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Alfalfa Production on a Profile-Modified Slowly Permeable Soil

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ABSTRACT

Yields of irrigated alfalfa (*Medicago sativa* L.) are lower on Pullman clay loam than on more permeable soils in the same climatic area. The objectives of this study were to determine (i) the residual effect of thoroughly mixing the soil profile on alfalfa growth and production, and (ii) the amounts and timing of irrigations required for maximum alfalfa production on modified and unmodified soil profiles.

Alfalfa was grown under three profile modification treatments (thoroughly mixing the soil profile to 0-, 90-, or 150-cm depth) on Pullman clay loam. For the first 3 years, all plots were either irrigated similarly (1970 and 1972) or unmodified plots were irrigated twice between harvests when necessary (1971). During the next 3 years, we expanded the study to include three irrigation treatments (two 10.2-cm, one 17.8-cm, or two 15.2-cm irrigations between harvests). During the first 3 years, when single irrigations were applied between harvests, profile modification increased dry-matter yields 40% (90-cm modified) to 60% (150-cm modified) over those for the unmodified check. However, with two irrigations between harvests, effects of modification were less marked.

In the second phase of the study, with two 10.2-cm irrigations between harvests, profile modification increased yields 30% (14.1 to 18.4 metric tons/ha). On 90-cm modified soil, 3-year average yields were 16.6, 18.3, and 20.1 metric tons/ha with one 17.8-, two 10.2-, or two 15.2-cm irrigations between harvests, respectively. Respective yields on 150-cm modified soil were 17.4, 18.5, and 18.6 metric tons/ha.

Yields, water intake rates, bulk densities, and surface elevations showed that profile modification treatments made in 1964 were still effective 12 years later.

Additional Index Words: **soil water infiltration, water-use efficiency, alfalfa rooting patterns.**

THE INCREASED cattle feeding industry in the Southern High Plains has increased the demand for alfalfa (*Medicago sativa* L.). Currently, most of the alfalfa is shipped from western Kansas, eastern Colorado, and New Mexico, or grown on the coarser-textured soils of the area. Little alfalfa is grown on Pullman and associated soils, which comprise about 5 million ha of arable soils in the area. The Pullman series is a member of the fine, mixed thermic family of Torrertic Paleustolls (order Mollisols). The moderately permeable surface soil (0 to 20 cm) is underlain by a dense, very slowly permeable montmorillonitic clay horizon (B22t) extending from the 20-cm through the 50- to 60-cm depth. Below this depth, the soil is somewhat more permeable. Depth to the highly calcareous "caliche" layer varies from 120 to 150 cm. A detailed description of the soil is available (7). Yields of irrigated annual field crops [winter wheat (*Triticum aestivum* L.), grain sorghum (*Sorghum bicolor* (L.) Moench), corn (*Zea mays* L.), sugarbeets (*Beta vulgaris* L.), etc.] on Pullman clay loam are comparable to those on coarser-textured soils, but alfalfa yields are lower. Jensen and Sletten[3] attributed these lower alfalfa yields on Pullman soil to inadequate penetration of irrigation water, since they were unable to wet the soil below about the 90-cm depth without having water ponded on the soil surface for several days.

Profile modification of Pullman clay loam has been shown to increase water intake rates and the amounts of stored water in the profile, and to change the distribution of stored water and plant-rooting patterns (1). Under limited irrigation, grain sorghum yields and water-use efficiency were increased. However, under adequate irrigation, profile modification had little effect on sorghum yields, but increased water-use efficiency, primarily by reducing seasonal water application required to prevent stress. Unger (8) found that profile modification effectively disrupted the slowly permeable horizon of Pullman soil. Soil bulk density and strength were significantly decreased.

Since soil profile modification created a more favorable rooting environment and alfalfa is adapted to deep, friable, well-drained soils, profile modification of Pullman soil could be expected to increase alfalfa yields. The objectives of this study were: (i) to determine the residual effect of thoroughly mixing the soil profile on alfalfa growth and production, and (ii) to determine amounts and timing of irrigations required for maximum alfalfa production on modified and unmodified soil profiles.

EXPERIMENTAL PROCEDURE

The experimental site was on a nearly level area of Pullman clay loam at the USDA Southwestern Great Plains Research Center, Bushland, Texas. Alfalfa production was studied on three depths (0, 90, and 150 cm) of profile modification for 6 years (1970–75). After 3 years with a single irrigation regime, the experiment was enlarged to evaluate three regimes. The profile was modified (thorough mixing of the soil to the prescribed depth with a wheel-type trenching machine) in November 1964 for a previous study as described in detail by Eck and Taylor (1).

The irrigation regime evaluated in 1970 and 1972 for Exp. I was single irrigations to replenish the root zone in early spring and after each harvest. After the third harvest in 1970 and in 1971, the schedule was changed to two irrigations before each harvest. Three irrigation treatments were evaluated during the second 3 years (Exp. II): (i) two 10.2-cm, (ii) one 17.8-cm, and (iii) two 15.2-cm irrigations before the first harvest and between succeeding harvests. Treatment 3 was not studied on unmodified soil. Irrigation water applied and precipitation received before and

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[3]USDA Southwestern Great Plains Research Center Annual Rep. 1957.

Table 1—Irrigation water applied and precipitation received before and between harvests, 1970–1972.

	Precip.	Soil profile: Unmodified Irrigation	Unmodified Total	Modified Irrigation	Modified Total
	cm				
1970					
Harvest 1	0.1	22.9	23.0	22.9	23.0
2	10.6	17.8	28.4	17.8	28.4
3	1.0	17.8	18.8	17.8	18.8
4	4.4	27.9†	32.3	20.3	24.7
Total	16.1	86.4	102.5	78.8	94.9
1971					
Harvest 1	1.7	27.9†	29.6	27.9†	29.6
2	7.2	25.4†	32.6	20.3	27.5
3	1.5	25.4†	26.9	15.2	16.7
4	13.2	12.7	25.9	20.3	33.5
5	9.6	15.2	24.8	20.3	29.9
Total	33.2	106.6	139.8	104.0	137.2
1972					
Harvest 1	7.4	38.1†	45.5	38.1†	45.5
2	5.7	17.8	23.5	17.8	23.5
3	11.2	17.8	29.0	17.8	29.0
4	10.9	17.8	28.7	17.8	28.7
5	11.4	17.8	29.2	17.8	29.2
Total	46.6	109.3	155.9	109.3	155.9

† Received two irrigations between harvests.

Table 2—Irrigation water applied and precipitation received before and between harvests, 1973–1975.

	Precip.	Irrigation treatment† 1: Irrigation	1: Total	2: Irrigation	2: Total	3: Irrigation	3: Total
	cm						
1973‡							
Harvest 1	0.5	12.7	13.2	12.7	13.2	12.7	13.2
2	6.1	12.7	18.8	12.7	18.8	12.7	18.8
3	4.9	20.3	25.2	17.8	22.7	30.5	35.4
4	4.3	20.3	24.6	17.8	22.1	30.5	34.8
5	3.2	10.2§	13.4	17.8	21.0	15.2§	18.4
Total	19.0	76.2	95.2	78.8	97.8	101.6	120.6
1974							
Harvest 1	4.2	20.3	24.5	17.8	22.0	30.5	34.7
2	8.5	20.3	28.8	17.8	26.3	30.5	39.0
3	3.3	20.3	23.6	17.8	21.1	30.5	33.8
4	22.7	10.2§	32.9	17.8	40.5	15.2§	37.9
5	13.8	10.2	24.0	0	13.8	15.2§	29.0
Total	52.5	81.3	133.8	71.2	123.7	121.9	174.4
1975							
Harvest 1	5.9	20.3	26.2	17.8	23.7	30.5	36.4
2	4.9	20.3	25.2	17.8	22.7	30.5	35.4
3	4.2	20.3	24.5	17.8	22.0	30.5	34.7
4	8.8	10.2§	19.0	17.8	26.6	15.2	24.0
5	1.7	20.3	22.0	17.8	19.5	30.5	32.2
Total	25.5	91.4	116.9	89.0	114.5	137.2	162.7

† Irrigation treatments are: 1. Two 10.2-cm irrigations between harvests.
2. One 17.8-cm irrigation between harvests.
3. Two 15.2-cm irrigations between harvests.
‡ Differential irrigation treatments were begun after the second cutting, 1973.
§ One irrigation withheld due to precipitation.

between harvests are given in Tables 1 (Exp. I) and 2 (Exp. II).

Plots were 9 by 49 m. The experimental designs were randomized blocks with three (Exp. I) and two (Exp. II) replications.

Alfalfa, variety 'Cody' was established on half of the plots in August 1969 and on the other half in April 1972. In each case, plots were releveled, fertilized at a rate of 224 kg P/ha, and planted with inoculated seed at a rate of 28 kg/ha. At the first four harvests each year, the forage was cut when it reached one-tenth bloom stage. First harvests were in late May or early June, and the following three at about 28-day intervals. Fifth harvests were made near first killing frosts. In 1970, one or more m^2 subsamples were hand-harvested for yield, then remaining forage was removed with a field chopper. In succeeding years, forage from entire plots was harvested with a field chopper, weighed, and subsampled for dry-matter content (determined by oven-drying to constant weight at 65°C).

Soil water was measured at initial growth in the spring, before each irrigation, and after the final harvest each year. It was measured gravimetrically in 1970-72 and by the neutron thermalization method in 1973-75. Measurement was to a 1.8-m depth at two locations per plot in 1970; to 3.6-m at two locations in 1971; to 3.6-m at three locations in 1972; and to 3.0-m at three locations per plot in 1973–75.

Water infiltration rates were measured on the three profile modification treatments under irrigation Treatment 2 in June 1975. The 17.8-cm irrigation was applied through gated pipe in 26 min, and subsidence rate was measured with FW-1 water stage recorders installed on each plot.

Alfalfa roots on unmodified and 90- and 150-cm modified plots of one replication of irrigation Treatment 1 were exposed, observed, and photographed in July 1976. Two small parallel trenches (about 1-m apart) were made across each plot with a ditching machine. The soil between the trenches was excavated with a backhoe, leaving a smooth-sided excavation about 1-m wide and 2.3-m deep. Another backhoe-excavated trench (about 1-m wide, 1.5-m deep at one end, and sloping to ground level on the other) perpendicular to and adjoining the initial excavation allowed access to the initial excavation. We exposed the roots on one side of the trench by washing the soil away with a stream of water from a garden hose. After drying, the roots were sprayed with white enamel paint. When the paint dried, the soil was rewashed from the roots, leaving the painted roots against the soil background. Then we photographed the trench face and roots.

Soil bulk density was determined from cores (62 mm in diam and 103-mm long) taken from the sides of root observation excavations with the sampler described by Lotspeich and Laase (3).

Elevations of plots and of adjacent undisturbed areas were measured with an engineer's level. Reported changes are differences in elevations between plots and undisturbed areas.

RESULTS

Yields

EXPERIMENT I

In the first year of the study (1970), alfalfa on profile-modified plots significantly out-yielded that on unmodified plots for the first three harvests (Table 3); forage yields on the 90- and 150-cm profile modified soil were 111 and 137% greater, respectively, than those on unmodified soil. Apparently, a single irrigation between harvests on unmodified soil was not nearly as adequate as it was on modified soil. Between the third and fourth harvests, the unmodified plots were irrigated twice (15.2 and 12.7 cm), while the modified plots were irrigated only once (20.3 cm). With the additional water applied on the unmodified plots, yields were not significantly different on modified and unmodified soil profiles.

Throughout 1971, we irrigated the unmodified plots twice between harvests when necessary, and on those plots the total seasonal yields approached those from the profile-modified plots.

Table 3—Effect of depth of profile modification on alfalfa yields, 1970–1972.

Depth of modification	Harvest 1	2	3	4	5	Total
cm	metric tons/ha					
			1970			
0	2.04 a*	1.92 a	1.21 a	3.02 a†	--	8.19 A**
90	5.29 b	3.12 b	2.51 b	2.57 a	--	13.50 B
150	5.16 b	3.84 c	3.27 b	3.48 a	--	15.75 C
			1971			
0	2.83 a†	3.01 a†	3.05 a†	2.70 a	1.85 a	13.44 A
90	2.38 a†	2.72 a	2.87 a	3.66 b	2.30 b	13.93 AB
150	2.12 a†	2.68 a	3.43 b	4.06 c	2.41 b	14.70 B
			1972			
0	4.92 a†	2.99 a	1.13 a	2.28 a	1.63 a	12.95 A
90	5.94 a†	3.74 ab	2.16 b	2.51 a	1.80 a	16.15 B
150	6.73 a†	4.29 b	2.51 b	2.79 a	1.81 a	18.13 B
			Mean			
	3.26	2.64	1.80	2.67	1.74	12.11
	4.54	3.19	2.51	2.91	2.05	15.20
	4.67	3.60	3.07	3.44	2.11	16.89

* Means in the same harvest followed by the same lower case letter are not significantly different at the 5% level.
** Total seasonal yields followed by the same capital letter are not significantly different at the 5% level.
† Received two irrigations before or between harvests.

In 1972, we re-evaluated the practice of irrigating plots similarly on the three profile-modification treatments. Total seasonal yields on the 90- and 150-cm profile modified soil were 24.7 and 40% higher, respectively, than those on the unmodified soil. The smaller yield response in 1972 (as compared with 1970) was probably attributable to all treatments being irrigated twice before the first harvest in 1972, and to higher growing season precipitation in 1972 (46.6 cm) than in 1970 (16.1 cm).

EXPERIMENT II

Yields from Exp. II are presented in Table 4. Since the different irrigation treatments were not initiated until after the second harvest in 1973, their season-long effects can only be assessed in the 1974 and 1975 data. Also, one unmodified plot under irrigation Treatment 2 became heavily infested with barnyard grass [(*Echinochloa crus-galli* (L.) Beauv.] in 1972 and 1975, which contributed large, but undetermined proportions of the third and harvests on this plot. Thus, including the data from this plot may make results somewhat misleading, but excluding it would leave only one replicate. So, although we included the data in the tables, when the treatment is used for comparisons in the text, we indicated the possible bias of the grass yield.

Under irrigation Treatment 1, profile modification to 90 and 150 cm increased 3-year average yields by 29 and 31%, respectively. In 1973, only the 150-cm modified plots significantly out-yielded the unmodified plots; in 1974, only the 90-cm modified plots significantly out-yielded the unmodified plots; and in 1975, both 90- and 150-cm modified plots out-yielded the unmodified plots.

On both 90- and 150-cm modified plots, irrigation Treatments 1 and 2 gave statistically similar yields.

Table 4—Effect of depth of profile modification and irrigation treatments on alfalfa yields, 1973–1975.

Depth of modification	Irrigation treatment†	Harvest 1	2	3	4	5	Total
cm		metric tons/ha					
				1973			
0	1	4.23 a*	2.79 a	4.13 a	2.78 a	0.70 a	14.64 A**
	2	5.81 a	2.73 a	4.49 a	2.29 a	0.96 b	16.28 AB
90	1	5.20 a	3.04 a	5.53 a	2.65 a	1.21 c	17.62 ABCD
	2	5.32 a	3.22 a	3.84 a	3.05 a	1.64 d	17.07 ABC
	3	6.46 a	3.93 a	5.61 a	3.64 a	1.57 d	21.20 D
150	1	5.48 a	4.43 a	5.94 a	2.98 a	1.22 c	20.05 CD
	2	6.10 a	3.58 a	4.94 a	3.53 a	1.49 d	19.63 BCD
	3	5.53 a	4.02 a	4.00 a	3.42 a	1.60 d	18.56 BCD
				1974			
0	1	2.80 a	3.56 ab	3.39 ab	2.80 a	1.14 a	13.70 AB
	2	3.18 a	2.68 a	2.75 a	2.91 a	0.71 a	12.23 A
90	1	4.90 a	4.74 cd	4.47 d	3.00 a	1.23 a	18.33 C
	2	4.38 a	3.60 ab	3.58 abcd	2.65 a	0.63 a	14.83 ABC
	3	5.13 a	4.94 d	4.42 d	2.71 a	1.18 a	18.38 C
150	1	4.19 a	4.34 bcd	3.88 bcd	2.50 a	1.02 a	15.93 ABC
	2	3.85 a	3.92 bc	3.45 abc	2.61 a	0.99 a	14.82 ABC
	3	4.81 a	4.44 bcd	4.14 cd	2.30 a	1.08 a	16.78 BC
				1975			
0	1	4.14 ab	3.63 a	3.46 ab	1.92 a	0.93 a	14.09 A
	2	3.26 a	2.60 a	2.96 a	4.12 a	1.48 a	14.41 A
90	1	4.82 bc	3.82 a	4.31 c	3.65 a	2.29 a	18.89 BC
	2	4.01 ab	3.80 a	3.74 bc	4.18 a	2.26 a	17.99 B
	3	5.44 cd	4.70 a	4.16 c	3.50 a	2.82 a	20.61 C
150	1	4.74 bc	4.12 a	3.86 bc	4.06 a	2.72 a	19.50 BC
	2	4.15 ab	3.55 a	3.73 bc	4.04 a	2.33 a	17.80 B
	3	6.37 d	4.09 a	3.90 bc	3.33 a	2.71 a	20.39 C
				Mean			
0	1	3.72	3.33	3.66	2.50	0.92	14.13
	2	4.08	2.67	3.40	3.11	1.05	14.31
90	1	4.97	3.88	4.77	3.10	1.58	18.28
	2	4.57	3.54	3.72	3.29	1.51	16.63
	3	5.68	4.52	4.73	3.28	1.86	20.07
150	1	4.80	4.30	4.56	3.18	1.65	18.49
	2	4.70	3.68	4.04	3.39	1.60	17.42
	3	5.57	4.18	4.01	3.02	1.80	18.58

* Means in the same harvest followed by the same lower case letter are not significantly different at the 5% level.
** Total seasonal yields followed the same capital letter are not significantly different at the 5% level.
† Irrigation treatments are: 1. Two 10.2-cm irrigations between harvests.
2. One 17.8-cm irrigation between harvests.
3. Two 15.2-cm irrigations between harvests.

Irrigation Treatment 3 produced yields similar to Treatment 1, but resulted in higher yields than Treatment 2 on 90-cm modified plots in 1973 and on both 90- and 150-cm modified soil in 1975. Irrigation Treatments 1 and 2 produced similar yields on the unmodified plots each year; however, much of the forage produced on one unmodified plot of Treatment 2 was barnyard grass.

Water-use Efficiency

We calculated water-use efficiencies (kg forage/ha-cm H_2O used) for individual harvests, but they are not presented due to variation in soil water data. This variation, both within plots and between replicate plots, caused calculated water-use efficiencies to be erratic. Apparently, our soil water sampling was inadequate to accurately measure soil water depletion on a plot-wide basis for short time periods between harvests. Beginning and end-of-season soil water data, used in calculating seasonal water-use efficiencies, contributed only small variations in total water use. Seasonal water-use efficiencies are presented in Table 5.

Fig. 1—Effect of profile modification on alfalfa rooting. Left to right: unmodified, 150-cm modified, and 90-cm modified profiles. Arrows in photographs indicate depths of profile modification.

Experiment I

Modifying the profile significantly increased water-use efficiencies in 1970 and 1971, but not in 1972. Increases from profile modification were much greater in 1970 when single irrigations were applied between harvests and precipitation was lower than in 1971 (when we irrigated unmodified plots twice between harvests), or in 1972 (when we irrigated plots once between harvests, but precipitation was greater than in 1970).

Table 5—Effect of depth of profile modification and irrigation treatments on water-use efficiency of alfalfa, 1970–1975.

Irrigation treatment†	Depth of modification, cm		
	0	90	150
	kg/ha-cm		
	Experiment I		
	1970		
	77 a*	133 b	160 c
	1971		
	93 a	101 ab	111 b
	1972		
	91 a	114 a	122 a
	Experiment II		
	1973		
1	136 a	163 a	189 a
2	144 a	159 a	172 a
3	--	165 a	151 a
	1974		
1	99 a	144 c	124 bc
2	102 ab	131 c	119 abc
3	--	95 a	99 a
	1975		
1	112 a	154 cd	164 d
2	128 abc	150 bcd	150 bcd
3	--	124 ab	119 a

* Means (within years) followed by the same letter are not significantly different at the 5% level.
† Irrigation treatments are: 1. Two 10.3-cm irrigations between harvests. 2. One 17.8-cm irrigation between harvests. 3. Two 15.2-cm irrigations between harvests.

Experiment II

Modifying the profile significantly increased water-use efficiency in 1974 and 1975, but not in 1973. On irrigation Treatment 1, modifying the soil profile to 90 cm increased water-use efficiency 20, 45, and 38% in 1973, 1974, and 1975, respectively. Comparative values for the 150-cm modified plots were 39, 25, and 46%. Irrigation Treatments 1 and 2 were similarly efficient for the 90- and 150-cm soil modification treatments. The data also indicated that they were similarly efficient on the unmodified treatment, but barnyard grass contributed to yields on irrigation Treatment 2.

Visual observations and results obtained in Exp. I indicated that irrigation Treatment 1 would usually be more efficient than irrigation Treatment 2 on unmodified soil. Water-use efficiency was lower on irrigation Treatment 3 than on Treatment 1 in 1974 and 1975. Apparently, the high irrigation rate supplied more water than the crop needed. In 1973, the high irrigation treatment did not decrease efficiency because less total water was applied than in 1974 and 1975 (irrigation treatments were not initiated until after the second harvest in 1973) and because the soil was initially dry. Much of the unused water remained in the sampled soil profile at the end of the season. In 1974 and 1975, the root zone was kept sufficiently wet so that more water was lost to percolation below the sampling depth than in 1973.

Root Profiles

Soil and root profiles are shown in Fig. 1. Alfalfa roots penetrated beyond the 2.3-m excavations on all three modification treatments. Roots were larger and more

Table 6—Soil bulk density as affected by depth of profile modification (12 years after modification).

Depth of modification, cm	Sampling depth, cm					
	15	45	75	105	135	165
	g/cm^3					
0	1.39	1.52	1.52	1.50	1.41	1.47
90	1.40	1.49	1.49	1.50	1.54	1.53
150	1.42	1.46	1.45	1.44	1.36	1.48

plentiful in the modified soil than in the unmodified soil; however, differences in rooting depth were not as great as might have been anticipated from differences in top growth, water infiltration rates, soil water accretion and depletion patterns, and grain sorghum root growth in the B22t layer of Pullman soil (5).

Water Infiltration Rates, Bulk Density, and Surface Elevation

We measured sustained water infiltration rates on 30 June 1975, for irrigation Treatment 2 for each of the three profiles. Within the 10-hour period, from 4 to 14 hours after inundation, average water infiltration rates were 0.16, 0.33, and 0.40 cm/hour for the unmodified, 90-cm, and 150-cm modified treatments, respectively. We also measured soil moisture 6 days before and 3 days after the 17.8-cm irrigation. Increases in soil moisture on the respective treatments accounted for 28, 54, and 58% of the applied water.

When we measured bulk density of soil cores taken from the sides of root observation excavations, we found that soil disturbed by profile modification 12 years earlier was less dense than unmodified soil (Table 6).

Changes in surface elevation induced by profile modification and resettling during cropping after modification are shown in Fig. 2. Twelve years after profile modification, the disturbed soil volume remained about 4% greater than before modification.

DISCUSSION

Profile modification of Pullman clay loam increased alfalfa yields 30% (Exp. II: 14.13 to 18.39 metric tons/ha) when two irrigations were applied between harvests. With single irrigations between harvests, the increase from modification averaged 50% (Exp. I: 10.57 to 15.88 metric tons/ha). Increases in water-use efficiency were 35% with two irrigations and 57% with single irrigations between harvests. In addition, profile modification simplified management. Because of the soil's slow water infiltration rate and resulting duration of ponding on unmodified plots, the 17.8-cm water application was sometimes excessive. If precipitation was appreciable just before or during the infiltration period, the plots had to be drained to prevent loss of stand. On the modified plots, water infiltration rates were more rapid and ponding was not a problem. As a result of differences in rates of water infiltration and surface drying, the surface of unmodified plots remained wet longer than that of modified soil. The longer wet period weakened the alfalfa stand. Also, it allowed barnyard grass to become established on unmodified plots. Apparently

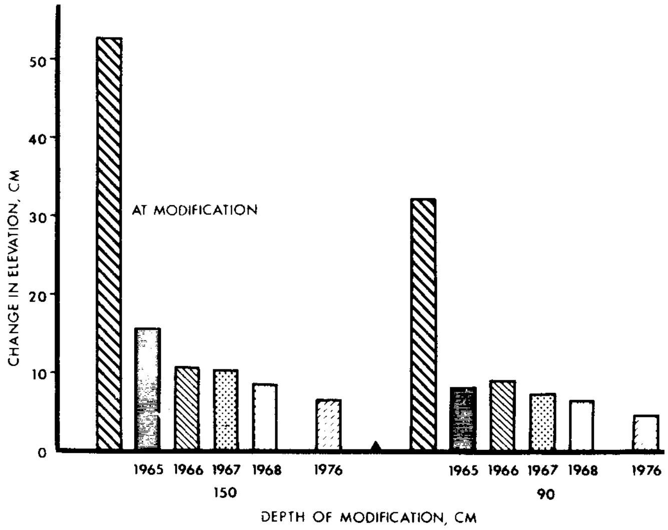

Fig. 2—Changes in plot surface elevation induced by profile modification, subsequent irrigation, leveling, and cropping.

satisfactory, productive stands of alfalfa can be maintained longer on modified than on unmodified soil. Our experience indicated that to maintain stands and to produce satisfactory yields of alfalfa on unmodified soil, it is necessary to apply two irrigations between harvests, while on modified soil, single irrigations would be sufficient. As compared with two irrigations between harvests, single irrigations soon after harvest not only reduced water and labor requirements, but also reduced the risk of soil surface wetness at the subsequent harvest.

Two 10.2-cm irrigations or one 17.8-cm irrigation between harvests on modified soil gave similar and near maximum yields at most harvests. Occasionally, two 15.2-cm irrigations gave slightly higher yields, but the added yield was not proportional to the additional water applied. Forage on the high water treatment was often taller and more luxuriant, but dry-matter content was lower and dry-matter yields were similar to or not much greater than those on the other water treatments. About 90 to 100 cm of irrigation water is required to produce 16,000 to 17,000 kg/ha of dry matter. In comparison, about 45 to 50 cm of water is required to produce near maximum yields of grain sorghum (7,500 kg/ha grain and 7,500 kg/ha forage) (1).

On modified soil, even though forage yields were higher, water infiltration rates were greater, and soil bulk densities were lower, alfalfa root systems seemed only slightly more vigorous than on unmodified soil. Apparently, the lower yields and lower water-use efficiency on unmodified soil resulted principally from inadequate penetration and the attendant loss of water to evaporation and from the effects of surface ponding of water after irrigation (up to 72 hours).

Differences in yields, infiltration rates, bulk densities, and surface elevations showed that the effects of profile modification are still present 12 years after treatment. We cannot predict the longevity of the practice, but, since its effects have persisted this long, they are not likely to disappear in the near future.

In this study, the profile was thoroughly mixed to the depth of modification. The yield data showed that in four of six seasons, there was at least a trend towards highest yields on the deepest modified plots. The major yield increase, however, was between the unmodified and 90-cm modified treatments. Possibly, a less drastic treatment would improve conditions for growth of alfalfa on Pullman soil. Rakov and Eck (5) found that disturbing the B22t (30- to 60-cm depth) layer increased grain sorghum yields, but once this layer was disturbed, degree of disturbance had no further effect on yield. Schneider and Mathers (6) and Musick and Dusek (4) showed that moldboard plowing into (but not through) the B22t layer was optimum for use under graded furrow irrigation. Hauser and Taylor (2) found that chiseling on 2-m centers did not have a lasting effect on water infiltration into this soil, while disk plowing did. Logically, a treatment that would disrupt the B22t horizon and rearrange the soil aggregates, like moldboard or disk plowing through the B22t horizon, might be almost as beneficial to alfalfa growth as the more drastic treatments tested in this study.

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