of the irrigations received by the controls in the later part of the growing season.

Leaf water potentials were measured on the wheat with the freezing point method, and on the beets and corn with the hydraulic press.[3] Leaf stomatal resistance was also measured on the beets and corn with a commercial LiCl cell.[3] These water relation measurements were generally made during the early afternoon when the stress was gratest.

One control and one mixed plot, both normally irrigated, were instrumented with soil water flowmeters at 0.5 and 1.2 m (Cary, 1973). Four thermometers were rotated randomly between the mixed and control plots to measure soil temperature at 15 cm. Tensiometers were used on two of the control and two of the mixed plots to schedule irrigation. Gravimetric soil moisture samples were taken to a depth of 1.5 m at 0.3-m increments from single random auger holes in each treatment in each replication on specific dates throughout the growing seasons. These data were used to calculate soil matrix water potentials and volumetric water content changes using bulk density and water desaturation curves from a composite of undisturbed samples.

Consumptive water use was estimated from the amount of water added by irrigation and rainfall, the net change in water held by the soil between the surface and the 1.5-m depth, and estimates of deep drainage from the flow meters.

Root growth patterns were observed in trenches dug across the ends of the plots at the close of each growing season following harvest.

The plots received annual blanket applications of fertilizer according to local recommendations guided by soil tests. Totals were 170 kg/ha P, 11 kg/ha Zn, and 670 kg/ha N with the mixed plots receiving an additional 110 kg/ha of P, 2 kg/ha of Zn and 30 kg/ha of N. Tillage following establishment of the treatments were in accord with normal local practices.

RESULTS AND DISCUSSION

Trends in rooting, water relations, and yields were similar for all three crops, so only those for corn grown in the fourth season after deep tillage are presented in detail, with exceptions for wheat and sugarbeets noted as they occurred. Both chiseling treatments and trenching on 1.2-m centers, produced the same results as the control, or were intermediate between the control and the mixed. Consequently, only results from the control, the completely mixed soil, and the close-spaced trenches are presented in detail.

In the control plots, roots spread out on top of the hard layer at 0.4 m, and only a few penetrated to depths > 1 m. All deep tillage treatments signifi-

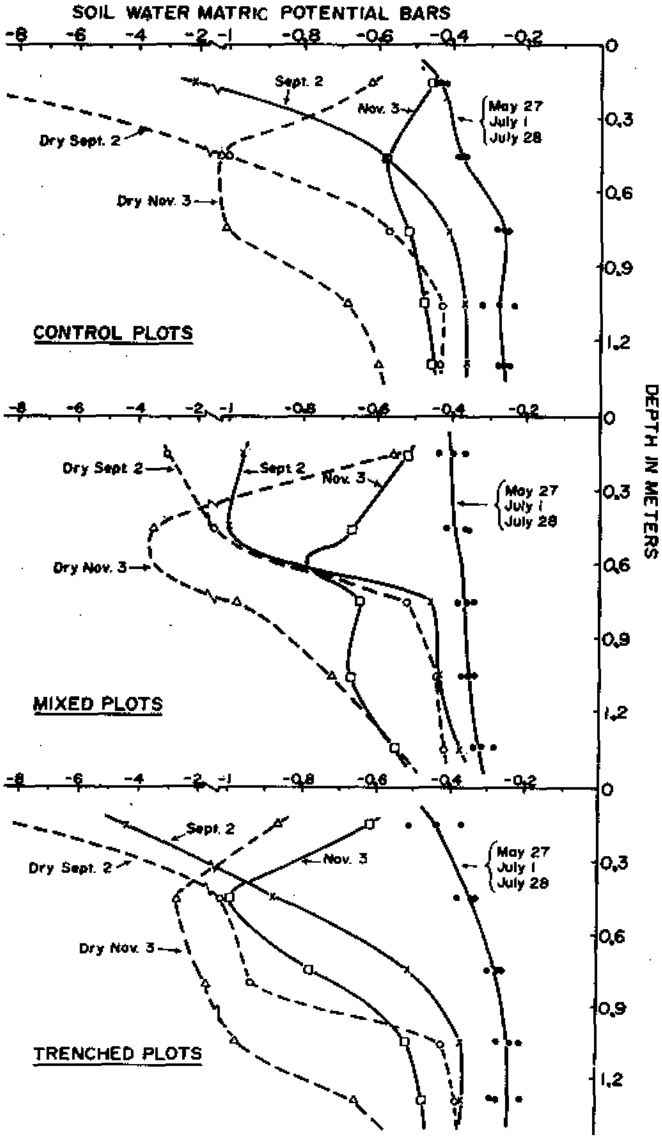

Fig. 1—Soil water potential profiles developed by corn growing on various tillage treatments. The solid lines indicate a mild stress irrigation sequence and the dashed lines the dry and well stressed treatments .

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[3] Campbell Scientific, Inc., Logan, Utah, and Lambda Instrument Corporation, Lincoln, Nebraska, respectively. Trade names and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product listed by the U. S. Department of Agriculture.

cantly changed the rooting patterns. Chiseling caused some shattering of the hard layer so that roots grew through the layer in a "V"-shaped pattern 0.5 m wide at the 0.4-m depth, narrowing to 5 cm at the bottom of the 1.2-m chisel depth. Roots proliferated very little below the chisel depth, and generally none were found in the unfractured hard layer. Roots grew prolifically down the trenches, and a few lateral branches developed below the hard layer. The mixed plots produced a root distribution pattern typical of a uniform soil with a few roots penetrating to 1.5 m. Visual observations below the 0.6-m depth suggested the relative vigor of the root systems was beets > wheat > corn. No obvious differences in rooting density resulted from the irrigation treatments.

The average soil water matrix potential profiles are shown in Fig. 1 for five sampling dates, beginning the end of May before the corn emerged and ending early in November after the plants were killed by frost. Soil water was maintained near optimum levels in all treatments until after the first part of August when pollination occurred. Plots in the "stressed" irrigation treatments received no irrigation water and only insignificant precipitation after 8 August until some light rains occurred in October. The normally irrigated plots continued to receive applications of water, though slightly less than the optimum amounts to emphasize any advantages of the deep-tilled treatments. The irrigation dates and amounts applied to the control and trenched plots were: 27 June, 9 cm; 10 July, 8.5 cm; 23 July, 8.5 cm; 8 August, 4.5 cm; 25 August, 4.5 cm; 8 September, 7.5 cm; and 22 September, 4.5 cm. Water movement at the 1.2-m depth was always < 0.5 mm/day, showing some downward movement before August and some upward after that time. The upward flow past the 0.5-m depth during the water-stress period of August, September, and October was < 3 cm of water. No water flowed downward past 0.5 m during this period, according to the tensiometers and flowmeters.

The amount of water provided by net soil moisture depletion below 60 cm was relatively small in all plots compared to the total water used by the crop. Only about one-half of the theoretically available water (17 cm) was removed from the deeper soil. In contrast, studies by Aarstad and Miller (1973) and Miller and Aarstad (1976) with daily sprinkler applications showed nearly all of the available subsoil water to 1.0 m could be extracted during the course of the growing season. In their studies only the surface few centimeters of soil was kept moist, so the roots had the whole growing season to deplete the deeper water, while in this study the depletion was allowed only after the end of July. Aarstad and Miller's results are in agreement with those observed here in that water from the subsoil would not support maximum production when the water content in the top 30 cm of soil became low.

Drying the topsoil did increase the rate of extraction of subsoil water, (Table 1) but as pointed out by Kohl and Kolar (1976), and Miller (1975), roots in the subsoil continue to extract water even when the subsoil is at a much lower water potential than the soil around the roots near the surface. This characteristic reduces the possibilities for managing subsoil storage as an emergency water source under irrigation. Even though the surface soil is kept moist, the plants begin to remove deep soil water as soon as even a few small roots reach it. This reduces the capacity of the deep soil to supply water rapidly enough for maximum growth should the top 0.5-m of soil later become dry.

The rooting density did not necessarily determine the amount of soil water extracted Fig. 1) which was also noted by Allmaras et al. (1975) and Arya et al. (1975). The occasional corn roots below 0.6 m in the control plots were more efficient in removing water than the more profuse and normal distribution of roots below 0.6 m in the mixed plots. Soil temperature and probably other unrecognized factors are involved in determining root water uptake efficiency.

The corn yields and average values for plant water relations in September are also shown in Table 1. In general, the irrigation variables created just enough stress to cause small reductions in plant growth. Though not always statistically significant at the 95% confidence level, the trench tillage treatment did tend to reduce the yield loss due to inadequate irrigation, but the mixed profile did not help.

The stomatal resistance and leaf water potentials in Table 1 are the averages of measurements made at random on leaves in the sun in the upper part of the canopy during the early part of the afternoon on 6 days between 4 September and 2 October. The measurements were made on at least three leaves from each treatment. These averages reflect the two irrigation levels, but show no differences due to tillage. Plant water potential, and particularly stomatal resistance, changed much more from day to day than the variation from leaf to leaf at the same time in the same plot. The leaf-to-leaf variation is characterized by the confidence levels in Table 1. Neither measurement would have been useful for detecting the onset of water stress

Table 1—Summary of average afternoon plant-water relations and yields of corn from the control and two deep-tillage treatments under two levels of irrigation. The stressed plots were irrigated four times, and the others seven. The available water holding capacity in the 60- to 150-cm depth was about 17 cm of water.

	Net soil moisture depletion, 60- to 150-cm depth		Total consumptive use	4 September to 2 October		Production	
Treatment	28 July–2 Sept.	28 July–3 Nov.		Average stomatal resistance	Average leaf water potential	Dry matter	Dry grain
	cm		cm	sec/cm	bars	metric tons/ha	
Control	4.2	6.7	63	6.5	−14.0	19.7	7.58
Stressed control	6.3	10.4	55	6.2	−16.5	15.3	6.48
Mix	2.3	6.5	51	5.4	−14.2	19.9	6.21
Stressed mix	3.5	8.7	45	9.1	−17.9	13.5	4.76
Trench	4.7	8.6	67	5.3	−13.9	20.5	8.41
Stressed trench	5.6	11.7	57	7.2	−16.2	18.4	7.32
Confidence intervals	±2.0	±2.0	±8	±3.0	±1.5	L.S.D. = 2.7 (5% level)	L.S.D. = 1.4 (5% level)

Table 2—The average yields of sugar and wheat in metric tons per hectare. Under optimum irrigation and growing conditions, the yields could have been as high as 10 for the sugar and 8 for the wheat.

	Sugar		Wheat	
No. of irrigations:	Seven	Nine	One	Two
Approximate cm of water added including rainfall	64	80	23	40
	yields in metric tons			
Treatments:				
Control	8.2	9.0	4.3	5.8
Trenched	7.2	8.9	4.7	5.4
Mixed	4.9	4.3	2.4	4.2
L.S.D. at 5%	1.3		1.0	

in corn on a field scale without reference to simultaneous measurements from an optimumly managed control plot.

Occasional, higher leaf water potentials in the wheat were found when the trenched treatments were compared to the controls. The differences were small though, and the leaf water potentials on both treatments were well below optimum. As with the corn, the water potentials and stomatal resistances of sugarbeets did not show differences between the trenched and control treatments.

Table 2 is a summary of the yields from the winter wheat and sugarbeets. Winter wheat requires three irrigations for maximum yields in south-central Idaho, so even the treatment that was irrigated twice experienced enough water stress to lower its yield. Both the mixed and trenched treatments failed to prevent the yield loss. This was also true for the beets, though the results were marred by a white mildew infestation in September, and lower plant N levels on the control and trenched plots than are normally found in commercial fields.

The poor production on the mixed soil was not associated with water stress, K deficiency, or high levels of soluble salts. The lower soil temperatures may have caused part of the yield reduction. The color of these plots was noticeably lighter when dry, and the temperatures at the 15-cm depths were about 1°C lower than corresponding depths on the control plots during the first part of the growing season before full plant cover was reached. The reduced growth and vigor of the seedlings of all three crops on all mixed plots was striking. The stand of wheat was reduced at least in part because the drill went too deep in the mixed soil but the overall decrease in plant vigor was evident until maturity. This was less of a problem with the beets, but the seedlings on the mixed plots suffered more root maggot and black crown damage than those on other treatments. There were no obvious cultural problems with the corn but it is difficult to believe all of the yield reduction on the mixed soil was due to the lower soil temperatures.

CONCLUSIONS

When adequate irrigation water is available and maximum production is the primary objective, resources should be directed toward optimum management of the surface 0.5 m of soil. Tillage below 0.5 m under these circumstances is of little benefit for reaching maximum production, provided, of course, there is no strata that can be modified to alleviate salt, waterlogging, or texture problems in the surface 0.5 m of soil. Moreover, mixing the whole soil profile can be unexpectedly detrimental, as shown here. On the other hand if water applications cannot be made on a timely basis, deep rooting can mean the difference between crop failure and limited production. Under such conditions tillage to depths below 0.5 m may be beneficial.

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