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Percolation and Water Requirement Studies with Alfalfa by Means of Lysimeters in Oregon

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SUMMARY

This paper reports the results of trials with 8 lysimeters conducted at the Umatilla, Oregon, Field Station covering a period 1915 to 1931. One unit was uncropped, one planted to soybeans in the summer and vetch in the winter, and the remaining 6 to alfalfa. Five soil types were used, ranging from a sandy type to a fine silt loam.

Varying amounts of water were applied under carefully controlled conditions ranging for the season from a seasonal minimum of 38.66 inches to a maximum of 141.64 inches. The lysimeters were so constructed that the percolations from the different units could be collected and determined.

For the 1922 to 1931 period the mean percolations from lysimeters 1 to 6 filled with sandy soil and having mean annual water applications of 60.5 inches ranged from a maximum of 72 per cent for the uncropped unit to a minimum of 7 per cent from No. 5 cropped to alfalfa. For the same period the mean seasonal water input applied to lysimeters 7 and 8 filled with finer textured and more productive soils was 116.85 inches and the percolations were only 9 and 8 per cent respectively.

In comparing the mean water losses by evaporation from uncropped lysimeter 1 and an evaporation tank there occurred 54 per cent as much as from the tank.

For the 1922 to 1931 10-year period the seasonal water requirements of alfalfa expressed in inches of water per ton of hay produced, have ranged from a minimum of 8.8 to a maximum of 11.59 inches. The more productive soils proved to be the most economical in the use of water. Approximately doubling the water input; i.e., 116.85 compared with 60.5, not only returned the highest yield of alfalfa but resulted in a highly efficient use of the irrigation water on the more productive finer textured soil types.

The computed per acre yields of alfalfa in this investigation from lysimeters 3 to 6 filled with rather sandy soil types are in line with, but somewhat in excess of, those harvested from comparable soils under favorable conditions in the Umatilla area. Such results were obtained with water inputs of approximately 5 feet. When this amount of water was applied to lysimeter 8 in which a productive silt loam soil was utilized, the indicated per acre yield was 7.72 tons. When the water inputs were nearly doubled or increased to 118.46 inches annually the mean yield of alfalfa was increased to 15.44 tons per acre. These substantially increased yields evidently are due to (a) the use of productive soils; (b) heavy water applications, and (c) by such frequent water applications that the soil moisture was maintained at more nearly the optimum. These results are in a measure corroborated by other published data on the use of irrigation water.

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By

S. H. Hastings and H. K. Dean*

THROUGHOUT the West where irrigation is practiced, the productivity of extensive areas has been destroyed or impaired due to the invasion of the root zone by subsoil waters. Where such conditions obtain, artificial drainage is a prerequisite to restoring productivity. This necessitates costly structures, and their maintenance is a continuing expense to water users. Commonly this water table problem has been attributed to the excessive use of water by irrigators. The desire to curtail the needs for such drainage facilities, combined with the fact that irrigation water supplies are becoming increasingly depleted, has resulted in stimulating a lively interest in the more effective utilization of irrigation water.

In considering the efficient use of irrigation water on the farm, it is recognized that there are involved: (1) proper leveling of the land in order that there may be a uniform distribution of the water; (2) adjusting the method of distribution of the water with a view to attaining uniform penetration throughout the field; (3) avoiding excessive surface runoff losses, which in some localities may result in soil erosion; (4) determining the time the water should be allowed to remain on the land so that adequate penetration may result; and (5) reducing the interval between applications of water, as well as the amount of water per application, where soils of low water-holding capacity are involved. This latter operation, if effectively performed, will not only eliminate seepage losses but also with certain crops such as alfalfa will increase production. Attaining a more uniform distribution of the water as well as preventing excessive runoff losses are matters of great importance, and definite progress is being made in eliminating such wastes. There is need, however, for more precise information regarding water relationships of different soils, the water requirement of crop plants, and where a salinity problem is involved, the excess water required to promote necessary leaching. (*12, 13, 14, 15*)†

Obviously, one of the more important functions of the soil is to act as a reservoir in which to store water for the use of crop plants. For most annual field crops the root zone is limited to a depth of not exceeding 6 feet. The effective storage capacity of that zone is the difference between the quantity of water the soil will hold against gravity and the quantity of water the soil withholds from absorption by the plant roots. This difference may be called the available supply. In providing water to the irrigator it is universally the custom to deliver it in a measured rate of flow, using the customary local unit or measurement; i.e., in gallons per minute, miners' inches, or second feet. (*9*) If the approximate water-holding capacity of the soil is known, it is not difficult

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† Figures in parentheses refer to "Literature cited," p 16.

to determine how long the irrigation water should be run on a given area to apply the number of acre-inches needed to moisten the soil to the full depth of the root zone. Further, the excess water required can be determined, if it is desired to displace the soil solution by leaching where appreciably saline waters are utilized.

On the more sandy types of soils, irrigation water losses as a result of percolation through and beyond the root zone of crop plants, have been believed to be notably excessive, although such assumptions have not always proved to be valid or have been greatly magnified. The soils of the Umatilla (Oregon) Reclamation Project located in the mid-Columbia River Basin, predominately are of a coarse, sandy texture, have a low water-holding capacity, and are rather typical examples of those soils where seepage losses of substantial proportions may occur. For several years these water losses were believed to be of such proportions that investigations were initiated in 1915 for the purpose of obtaining information as to their magnitude by means of lysimeters filled with soils typical of the section. The chief emphasis placed on the work was along the lines of obtaining information as to the rate and volume of percolation resulting from lysimeters having different soils and treatments and to which varied quantities of irrigation water were applied. In addition, information was obtained regarding the influence on the yields of alfalfa of the applications of different quantities of water, as well as data as to the net water requirement of this crop.

DESCRIPTION OF THE AREA

The Umatilla Reclamation Project is located adjacent to the Columbia River in northcentral Oregon and has an altitude of approximately 470 feet above sea level. The Umatilla field station on which these investigations were conducted was located near the town of Hermiston, centrally situated within the project.* The mean annual rainfall is about 8 inches, the greater part of which falls during the winter months of November to February; consequently, the climate is distinctly arid. The mean frost-free period is 170 days, and summer temperatures are relatively high for this latitude; maximum readings often exceeding 100° F. in June, July, and August. During the winter months of December to February, minimum temperatures of well below 0° F. are ordinarily recorded, and freezing temperatures are to be expected from October 15 to April 15. Consequently, because of low temperatures, it was considered advisable to limit the lysimeter observations to the summer months, April to October.

DESCRIPTION OF THE APPARATUS

The lysimeters were constructed in the form of pits with their tops slightly above the ground surface, and were located sufficiently far from buildings and other obstructions so that field conditions were represented as nearly as possible. The material used in their construction was oil-mixed concrete, with a view to reducing to a negligible quantity water losses through the walls. Each lysimeter was 3.3 feet square inside measurement, with depth adequate to hold 6 feet of soil and had a volume of 65.34 cubic feet. Below the 6-foot level the

* The legal description of this tract, which comprises 40 acres, is the NE ¼ of the NW ¼, Sec. 3, T. 4 N., R. 28 E., Willamette Base and Meridian. In 1931 this tract was abandoned and a new and enlarged station site was acquired, comprising 180 acres, located about 2 miles south of the town of Hermiston.

bottom of each tank sloped to a center drain through which the percolates passed. The space below the 6-foot level to a depth of from zero at the edges to 4 inches at the center was filled with fine gravel to facilitate the movement of the percolates to the drain hole in each lysimeter. Underneath each lysimeter was a chamber 30 inches high designed to hold a container in which the percolates were collected. When completed there were lysimeters on each side of a pit 4 feet wide and 10 feet deep provided with a stairway. The 4-foot space between the lysimeters ran north and south and was not covered. Hence one side of each unit was exposed to the sun rays a portion of each day. The soil for each lysimeter was collected from the field in 6-inch layers to a depth of 6 feet and, beginning with the bottom 6-inch layer, placed in the lysimeters in the order collected and as nearly as possible at the original field density. As there was no appreciable settling of the 6-foot soil columns later, it is evident that field density was closely attained. Lysimeters Nos. 1 to 4 were constructed and put into operation in the spring of 1915. Lysimeters Nos. 5 to 8 were added to the series later but in time to permit observations to be taken in 1917. These experiments were discontinued in 1931.

DESCRIPTION OF SOILS USED

Lysimeters 1 to 4 were filled with virgin, sandy soil obtained from Field D 2,* located on the old Umatilla field station. This soil has a relatively low water-holding capacity and is representative of much of the cultivated soil on the Umatilla Irrigation Project as well as adjoining desert areas.

The soil used in No. 5 was obtained from a field adjoining and southeast of the old station site and appeared to be similar to but of a somewhat finer texture and more productive than the soil used in lysimeters Nos. 1 to 4.

For lysimeter No. 6 soil was selected from a field 1 mile north and 1 mile east of the station. This soil appeared to be intermediate between the soil used in lysimeters Nos. 1 to 4 and No. 5.

The soil selected for lysimeter No. 7 was obtained from a field 2 miles east of the town of Stanfield and was designated as very fine sandy loam.

Lysimeter No. 8 was filled with a soil obtained from a field located 1 mile above the mouth of Butter Creek and 5 miles south of the town of Hermiston, and classed as silt loam. At the time this soil was selected, it was believed to be the most productive of those chosen for the lysimeter experiments.

Information as to the texture of the soil types used is given in Table 1, which records the mechanical analyses and the moisture equivalents expressed as a percentage of the dry weight of the soils. The term moisture equivalent is defined as the quantity of water retained by the soil against a centrifugal force one thousand times that of gravity. (*1*)†

From the data recorded in Table 1, it is apparent that there is a wide range in the texture of the different soil types, notably when the soils used in lysimeters 1 to 6 are compared with the soils used in Nos. 7 and 8. Also, the moisture equivalent ranges are substantial when a like comparison is made. When the moisture retained by soil used in lysimeters 1 to 4 is compared with that held by Nos. 7 and 8 the mean is found to be more than 3 times as great in the instance of No. 7, and more than 7 times as great in the case of No. 8.

* The exact location of Field D 2 may be obtained by referring to U. S. Department of Agriculture Circular 422, Work of the Umatilla Field Station in 1923, 1924, and 1925, by H. K. Dean, 20 pp., illustrated.

† The authors acknowledge the cooperation of Dr. H. G. Byers and his associates of the Bureau of Plant Industry for making the mechanical analyses and for the moisture equivalent determinations of the different soil types.

Table 1. MECHANICAL ANALYSES AND MOISTURE EQUIVALENT OF THE SOIL TYPES USED IN THE LYSIMETER INVESTIGATIONS.

Lysimeter numbers and depth		Mechanical analyses									
		Fine gravel 2-1 m.m.	Coarse sand 1-0.5 m.m.	Medium sand 0.5-0.25 m.m.	Fine sand 0.25-0.1 m.m.	Very fine sand 0.1-0.05 m.m.	Silt 0.05-0.002 m.m.	Clay less than 0.002 m.m.	Total less than 0.005 m.m.	Organic matter by H_2O_2	Moisture equiva-lent
	Feet	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1–4	0–1	1.4	26.6	27.1	20.5	7.3	116.	5.1	6.6	0.2	6.0
	2–3	1.4	52.5	36.2	7.7	0.8	0.4	1.0	1.2	0.0	3.4
	4–5	1.7	51.8	36.1	7.7	1.2	0.5	0.9	1.2	0.0	3.8
5	0–1	0.9	13.2	24.9	32.1	12.7	11.4	4.3	5.3	0.3	6.6
	2–3	2.2	11.0	20.6	33.8	19.9	9.9	2.5	3.3	0.0	5.6
	4–5	8.4	43.6	16.4	25.4	3.3	1.7	1.2	1.8	0.0	3.8
6	0–1	2.7	30.5	25.0	19.5	7.0	10.4	4.6	6.0	0.2	6.3
	2–3	0.9	26.7	29.5	30.5	8.2	2.0	2.2	2.3	0.0	4.2
	4–5	1.4	23.9	27.2	32.1	10.2	3.6	1.4	1.9	0.1	4.0
7	0–1	0.0	0.4	1.5	9.9	44.6	39.8	3.4	6.0	0.2	12.6
	2–3	0.0	0.5	0.9	6.3	34.1	54.9	3.1	6.2	0.0	16.8
	4–5	0.0	0.3	0.9	5.9	33.2	57.3	2.2	5.0	0.0	14.6
8	0–1	0.2	0.7	1.1	5.1	15.3	59.8	14.2	24.1	2.4	37.6
	2–3	0.0	0.6	1.6	7.8	19.8	55.4	13.0	21.2	1.4	34.2
	4–5	0.0	0.3	0.7	6.1	25.9	61.0	5.7	15.0	0.1	26.3

TREATMENT OF THE LYSIMETERS

Throughout the period of the investigation the eight lysimeters were not uniformly treated as to cropping. The aim was to acquire information as to losses of irrigation water from percolation under different cropping programs and under conditions where the applications varied, and at the same time determine the consumptive use requirements of alfalfa where field conditions were fairly well represented. The treatment procedure for the different lysimeters was as follows:

Lysimeter 1. This lysimeter remained uncropped throughout the 17-year period with a view to ascertaining the quantity of percolation and evaporation from a soil not cropped and to which there was applied no treatment other than the irrigations and the removal of weed growth.

Lysimeter 2. The Ito San variety of soybeans was planted on this lysimeter each spring, followed by winter or hairy vetch in the fall. The soybeans were planted 3 inches apart, and when the plants were well established the spacing was increased to 6 inches each way. The vetch was broadcast. Both of these crops were incorporated in the soil in the fall and spring, respectively, for the purpose of obtaining information as to the effect plant growth combined with the addition of organic matter to the soil would have on the rate and amount of percolation.

Lysimeter 3. Alfalfa was continuously grown on lysimeter 3. In the fall of 1916, after the last crop was harvested, the remaining tops and roots were worked into the soil and rye immediately seeded. The rye growth was worked into the soil the following spring and alfalfa again seeded. Other than this variation, this lysimeter was cropped similarly to Nos. 5 to 8.

Lysimeter 4. Alfalfa was continuously grown on this lysimeter. Farm manure was applied at the rate of 32 tons per acre in the springs of 1915, 1916, 1917, 1919, 1920, and 1921 with a view to ascertaining the influence such treatment might have on percolation as compared with the other units.

Lysimeters 5 to 8. Alfalfa was maintained on these four units continuously with no special treatment.

The variety of alfalfa used for planting lysimeters 3 to 8 was a common, hardy, commercial strain, seeded at a rate equivalent to 32 pounds per acre. In order to maintain a uniform stand of alfalfa on the different units it was found necessary to reseed all of them in the spring of 1921 and again in 1925. The procedure followed was to work the stubble into the soil to a depth of 5 or 6 inches and the alfalfa immediately reseeded.

The water applied and the percolates were weighed on a balance graduated to 1 gram. The water was applied to the different lysimeters at weekly intervals with a sprinkling can, which corresponded in effect to the flooding system of irrigation. The lysimeters were irrigated with project irrigation water, although occasionally it was necessary to use water from the domestic well. Both water supplies were relatively low in salinity, an analysis in 1915 indicating that the irrigation water has 102 and the well water 243 parts per million of total salts, respectively.

The weekly individual application as well as the total annual water applications at times varied materially. For the first 6 weeks in 1915 the water applied to lysimeters 1 to 4 was at the rate of 3 inches weekly. This amount of water applied to the newly seeded alfalfa units resulted in rather excessive water losses from percolation. For the next 11 weeks the applications, therefore, were reduced to 1.5 inches weekly. For the first 6 weeks in 1916, 1.5 inches of water were applied at the usual weekly intervals. This amount was increased to 2.0 inches for the next 10 weeks followed by a further increase to 3.0 inches per application for the remaining 5 weeks of that season. In 1917 the water applied was 2.0 inches weekly for the first 12 weeks and again increased to 3.0 inches per weekly application for the remaining 10 weeks of that season to lysimeters 1 to 6. For the 1918 to 1931 seasons, the water applied to units 1 to 6 was at the rate of 3.0 inches each week.

For the seasons of 1917 to 1921, equal quantities of water were applied to all 8 of the lysimeters including 7 and 8 with the exception of the season of 1917. That year lysimeters 5 to 8 were not put into operation until early in June, nearly 6 weeks after the beginning of the operation season for Nos. 1 to 4. Water applications at the rate of 3.0 inches weekly did not result in any losses from percolation from 7 and 8. With a view to developing percolation in Nos. 7 and 8 for the first 4 weeks in 1922, weekly water applications were increased to 4.0 inches followed by a further increase to 6.0 inches for the remaining 16 weeks of that season. With the exception of the season of 1925 when the alfalfa was reseeded on all units, the weekly applications were at the rate of 6.0 inches for lysimeters 7 and 8 from 1922 to 1931.

PERCOLATION AND EVAPORATION-TRANSPIRATION RESULTS SUMMARIZED

The number of individual weekly recordings annually ranged from 17 to 24 for the 17-year period 1915 to 1931, consequently an extensive volume of data was accumulated; over 2,500 individual readings being made and recorded. In analyzing these data throughout the period, it was found that the differences between the individual readings were not of a magnitude to influence significantly the annual means when the results from one unit were compared with another. It is believed, therefore, that the more significant features resulting from this investigation are made available by summarizing the results. These condensed data are presented in Table 2, which records the net annual water inputs and the percolations from lysimeters 1 to 8, with percolations expressed as a percentage of the water inputs. In reviewing the percolations from the different lysimeters, it should be kept in mind that the data from Nos. 1 to 6 are not directly comparable with those from Nos. 7 and 8 for the reason that from 1922 until the end of the investigation, nearly double the amount of water was applied to these two latter units as compared with that applied to Nos. 1 to 6.

The higher percolation percentages from all lysimeters were high in 1923. It is probable that this was due to the higher water applications for that season. The percolation from lysimeters 6, 7, and 8 devoted to alfalfa again were comparatively high in 1927. These increased losses appeared to be due, also, to the weather conditions for that season as compared with the previous and following years. The growing season for the years 1926 and 1928 were about normal with respect to precipitation, there being no significant rainfall after readings began. On the other hand, in 1927 from May 1 to June 27, there were 8 days when measurable precipitation fell and totaled for the period 1.59 inches. It seems probable also, that the temperature conditions may have been

Table 2. Summary During the Treatment Periods of the Net Annual Input in Inches of Water and the Percolations from Lysimeters 1 to 8 Expressed as Percentages of the Water Input.*

Year	Water input		Percolations							
	†Lysimeters 1 to 6	Lysimeters 7 and 8	Lysimeter 1	Lysimeter 2	Lysimeter 3	Lysimeter 4	Lysimeter 5	Lysimeter 6	Lysimeter 7	Lysimeter 8
		Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1915	38.66	....	64	48	35	34	....	....	....	....
1916	50.36	....	76	41	12	12	....	....	....	....
1917	53.57	42.00	74	41	31‡	21	12	24	0	0
1918	61.67	61.67	62	48	15	12	10	23	0	0
1919	60.33	60.33	62	46	14	9	6	18	0	0
1920	57.19	57.19	74	45	17	12	11	30	0	0
1921§	61.38	61.38	67	41	12	9	2	25	0	0
1922	61.02	113.02	65	42	13	9	1	17	0	0
1923	72.64	141.64	82	43	12	13	5	25	13	16
1924	68.00	134.00	78	32	18	9	4	18	2	7
1925§	57.43	88.93	70	54	35	38	25	45	21	13
1926	61.12	121.12	72	22	1	6	0	4	0	0
1927	59.67	122.67	73	44	12	16	3	30	14	13
1928	61.24	121.24	67	38	4	3	0	5	4	0
1929	51.74	102.74	65	33	23	25	31	39	22	19
1930	54.50	108.50	70	63	9	8	3	14	5	8
1931	57.63	114.63	73	33	5	5	2	11	7	7
Mean:										
1915-1921	54.74	56.51	68	44	19	16	8	24	0	0
1922-1931	60.50	116.85	72	40	13	13	7	21	9	8
1922-1931 means in inches of water			*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Evaporation and transpiration			16.94	36.30	52.64	52.64	56.26	47.80	106.33	107.50
Percolation			43.56	24.20	7.86	7.86	4.24	12.70	10.52	9.35

* These totals include the water applied and the precipitation for the observational period only. The fall, winter, and early spring precipitation is not included.

† Lysimeter 1: virgin sandy station soil, not cropped.
Lysimeter 2: virgin sandy station soil, soybeans grown in the summer, hairy vetch in the winter.
Lysimeter 3: virgin sandy station soil, cropped to alfalfa.
Lysimeter 4: virgin sandy station soil, cropped to alfalfa, manured in 1915, 1916, 1917, 1919, 1920, and 1921.
Lysimeter 5: fine sandy soil, cropped to alfalfa.
Lysimeter 6: soil intermediate between 4 and 5, cropped to alfalfa.
Lysimeter 7: very fine sandy loam, cropped to alfalfa.
Lysimeter 8: silt loam, cropped to alfalfa.

‡ Alfalfa reseeded in the spring.

§ Alfalfa reseeded on units 3 to 8 in the spring.

a contributing factor. The period of greatest seasonal percolation in 1927 occurred for the 16 days from June 20 to July 5. The mean maxima temperatures were 96, 84 and 85, and the mean minima were 58, 54 and 58, respectively, for the 3 years in question for the 16 days.

Percolations in 1929 were high for all the lysimeters devoted to alfalfa, and here again the existing temperatures for that season appear to be the explanation. While there was not a significant difference in the mean maxima temperatures for the years 1928, 1929, and 1930, there occurred a marked difference in the mean minima temperatures. In 1929 the mean minimum up to July 23 was 4 degrees lower than in 1928. Again for the season of 1930 the mean minimum temperature proved to be 4 degrees higher than in 1929.

In considering the results from uncropped lysimeter 1, it is found that the percolations have ranged from a maximum of 82 per cent in 1923 to a minimum of 62 per cent in the years 1918 and 1919, with a 1922 to 1931 mean of 72 per cent based upon a mean water input of 60.50 inches, which is equivalent to 43.56 inches of water that passed downward through the 6-foot soil column and was lost through percolation. The percolations resulting from lysimeter 2 have ranged from a minimum of 22 per cent in 1926 to a maximum of 63 per cent in 1930 with a 1922 to 1931 mean of 40 per cent. While the losses from this unit were 32 per cent less than from uncropped lysimeter 1, it is apparent that the combination of soybeans and vetch with these crops incorporated in the soil did not nearly as effectively utilize the water as did similarly irrigated alfalfa lysimeters 3 to 6, with the crop removed. There appeared also to be no tendency for percolations to decrease in the later years in lysimeter 2. The mean air dry weight of alfalfa produced on lysimeters 3 to 6 averaged to be the equivalent of 6.95 tons per acre, while the 17-year mean green weight of soybeans and vetch, which was worked into the soil, amounted to slightly less than the equivalent of 12 tons per acre.

Alfalfa lysimeters 3 and 4 were filled with similar soils, the only significant difference in their treatments being that alfalfa was reseeded on the former unit in the spring of 1917 and the latter received applications of farm manure at the beginning of the seasons 1915, 1916, 1917, 1919, 1920, and 1921. The percolations from each of these units for the 10-year period, 1922 to 1931, amounted to 13 per cent. From 1915 to 1921 the losses from No. 3, however, were 3 per cent in excess of those from the manured lysimeter 4; eliminating 1917 when new alfalfa was seeded on No. 3, the mean losses for this period were 18 and 15 per cent, respectively.

The mean percolation from lysimeter 5 was the lowest of any of the units for the last 10-year period, amounting to only 7 per cent of the water applied. In this connection, it should be taken into consideration, however, that the recorded vegetative growth produced from No. 5 was in excess of that from either No. 3 or No. 6 but was exceeded by No. 4, to which farm manure was applied during the earlier years.

To lysimeters 7 and 8, filled with soils definitely finer in texture than those used in Nos. 1 to 6, the same water applications were made for the first 4 years as were received by the first 6 units. Even in view of the fact that the water input exceeded 5 feet three seasons out of the four, there were no percolations from these 2 units for the period. Even in 1922 when the total water input amounted to 114.80 inches, or more than 9 feet, percolation did not occur. It was not until the following year, 1923, when the water input amounted to 141.64 inches or nearly 12 feet, that percolation was induced, and then the mean losses amounted to only 13 and 16 per cent, respectively, for lysimeters 7 and 8. For the last 10-year period the mean percolations from these lysimeters were less than 10 per cent, an amount insufficient to provide for very effective leaching. Where substantially saline irrigation waters are used, as is characteristic of many water supplies of the West, there must be removed in the form of drainage waters 15 per cent or more of the water applied to the lands, the amount recognized as necessary being dependent upon the salinity concentration of the water used for irrigation. (*14*)

SOIL AND EVAPORATION TANK LOSSES COMPARED

The results from lysimeter 1 afforded an opportunity for comparing the annual evaporation losses from a soil maintained in a fallow condition and the losses from a free water surface for similar periods. The only treatments lysimeter 1 received were the regular water applications and the removal of weed growth. The soil was not mulched or otherwise disturbed. In Table 3 are recorded the seasonal losses from a standard 6-foot evaporation tank, the evaporation from lysimeter 1, and the differences expressed as percentages of the tank losses.

Table 3. THE ANNUAL EVAPORATIONS FROM A TANK AND FROM UNCROPPED LYSIMETER 1 RECORDED AS INCHES OF WATER AND THE LOSSES FROM LYSIMETER 1 EXPRESSED AS PERCENTAGES OF THOSE FROM THE TANK.

		Evaporation, lysimeter 1				Evaporation, lysimeter 1	
Year	Evaporation, tank		Tank losses	Year	Evaporation, tank		Tank losses
	Inches	*Inches*	*Per cent*		*Inches*	*Inches*	*Per cent*
1915......	33.58	13.74	41	1924......	37.14	15.10	41
1916......	30.67	12.02	39	1925......	32.04	17.09	53
1917......	31.10	13.77	44	1926......	34.80	17.34	50
1918......	31.58	23.53	74	1927......	29.34	16.19	55
1919......	32.10	23.14	72	1928......	32.27	20.06	62
1920......	26.95	15.05	56	1929......	28.42	18.13	64
1921......	30.87	20.01	65	1930......	28.93	16.43	57
1922......	31.66	21.58	68	1931......	31.36	15.33	49
1923......	32.47	12.75	39				
17-year-mean:					31.49	17.14	54

The highest relative losses from the lysimeter occurred during the years 1918 and 1919 with percentage differences of 74 and 72 per cent, respectively. In 11 years out of the 17 the evaporation from the lysimeter was 50 per cent or more of that from the tank. For the 17-year period, lysimeter 1 lost 54 per cent as much as occurred from the tank. These rather substantial evaporation losses from the soil in lysimeter 1 are an indication of those that may occur under field conditions having similar soils and treatments in the region where these investigations were conducted.

YIELDS AND WATER REQUIREMENT OF ALFALFA

In the foregoing pages there has been presented information relative to the percolation and evaporation-transpiration losses from the lysimeters based upon known water applications. In addition to recording these data, the alfalfa growth on lysimeters 3 to 8 was harvested each season and the air-dry weights determined. With this information available combined with the water input, it is possible to determine the water requirements of alfalfa for the different units, which has been computed and expressed as inches of water required to produce 1 ton of air-dry alfalfa hay.

Table 4. THE WATER REQUIREMENTS OF THE ALFALFA GROWN IN LYSIMETERS, EXPRESSED AS ACRE-INCHES OF WATER DISSIPATED SEASONALLY BY EVAPORATION AND TRANSPIRATION FOR EACH TON OF HAY PRODUCED.

Year	Water requirements of alfalfa grown					
	Lysimeter 3	Lysimeter 4*	Lysimeter 5	Lysimeter 6	Lysimeter 7	Lysimeter 8
	Acre-inches	*Acre-inches*	*Acre-inches*	*Acre-inches*	*Acre-inches*	*Acre-inches*
1915	19.98	17.07	....	....	....	....
1916	....	10.69	....	....	....	....
1917	16.67†	8.76	17.24	22.61	11.09	11.87
1918	13.27	9.84	10.51	10.72	9.23	9.35
1919	15.22	12.36	15.36	14.73	10.61	8.14
1920	14.92	7.79	9.17	10.30	10.55	8.38
1921‡	27.10	20.27	26.29	21.21	20.71	16.70
1922	9.73	7.74	9.52	10.92	10.02	7.58
1923	8.46	8.27	9.90	9.69	10.20	10.10
1924	13.55	9.88	11.22	13.35	11.55	11.14
1925‡	22.41	15.37	19.67	23.58	14.30	12.46
1926	9.18	8.62	9.32	10.53	8.41	8.54
1927	8.53	7.75	8.87	8.81	7.77	6.71
1928	10.32	9.91	8.98	12.36	7.90	7.46
1929	7.37	6.10	5.84	5.50	6.58	5.52
1930	9.72	8.73	9.43	9.43	9.11	8.79
1931	12.74	10.53	12,45	11.71	11.60	9.73
Means:						
1917-1931	13.28	10.13	12.25	13.03	10.64	9.50
1917-1921	17.44	11.80	15.71	15.91	12.44	10.89
1922-1931	11.20	9.29	10.52	11.59	9.74	8.80

* Farm manure applied to this unit at the rate of 32 tons per acre in the spring of 1915, 1916, 1917, 1919, 1920, and 1921.
† In rye during the winter of 1916-17, alfalfa reseeded in the spring of 1917.
‡ All lysimeters reseeded in the spring.

Naturally the number of inches of water required to produce 1 ton of hay was relatively high for first-year alfalfa in all instances. It is not to be assumed, however, that these rather excessive water losses for these seasons were a result of excessive plant transpiration. The evaporation from the uncropped lysimeter has been shown to be of substantial proportions. Following seeding and well into the summer months until the plants were well established and the soil not well shaded, soil evaporation, therefore, probably represented a substantial part of the losses at least for some weeks after seeding. The least efficient lysimeters were 3 and 6, requiring 11.20 and 11.59 inches of water respectively, to produce 1 ton of hay for the 1922 to 1931 period. As both lysimeters 3 and 4 were filled with soil from the same locality, an opportunity is afforded of observing the indicated influence of the manurial treatment to which No. 4 was subjected from 1915 to 1921 on the water requirements of alfalfa. In every year fewer inches of water were used to produce a ton of hay than was required for No. 3. For the last 10-year period the requirements were 11.20 to 9.29 inches respectively for Nos. 3 and 4, or a difference of 1.91 inches per ton of hay. The influence of soil productivity on the water requirement of plants has been emphasized by Briggs and Shantz (*3, 4*) as well as others. (*7.*)

The difference in the efficiency of lysimeters 3 and 6 is very small, amounting to a mean of only 0.39 of an inch for the 10-year period 1922 to 1931. The lysimeter requiring the fewest inches of water to produce a ton of hay was lysimeter 8, which was filled with a silt loam believed to be the most productive soil utilized in any of the units. Manured lysimeter 4, however, required only 0.49 of an inch more water to produce a ton of hay. By referring to Table 2 it will be noted that from 1922 to 1931 the growing season water inputs for lysimeters 7 and 8 were nearly double those applied to Nos. 3 to 6, totaling 116.85 inches for the former and 60.50 inches for the latter units. The fine-textured productive soil used in lysimeter 8 not only returned the highest yield of alfalfa but also proved to be the most economical in the use of water. These results afford significant information to the effect that where productive rather fine-textured soils are involved, irrigation water may be quite efficiently utilized by water applications materially in excess of 5-acre feet, if the soil moisture is maintained more nearly at the optimum conditions by more frequent water applications than is the generally accepted practice. There is justification for the assumption that normal, vigorous plant growth cannot be expected when the soil moisture falls below a point where the roots are able readily to provide for the losses due to plant transpiration. Kiesselbach (*7*) has shown that increased plant growth due to productive soil is brought about by increased transpiration, and the lowering of the plants' water requirement under such conditions is a result of a more normal, vigorous vegetative growth but without a proportional increase in the amount of water transpired.

These mean water requirements of alfalfa, as a result of these lysimeter investigations are not greatly at variance from those reported by Briggs and Shantz (*2, 3, 4*), which were reported on the oven-dry basis and expressed as pounds of water required to produce 1 pound of dry matter, but under conditions where soil evaporation was eliminated. These results correspond, also, with those obtained by Dillman (*5*) in the Dakotas, even when considering lysimeters 7 and 8 to which rather excessive amounts of water were applied.

In considering the question of the efficient use of irrigation water on field crops, such as alfalfa, the chief emphasis has been placed upon the total amount of water applied seasonally. Investigations have been conducted, also, in respect to how water could be conserved by avoiding losses by excessive percolation downward through and beyond the root zone. The results herein reported have emphasized that there is another highly important factor that is related to the amount of and uniformity of the soil moisture maintained in the soil zone occupied by the plant roots. In these investigations there was applied to the different lysimeters irrigation water at approximately weekly intervals varying from 2 to 6 inches in depth and of a magnitude to promote some but to avoid excessive leaching in the basic lysimeters. By following this procedure the total amount of water that was applied seasonally would, under field conditions, be considered excessive. To lysimeters 7 and 8 irrigation water was applied greatly in excess of that ordinarily applied to alfalfa. Yet the summary presented in Table 4 shows that the water use of alfalfa is moderate, even in the instances of lysimeters 7 and 8, which were subjected during certain seasons to applications of more than 10 feet in depth. In Table 5 are presented the yields of alfalfa from lysimeters 3 to 8, expressed in tons per acre, included for the purpose of indicating the range and magnitude of the yields.

The per acre yield of alfalfa harvested from lysimeters 3 to 6 filled with rather sandy soil types are in line with, but somewhat in excess of those harvested from comparable soils under favorable conditions in the Umatilla area. On the other hand the mean yields of alfalfa for the last 10-year period from lysimeters 7 and 8 were more than double the mean yield from Nos. 3 to 6 for the same period, amounting to more than 12 tons of air-dry hay per acre. This uniformly increased vegetative growth obviously is due in large measure to the productivity of the soil and its texture, and also to the fact that irrigation water was applied in what would ordinarily be considered excessive amounts

Table 5. TOTAL SEASONAL ALFALFA YIELDS FROM LYSIMETERS 3 TO 8, EXPRESSED AS TONS PER ACRE.

Year	Alfalfa yields per acre					
	Lysimeter 3	Lysimeter 4	Lysimeter 5	Lysimeter 6	Lysimeter 7	Lysimeter 8
	Tons	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*
1915	1.250	1.487	....	....	....	....
1916	2.715	4.919	....	....	....	....
1917	1.993*	5.562	1.958	1.197	3.612	3.374
1918	4.347	6.036	5.808	4.936	7.269	7.176
1919	3.880	4.976	4.118	3.884	6.318	8.237
1920	3.661	7.397	6.376	4.536	6.151	7.748
1921*	2.257	3.110	2.556	2.525	3.318	4.113
1922	5.918	7.768	6.846	5.112	11.453	15.145
1923	7.854	8.017	7.168	6.023	12.122	11.955
1924	4.651	6.877	6.565	4.651	11.783	11.735
1925*	2.130	3.062	2.720	1.786	6.200	7.493
1926	6.970	7.049	6.913	5.975	14.440	14.212
1927	7.731	8.166	7.889	6.257	15.057	17.463
1928	6.340	6.666	7.652	5.192	15.308	16.975
1929	6.106	7.141	6.965	6.648	13.006	15.923
1930	5.769	6.494	6.287	5.636	12.021	12.096
1931	4.871	5.909	5.120	5.016	9.777	11.652
Means:						
1917-1931	4.965	6.282	5.663	4.625	9.856	11.020
1917-1921	3.228	5.416	4.163	3.416	5.334	6.130
1922-1931	5.834	6.715	6.412	5.230	12.117	13.465

* Alfalfa reseeded in the spring.

and at such frequent intervals that the soil moisture was maintained at or near the optimum.

DISCUSSION

The results from these investigations indicate that where alfalfa is grown on productive soils of a relatively high water holding capacity, water may be applied copiously and with safety as far as losses from seepage are concerned. Further, that such conditions have returned large yields and that there has occurred an economical use of water by the plants. The results obtained from lysimeter 8 afford an opportunity of corroborating this assumption. For the 3 years 1922 to 1924 the mean seasonal water input was 59.73 inches and the computed alfalfa yield was 7.72 tons per acre. During the 1922 to 1931 10-year period when the water inputs were substantially increased for the years 1922, 1926, and 1928 and there were no losses from percolations, the mean water input was 118.46 inches and the yield of air-dry alfalfa for the 3 years was at the rate of 15.44 tons per acre. A comparison shows that the mean alfalfa yield following the heavier applications was exactly double, whereas the water input was slightly less than double, or 59.73 inches as compared with 118.46 inches respectively. Computed on the basis of inches of water required to produce 1 ton of hay, the amounts are 7.74 and 7.67 inches. From these results it appears, therefore, that by the more copious use of irrigation water yields of such crops as alfalfa could be substantially and economically increased in respect to water use. While the efficient use of irrigation water is recognized as a matter of great importance, yet to limit the use of water so that the productive capacity of our soils is materially restricted may be a questionable procedure.

Results from other investigations, chiefly of a field nature, have shown also that the seasonal per acre production of alfalfa would be increased materially by the addition of more irrigation water to the soil. Furthermore, some of these investigations have indicated that better results may be obtained if the soil moisture conditions are maintained at more nearly the optimum rather than following the somewhat usual practice; i.e., allowing the soil moisture to be so reduced that the plants show the need of water. There is evidence to indicate that by this procedure plant growth is retarded and a recovery or readjustment is required, which in turn is not contributing to the normal, vigorous growth of the plants. Where such conditions exist, it is logical to assume that production may be impaired. The correctness of this assumption is in a measure confirmed by other investigators. In a review of the literature on the effect of soil moisture content on the water requirement of plants by Briggs and Shantz (*4*) substantial evidence was found to the effect that the water requirements increased when the water content of the soil approached either extreme. The crops reported in these investigations, however, included chiefly cereals, potatoes, and sugar beets.

Investigations conducted by Richardson (*11*) show that alfalfa had the lowest water requirement and produced the highest yields when the moisture conditions in the soil were maintained at between 60 and 75 per cent of saturation. The results of his rather comprehensive investigations afforded evidence to the effect that conditions favorable for optimum plant growth (i.e., moisture supply) not below 60 per cent of saturation with a productive soil resulted in the most efficient use of water. His results further indicated that plants grown on unproductive soils continue to transpire water at a relatively rapid rate, but that growth is retarded because of malnutrition. Investigations conducted in Utah (*6*) have shown that in Cache Valley up to 90 acre-inches, the largest yields of alfalfa were produced by the heaviest water applications. It was found, however, that applications greatly in excess of 30 acre-inches were not justified when the cost of both the water and of its application was considered. The results further afforded evidence to the effect that the largest yields were harvested when the soil is kept at the optimum moisture content and not permitted periodically to become substantially below the optimum.

In southern Arizona, Marr and Smith (*8*) found that alfalfa yields increased with water applications up to 7 acre-feet, although the influence on production and economy in the use of water if the soil moisture had been maintained more nearly at the optimum for plant growth was not given consideration. Their practice was to apply one irrigation just prior to each cutting, the different amounts for the season being controlled by varying the amounts applied at each irrigation. For the 7 tests the individual water applications ranged from 4.7 to 16.6 inches per irrigation and from 2.0 to 6.9 acre feet per season. Per ton of hay the most economical use of water was found to be the 4.1 acre feet per season with 9.8 inches per application. The next higher individual applications were 13 and 16.6 inches with a seasonal maximum of 6.9 acre feet. With such excessive individual irrigations, seepage losses are to be expected, which is confirmed by their assumption that 0.8 of an acre foot of water would wet the soil to a depth of 8 feet, which they found to be the maximum that could be applied at a single irrigation without losses from deep percolation. At Logan, Utah, Pittman and Stewart (*10*) found that more than 30 acre-inches of water tended to reduce the yields of such crops as sugar beets, potatoes, and corn as well as small grains. On the other hand, alfalfa yields continued to increase up to 60 or more inches of applied water. Here again apparently no consideration was given to the possibilities of maintaining a reasonably uniform and more nearly optimum moisture condition in the soil.

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