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Bulletin No. 182 - The Net Duty of Water in Sevier Valley

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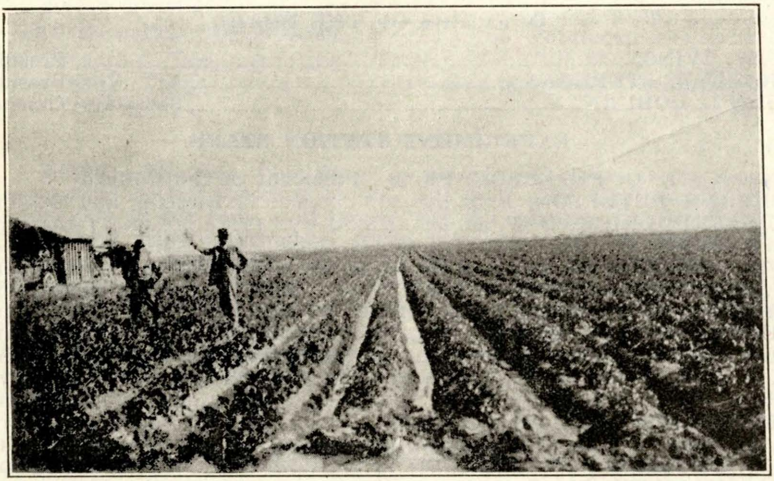
THE NET DUTY OF WATER IN SEVIER VALLEY

By

ORSON W. ISRAELSEN and LUTHER M. WINSOR



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UTAH AGRICULTURAL EXPERIMENT STATION

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IN CHARGE OF COOPERATIVE INVESTIGATIONS WITH THE U. S. DEPARTMENT OF AGRICULTURE

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THE NET DUTY OF WATER IN SEVIER VALLEY

By

ORSON W. ISRAELSEN and LUTHER M. WINSOR[1]

CONTENTS

NOTE.—The term "net duty" as used herein refers to the actual amount of water absorbed by the soil and does not include the water lost in the canal and lateral nor the quantity lost in run-off. These and other unavoidable losses must be added to the net requirement in determining the gross duty of any canal system. The meaning of the expression "inches water applied" as used in tables and charts means the number of acre-inches of water used per acre. One acre inch is equivalent to one inch in depth over one acre of land, or the quantity supplied by a stream of one cubic foot per second flowing continuously for one hour.

INTRODUCTORY

The Sevier River is one of the most important sources of irrigation water in Utah. It rises in two main branches. The south fork rises in Kane County and flows almost due north to Junction in Piute County, where it joins the east fork, which rises partly in Garfield County and partly in Sevier County. The Garfield County branch of the east fork flows north, and the Sevier County Branch flows south to Coyote where the two tributaries join and flow westward into Junction. From Junction,

[1]The work here reported was conducted under cooperative agreement between the Utah Agricultural Experiment Station and the Irrigation Division of the Bureau of Public Roads of the United States Department of Agriculture. From 1914 to 1916, inclusive, the work was under the supervision of Luther M. Winsor, in charge of cooperative irrigation studies in Utah, and from 1917 to 1920 it was done under the direction of Orson W. Israelsen, in charge of experimental irrigation of the Utah Experiment Station. The authors gratefully acknowledge their indebtedness to Messrs. J. F. Ogden, L. A. Wilson, W. V. Halverson, and L. T. Oldroyd for intelligent and faithful work in the management of the farm. Mr. Ogden managed the farm in 1914, Mr. Wilson in 1915, Mr. Halverson in 1916, Mr. Oldroyd in 1917, and during the years 1918, 1919, and 1920 it was again managed by Mr. Ogden, to whom special credit is due.

the river flows northward past Marysvale, Sevier, Richfield, Salina, Gunnison, and Mills, where it takes a westerly course to Leamington and from there a southwesterly course past Delta, Oasis, and Deseret, and into the Sevier Lake, part of which lies in Millard and part in Beaver County.

Irrigation is practiced to some extent in the upper valleys of the Sevier River System. These valleys form a part of Garfield and Piute Counties. The Sevier, Gunnison, and San Pitch Valleys in Sevier and San Pete Counties, according to the 1920 irrigation census, contain nearly 150,000 acres of irrigated land, whereas the Garfield and Piute Counties contain only 35,000 acres. In all of these valleys part of the land included in irrigation projects is not actually irrigated. The last census indicates that the irrigation projects in Sevier and San Pete Counties include nearly 210,000 acres and those in Garfield and Piute Counties but 65,000 acres. Millard County, which obtains its irrigation water largely from the Sevier River, has 138,000 acres of land irrigated and 374,000 acres included in irrigation projects. The census reports show that the five counties—Garfield, Piute, Sevier, San Pete, and Millard, all of which depend largely on the Sevier River System for a water supply—now have included in their irrigation projects nearly 650,000 acres, which is approximately equal to two-thirds of the total area irrigated in Utah in 1909. In the three counties lying below the town of Sevier, which is at the entrance of the river to Sevier Valley, irrigation projects now include more than 580,000 acres.

Stream measurements made by the United States Geological Survey at the town of Sevier indicate an average discharge of 260,000 acre-feet. It is, therefore, obvious if these measurements are even approximately correct that the total water supply of the Sevier River System is insufficient for the irrigable lands. It is equally apparent that the value of, and the demand for, irrigation water will greatly increase as more of the land now included in the irrigation projects is brought under cultivation. Conditions on the Sevier System are, moreover, typical of those in most intermountain valleys.

The Sevier Valley, in which the experiments were conducted, lies almost wholly in Sevier County below the town of Sevier. However, the results of the experiments, it is believed, apply closely to similar soil conditions in the Gunnison and San Pitch Valleys, provided due allowance is made for small differences in rainfall and other climatic factors which are considered below. The experiments were conducted near the towns of Joseph and Richfield. In 1914 the work was done on the Peterson Farm about one mile north of the Richfield railroad station; in 1915 on the Parker Farm near Joseph; and from 1916 to 1920 on a 20-acre farm owned by R. D. Young about five miles north of Richfield.

THE CLIMATE OF SEVIER VALLEY

The climate of Sevier Valley, together with the climate of Utah's other important agricultural valleys, is fully described in Utah Experiment Station Bulletin No. 166 by Frank L. West and N. E. Edlefsen. In order to obtain a clear understanding of the differences of Sevier Valley climate from that of other Utah valleys, it is desirable that the reader refer to Bulletin No. 166. For convenience, however, Figure 1, taken from Bulletin No. 166, together with some comparisons of Sevier Valley climate to Cache Valley climate and to the climate of the state as a whole, is presented here.

The graph at the top of Figure 1 shows the annual rainfall at Richfield from 1890 to 1917, with a few exceptions. The height of the heavy black line indicates the inches of rainfall for each year of record. It will be noted that the minimum rainfall for the period occurred in 1900, when a little less than 2 inches fell, and the maximum rainfall of 14 inches came in 1911.

The second graph directly underneath the one just explained shows the mean amount of rainfall each month of the year. This graph and also a summary table in Bulletin No. 166, page 61, shows a minimum monthly summer rainfall of 0.39 of an inch during the month of June. A comparison of the summer rainfall at Logan in Cache Valley from April to September, inclusive, to that at Richfield shows 7.40 inches in Cache Valley and 3.84 inches in Sevier Valley. In April, May, and June the Cache Valley rainfall was nearly three times that of Sevier Valley, while in July, August, and September it was but slightly greater.

"The third graph shows the frequency of summer rains. The months are marked along the bottom, and each time 0.2 of an inch of rainfall accumulates, a dot is placed on that date. The respective years are marked along the left margin.

"The fourth diagram represents the date of the last killing frost in the spring and the earliest killing frost in the fall.

"The fifth graph represents the four leading agricultural products for Sevier County as given by the United States Census Report for 1910."

Referring again to the upper graph in Figure 1, it will be noted that the five years 1900 to 1904, inclusive, were unusually dry. During this period the rainfall at Logan, although smaller than usual, varied from two to seven times that at Richfield.

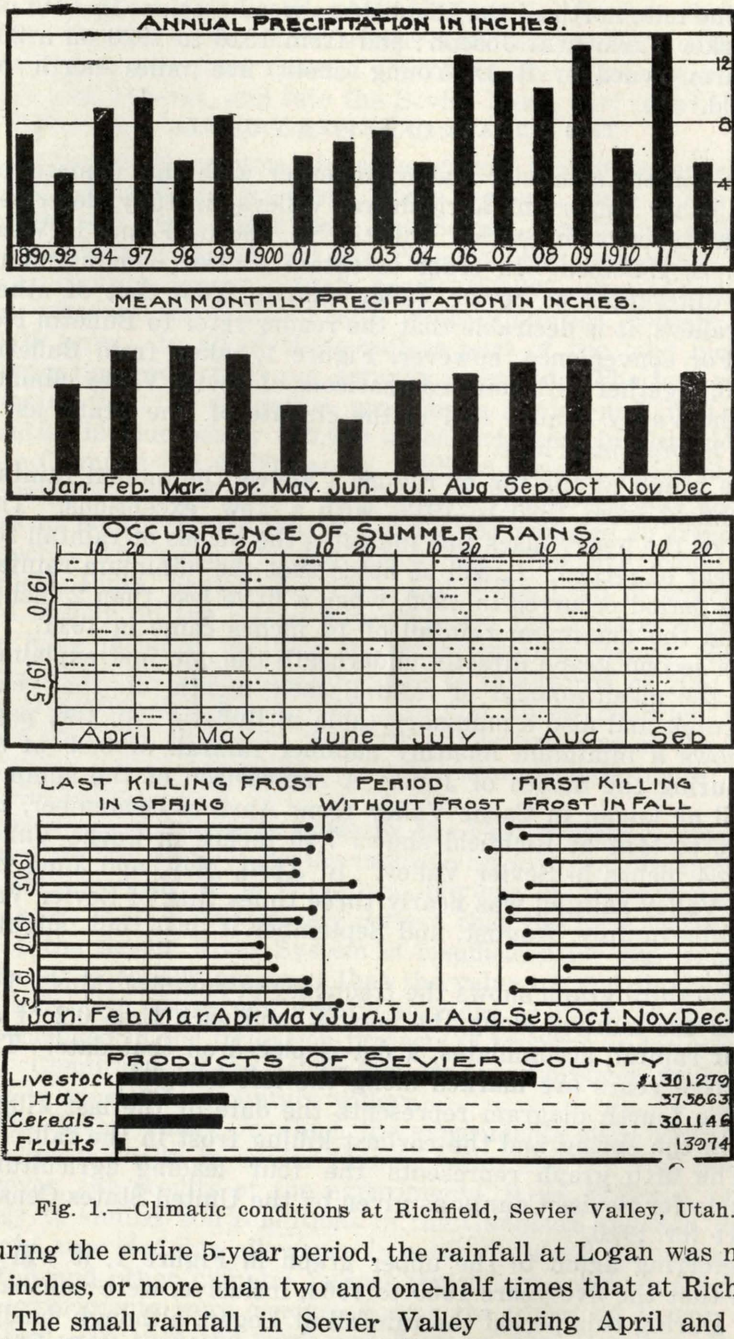

Fig. 1.—Climatic conditions at Richfield, Sevier Valley, Utah.

During the entire 5-year period, the rainfall at Logan was nearly 72 inches, or more than two and one-half times that at Richfield.

The small rainfall in Sevier Valley during April and May makes it desirable for Sevier Valley farmers to irrigate their soils before seeding sugar-beets, potatoes, and other annual crops. This practice has developed quite fully in recent years and is spoken of locally as "irrigating the crops up".

With respect to Utah as a whole, Sevier Valley is comparatively dry. The mean annual rainfall at Richfield is 8.34 inches as compared to 12.26 for Manti, about 40 miles north; 16.17 inches for Logan; and 12.50 inches for the state as a whole.

Measurements of the relative atmospheric humidity have not been made, but it is likely that it is not greatly different from that at Modena in Iron County, where the mean is 46 per cent.

The average number of days between killing frosts is 109 as compared to 144 at Logan.

SEVIER VALLEY SOIL PROPERTIES

The United States Bureau of Soils[1], in cooperation with the Utah Experiment Station, made a reconnaissance soil survey of Sevier Valley during the summer of 1900. The following general description of the soils of the valley is taken from the report of this survey:

"The soils, usually light in texture are formed largely from the adjacent mountains, although in certain level areas along the present river channel are deposits of material brought down from far up the valley. Owing to their mode of formation the soils are very diversified in character. At Joseph, Elsinore, and Monroe the soils are formed largely from igneous and lava rocks, and are consequently dark in color, while at Richfield the red sandstone gives rise to a soil of similar texture but almost vermilion in color.

"About Joseph, Elsinore, and Monroe the soils are underlain by well-rounded, coarse river gravel, which continues for several hundred feet in depth, with occasional intervening strata of finer material or clay. In the river bed and over certain adjacent area this gravel comes directly to the surface. It extends well toward the foothills, but is there covered by a much greater depth of soil. As we go northward along the valley this gravel becomes smaller and is found at greater depth beneath the surface."

The soils of the valley are further classed as Redfield fine sandy loam, Bingham gravelly sandy loam, Redfield loam, Bingham clay loam, and some other classes of which the areas are less extensive. The Redfield fine sandy loam and the Bingham gravelly sandy loam comprise approximately 82,500 acres which is 55 per cent of the area surveyed.

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[1]U. S. D. A. Field Operations of the Division of Soils, 1900. (Second Report.)

The soil of the Parker Farm at Joseph is classed as Bingham gravelly sandy loam and that of the Petersen Farm and the Young Farm, north of Richfield, is classed as Redfield fine sandy loam.

The Bingham gravelly sandy loam comprises 25 per cent of the area. It consists of two types—one a dark color occurring largely in the Richfield district, and one a light color occurring largely north of Gunnison. According to the Bureau of Soils, the dark color of the first phase, which is the one that comprises the soil of the Parker Farm at Joseph, is due to the fact that much of the soil originated from the adjacent lava rock mountains. A mechanical analysis made by the Bureau of Soils shows an average of nearly 10 per cent clay, almost 20 per cent silt, over 26 per cent very fine sand, and 22 per cent fine sand. The balance of the soil is largely coarse and medium sand. This soil is more fully described in the Soil Survey report as follows:

"In the vicinity of Joseph and Monroe this type of soil is quite generally gravelly, the gravel being, as a rule, small and more or less rounded, so that it does not interfere with cultivation, even when it occurs immediately at the surface, which it often does. The gravelly areas on the map show gravel within 3 feet or less of the surface. All of this type of soil occurring south of Annabella is underlaid with gravel at a depth rarely greater than 10 feet. In the vicinity of Glenwood, the gravel is less abundant. A profile of the soil to a depth of 6 feet shows, on an average, continuous sandy loam with gravel below 2 feet. It must of course be recognized that gravel sometimes occurs throughout the profile, while in other cases it is entirely absent.

"A large percentage of this land is under cultivation, and gives excellent results with both alfalfa and grain. In its lighter and more gravelly portions it is well adapted to fruits. Three miles southwest of Monroe is a nursery and fruit farm, on which apples, pears, peaches, and various kinds of small fruits are doing well. The land is easy of cultivation and retains moisture remarkably well."

The Redfield fine sandy loam, which includes the Petersen Farm just north of Richfield and also the Young Farm about five miles north, is confined to the west side of the valley. From Elsinore, it extends northward along the entire length of the Richfield district and throughout the length of the Gunnison district. It is formed from the mountains of red sandstone on the western part of the valley and is very much like them in color. It comprises nearly 30 per cent of the area surveyed by the Bureau of Soils. One phase of this soil is a deep sandy loam. uniform in texture, but sometimes underlain with gravel at a depth of 3 or more feet. The other phase contains a large amount of gravel which in many places appears on the surface. Irrigation is largely confined to the first phase of soil that is free from gravel.

The physical properties of the Redfield fine sandy loam on the Young Farm were further investigated by one of us, with special reference to the relative weight or apparent specific gravity, the pore space, the permeability to water, and the capacity to absorb and retain water.

Determinations of the apparent specific gravity of the soil (the weight of a cubic foot of dry soil divided by the weight of a cubic foot of water) at 12 points in Field B[1] agree closely with each other. The average apparent specific gravity was found to be 1.33, which indicates a weight of soil of 83 pounds a cubic foot when oven-dry. This shows further that more than one-half, or nearly 52 per cent, of the total soil bulk in its natural condition consists of air and water.

Soils vary greatly in the rate at which they absorb water, and this variation in permeability to water frequently makes irrigation difficult. In very porous soils large amounts of water are lost through deep percolation near the upper end of the land, whereas impervious soils prevent adequate penetration of water into the soil. It was found that after the first hour the soil absorbed water at the rate of 0.7 inch in depth of water an hour. The maximum permeability during the first hour was 2 inches, and the average was 1.6 inches.

On the basis of the cylinder tests, showing an average permeability of 0.7 inch an hour, it would require about nine hours for a 6-inch irrigation uniformly distributed to disappear into the soil. The permeability measurements were made on Field B in 1918, which was then growing beets. The average rate[2] of application of water was 0.75, 0.33, and 0.57 inch depth an hour for the sugar-beets, the potatoes, and the alfalfa, respectively.

On June 8 and also on August 26, 1918, moisture determinations were made in each foot of soil to a depth of 6 feet from samples taken from four borings in each of plats 1, 2, 3, and 4 in Field B. The observations indicate that the upper six feet of soil contained average percentages of 14.2, 12.5, 11.6, and 11.5, in plats 1 to 4, respectively.

The percentages above given are equivalent to 2.26, 2.00, 1.85, and 1.84 inches of water for each foot depth of soil in the

[1]The division of the Young Farm into fields A, B, and C is fully described on page 13 and in Figure 2.

[2]The term "rate", as here used, refers to speed of application, not amount applied.

respective plats. It will be noted in the description of the experiments for sugar-beets that the heavy irrigation for beets was given plat 1, the intermediate amount was given plat 2, the small amount plat 3, and the plat 4 was given only the one 6-inch irrigation before seeding.

Since the June moisture tests were made after the early 6-inch irrigation was given all of the plats and before the beets began to draw on the water supply, it is apparent from these tests that the heavily irrigated plats held some water over from the irrigation the preceding year. The moisture determinations thus confirm the statement heretofore made that the high yields of non-irrigated plats during the first year of the experiment are due in part to the moisture in the soil held from the irrigation of the preceding year.

On August 26, despite the fact that water was applied to plats 1, 2, and 3 on July 7 and August 8, they held but small amounts of water. Plats 1, 2, 3, and 4 contained 8.56, 7.77, 9.66, and 8.80 per cent, respectively, being 1.36, 1.27, 1.54, and 1.40 inches for each foot of soil, respectively.

Of the soil properties which are important in irrigation, the capacity of soils to absorb and retain water is greatly significant. To determine this capacity for the Redfield fine sandy loam on the Sevier Farm a levee was built around a plat 20 by 20 feet. Soil for the levee was taken from the outside so as to prevent any disturbance of the surface soil. There was no crop growing on the area. It was cleared of weeds. Soil samples were then taken to a depth of six feet in six borings, making a total of 36 samples. The holes were carefully filled and an 18-inch irrigation was applied to the plat. The following day, July 18, a second set of soil samples was taken, and on August 7, twenty days after flooding, a third set was taken. The results are presented in Table I.

TABLE I.—WATER-CONTENT OF SEVIER EXPERIMENT FARM SOIL BEFORE FLOODING, ONE DAY AFTER FLOODING, AND 20 DAYS AFTER FLOODING

(Results expressed in inches of water for each foot of soil)

	Water Content						Total
Depth of soil in feet	0.5	1.5	2.5	3.5	4.5	5.5	1-6
One day (2 hours after flooding)	3.80	3.07	3.34	3.34	3.48	3.08	20.15
One hour before flooding	1.61	1.78	1.81	2.15	1.72	2.24	11.31
Water retained one day after flooding	2.19	1.29	1.53	1.23	1.76	0.84	8.84
Twenty days after flooding	2.62	2.48	2.58	3.11	3.18	3.15	17.12
One hour before flooding	1.61	1.78	1.81	2.15	1.72	2.24	11.31
Water retained twenty days after flooding	1.01	0.70	0.77	0.96	1.46	0.91	5.81

It will be noted in Table I that before flooding the soil, it contained moisture in the first foot equivalent to 1.61 inches of water; in the second foot, 1.78 inches; the third foot, 1.81 inches; and so on, to 2.24 inches in the sixth foot. One day after flooding, the soil contained 3.80 inches of water in the surface foot, 3.07 inches in the second foot, 3.34 inches in the third foot, the same amount in the fourth foot, 3.48 inches in the fifth foot, and 3.08 inches in the sixth foot. To find what amount of water was actually retained from the flooding, it is necessary to subtract the amount held before irrigation from that held after irrigation. For example, in the surface foot 3.80—1.61=2.19, showing that one day after flooding the soil held 2.19 inches more water than before. Similarly, it will be noted that one day after flooding, the sixth foot retained 0.84 of an inch, the smallest amount retained in any foot. Of the 18.00 inches applied to the plat, the upper six feet retained one day after flooding 8.84 inches, or less than one-half. Twenty days after flooding the largest amount, 1.46 inches, was retained by the fifth foot; and the smallest amount, 0.70 inch, by the second foot. Of the total 8.84 inches, retained one day after flooding, 5.81 inches, or two-thirds, was held twenty days after flooding.

Immediately after obtaining the soil samples one day after flooding, the plat was covered with weeds and straw in order to reduce the evaporation losses to a minimum. It is likely, therefore, that the major part of the decrease in water content from 8.84 inches in the upper six feet of soil one day after flooding to 5.81 inches twenty days after resulted from downward percolation rather than from evaporation.

The moisture tests twenty days after flooding are further significant in showing that nearly 6 inches of water can be absorbed and retained from one irrigation, or approximately one inch of water per foot depth of soil. Clearly the amount of water retained depends on the moisture content before irrigation and on the final moisture content. The greater source of error is probably the variation in moisture content before irrigation. Undoubtedly, there may be much more water in the soil before irrigation on some occasions than existed before the tests just reported. On the other hand, it is possible that under conditions of excessive drouth there may be less water in the soil before irrigation, in which case the soil would have retained more than it did in the test. But the difference in this direction is relatively small. It is necessary to guard against the erroneous conclusion that the soil can become completely dry before irrigation. It is unwise to permit the soil to become much drier before irrigation than it was in the test reported. Moreover, it is impossible for this soil in its natural condition to get very much drier. These statements are supported by moisture determinations made August 26, 1918. Plat 4 had received no water since May 1, and yet it held practically the same amount as was held by Plats 1, 2, and 3 which had been given two irrigations—one on July 7 and one on August 8. Moreover, if we take as the original water content the average amount of water in the soil on August 26, i. e., 1.4 inches per foot of soil, and compare this amount to the quantity held 20 days after irrigation the absorptive capacity would be 1.45 inches per foot of soil. Therefore, it seems safe to conclude that for similar soils in Sevier Valley, it is likely that one inch of water per foot depth of soil that needs moistening is adequate in any single irrigation, provided that it is spread uniformly over the surface, and further it is probable that any amount in excess of 1.5 inches of water to each foot depth of soil will result in waste through deep percolation. The above conclusion should be interpreted with two further conditions in mind; namely, first that the selection of 6 feet depth of soil as a test for water capacity is somewhat arbitrary, and second that a measurement of the moisture capacity at a different time, say fifteen days or twenty-five days after flooding, might have given a slightly different result. However, while the water capacity given is admittedly subject to slight variation for the reasons stated, it is believed to be more accurate as a guide to the amount of water to apply in single irrigataions than has heretofore been available without the test of water capacity. Relative to the accuracy of the ordinary guess method of determining in practice the amount of water to apply in single irrigations, the water-capacity tests are believed to be quite accurate.

THE IRRIGATION EXPERIMENTS

The experiments consist of observations of (1) yields of various crops with different amounts of water and (2) the percentage of water applied which was lost from the plats as surface runoff. The work was devoted largely to a study of the water needs of sugar-beets, potatoes, and alfalfa. Wheat, corn, peas, oats, and barley, and other miscellaneous crops were included in the investigations during 1914-1915 and 1916, but the observations are insufficient in number to be really significant. Since 1917 the experiments have been limited to the three crops: sugar-beets, potatoes, and alfalfa.

Only the net duty of water or the amount of water absorbed by the soil is here considered. The investigations do not include a study of conveyance losses, which must, of

course, be included in the ascertainment of amounts of water needed at storage works or at canal intakes.

A description of the plan of irrigation and a statement of the results for sugar-beets, potatoes, and alfalfa are given below:

SUGAR-BEETS

Sugar-beets were included in the experiments during the entire 7-year period. Four irrigation treatments were given the beets each year.

The Irrigation of Beets.—In 1914, each plat was given a 13-inch irrigation before seeding. After seeding, each plat was given 3 irrigations. To one series light applications were made, to one series, medium; and to one series, heavy applications were given. Runoff measurements were made, and the amounts of water here reported for the year 1914, therefore, refer to net amounts applied. Only one plat was used for each treatment.

During the year 1915 the experiments were designed to ascertain: (1) the comparative value of early and late irrigations in which the same amounts of water were applied at different times, and (2) the effect of different amounts of water. The differences observed, due to differences in time of applying the water, are too small to be of significance, and the yields from early, average, and late irrigations are averaged for the light, fair, medium, and heavy amounts of water. The yields for 1915 as here reported are, therefore, averages of three plats in each case.

The 1916 experiments were designed to show the effect of time of irrigation on sugar-beet yields. The differences observed are not large enough to be significant. Since the amounts of water applied to all of the plats were practically the same, the year's work does not show the effect of different amounts of water and is, therefore, not included in the yields reported in Figure 3.

In the fall of 1916 and the spring of 1917, the experimental farm was divided into three fields, A, B, and C, as indicated in Figure 2.

Fields A and B were each divided into twelve plats, and field C, which had been in alfalfa for a number of years, was divided into eight plats. Fields A and B were carefully leveled and so arranged that the water could be run toward the south instead of toward the east, down the steepest slope, as formerly.

Field A was planted to sugar-beets. All of the plats were given a 6-inch irrigation before seeding. After seeding, four treatments were given: namely, (a) no irrigation, (b) three

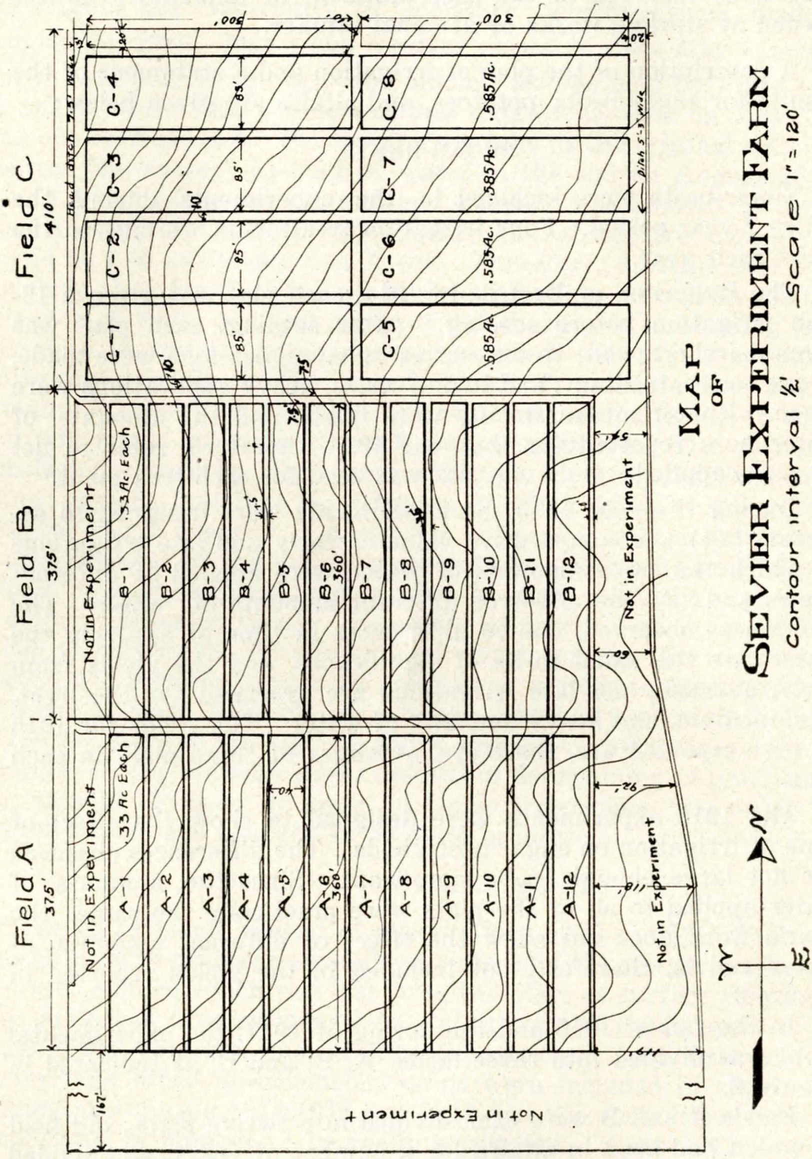

Figure 2.

4-inch irrigations, (c) three 6-inch, and (d) three 8-inch irrigations. The same total amounts of water were applied in 1918 and 1919, but in four irrigations as follows: (a) no irrigation, (b) four 3-inch applications, (c) four 4.5-inch applications, and (d) four 6-inch applications. In 1920 all of the plats were irri-

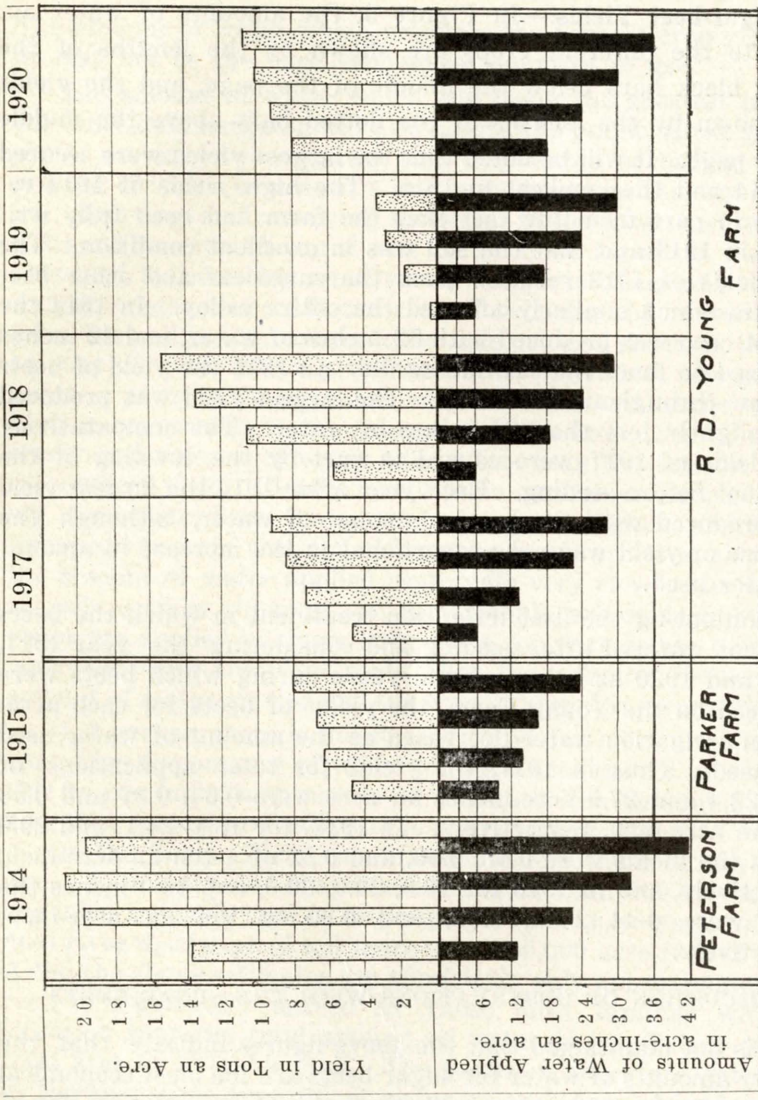

Fig. 3.—Yields of sugar-beets produced on different farms in Sevier Valley with various amounts of irrigation water.

gated after seeding, the amounts of water applied being as follows: (a) three 4-inch irrigations, (b) four 4.5-inch irrigations, (c) four 6-inch irrigations, and (d) five 6-inch irrigations. The amounts of water actually applied to the various plats, which vary slightly from the amounts it was planned to apply, are reported in Figure 3, where the yields of beets with the different amounts of water are also given.

Sugar-beet Yields.—In Figure 3, the amounts of water applied to the different crops are shown by the lengths of the heavy black bars below the middle of the page, and the yields are shown by the lengths of the dotted bars above the middle of the page. It will be noted that the largest yields were secured in 1914 and the smallest in 1919. The high yields of 1914 resulted in part from the fact that the farm had been fully irrigated in 1913 and that the soil was in excellent condition. The low yields of 1919 resulted from the curly-leaf and other beet troubles which similarly affected the entire valley. In 1914 the largest crop was produced with 32 inches of water, and 42 inches produced no more than 22 inches did. In 1915 the yield of beets was low throughout the valley. The largest yield was produced with slightly less than 24 inches of water. The comparatively low yields of 1917 were caused in part by the leveling of the land just before seeding. Each year after 1914 the largest yield was produced with the largest amount of water, although the increase of yield was not proportional to the increase in amount of water used.

Eliminating the first irrigation treatment in which the beets were not watered after seeding and considering the year 1917, 1918, and 1920 as being normal years during which beets were produced on the Young Farm, the yields of beets for each acre-inch of irrigation water decreased as the amount of water used increased. Thus in 1917, the yields for total applications of 13.4, 22.4 and 27.9 acre-inches an acre were 0.54, 0.37 and 0.33 tons an acre-inch, respectively. In 1918, for 18.1, 24.1, and 29.0 inches the yields were 0.58, 0.56, and 0.52 of a ton an acre-inch, respectively, and in 1920 for 18.0, 24.0, 30.0, and 36.0 inches the yields were 0.44, 0.38, 0.34, and 0.30 of ton an acre-inch, respectively.

DISCUSSION OF OBSERVATIONS WITH THE SUGAR-BEETS

It is not maintained that the above figures indicate that the smaller amounts of water for sugar-beets are the most economical to the individual irrigator or to the public. Economy of use of water in the growth of sugar-beets depends on many additional factors, most important among which is the labor necessary to produce the crop.

The ultimate aim of the experiments is to obtain a relation between water used and crop produced that will make it possible at some time to arrive at the amount that is most economical. In order to accomplish the final goal it is clearly necessary to consider *all of the factors* which enter into the cost of producing a crop.

The amount of water which produces the highest crop yield may or may not be the most economical quantity to use.

The amount of water which will bring the greatest profit to the individual irrigator will also assure the public of the greatest profit, provided the irrigator pays for water according to the amount of water he uses at a unit price based on the cost of storing, diverting, and conveying the water to the farm, and provided further that enough water may be obtained for all of the available land by investing more money in the building of additional irrigation structures. If the cost of bringing the water to the farm is small in comparison to the sale price of the crop, then the amount of water which gives the highest yield will also give the greatest profit to the irrigator, whereas if the cost of the water is high in comparison to the sale price of the crop then the most economical amount of water will be less than the amount giving the highest yield. Clearly it will in no case be economical to apply more water than the amount giving the highest yield. It is important to note that the above statements are true only when the amount of water applied represents very closely the amount actually used by the crop. If, for example, excessive amounts of water are applied in single irrigations, so that large quantities percolate below the plant roots, then the relation between the amount of water applied and the crop produced is meaningless.

If, however, there is insufficient water for all of the available land, then the amount of water for each acre that is most profitable to the individual may be in excess of the amount for each acre that is most profitable to the entire community.

On the Sevier River, conditions are like those of the latter case. It is estimated that there are more than 600,000 acres of available irrigable land to be irrigated with an average total annual river discharge of not more than 350,000 acre-feet of water. Altho the above estimates are admittedly only approximately correct, it is generally agreed by those most familiar with the situation that the total amount of water is insufficient for the total area of irrigable land. The public is, therefore, interested in learning what quantity of water on each acre of land will assure the most economical returns to the individual irrigations, and also what quantity will assure the public of the most economical returns.

The experiments here reported will, it is believed, contribute in some measure to the total information necessary for solving this problem. To illustrate, suppose a farmer who owns 100 acres of irrigated land has been accustomed to using in a small mountain valley 300 acre-feet of water, the entire amount in the valley, to irrigate his 100-acre farm. It is clear to him that, provided additional labor were available, he could acquire 50 acres more land and apply the 300 acre-feet of water to 150 acres and thus increase his crop returns enough to pay for his extra labor in irrigating and cultivating the additional 50 acres and leave him a substantial profit. Clearly the owner of the water would continue to increase the area to which the water is applied till he reached the point at which he obtained the greatest profit with the water available, which may possibly be obtained by applying the 300 acre-feet on 300 acres. Such expansion of the irrigated area would doubtless, at some point, decrease his net return per acre, but it would increase his total net return, and since all of the water is owned by the one man he will continue the expansion till he reaches the greatest return for the total amount of water available, because what he loses in net return per acre he more than regains in net return on the larger number of acres.

If now we quickly transfer our illustration to a large valley having a total annual available water supply of 300,000 acre-feet and 300,000 acres of land none of which can be dry-farmed, then the single owner in the small valley is represented by the community or group of owners in the large valley, and the 50-acre subdivisions of the 300-acre farm of the small valley is represented by individual farms in the large valley. The expansion of irrigation in the large valley, tho admittedly adding to the community wealth, does not directly and fully compensate the owner of the original tract for the decrease in *net* returns which results from the spreading of the water over 150,000 or 200,000 acres instead of 100,000 as originally. Therefore, as above stated, if there is insufficient water for all of the available land and if the unirrigated land cannot be dry farmed, then the amount for each acre that will bring the greatest *net* profit to the community or group of owners will not bring the greatest *net* profit to the individual owner.

A careful analysis of the cost of production of sugar-beets in 1918 under the four different irrigation treatments on the Sevier Farm shows a cost of $100 an acre with 13 inches of water, $114 with 22.5 inches, $120 with 31.9 inches, and $122 with 41.7 inches. These cost analyses with respect to machinery and labor are based largely on experiments conducted by the United States Department of Agriculture[1], horse labor being placed at 15 cents an hour and man labor at 35 cents an hour.

[1]Connor, L. G.—Labor Costs and Seasonal Distribution of Labor on Irrigated Crops in Utah. Utah Exp. Sta. Bul. 163.

Moorhouse, L. A. and Nuckols, S. B.—Cost of Producing Sugar Beets in Utah and Idaho, 1918-1919.

To arrive at the other costs it is assumed that the land has an inherent value of $100 an acre, that the initial water-right cost $50 an acre-foot, that the operation and maintenance is $1 an acre-foot each year, and the interest on land and water is 7 per cent and taxes 1 per cent per annum. The cost data are approximately representative of conditions in 1918; therefore, the value of beets may be taken as $10 a ton, the 1918 factory price. On this basis the profit for the different irrigation treatments in 1914 is computed as presented in the following table:

TABLE II—PROFITS PER ACRE OF SUGAR-BEETS WITH DIFFERENT AMOUNTS OF WATER ON THE PETERSON FARM IN 1914

Depth of water applied in inches	Cost of producing beets on 1 acre	Amount received for beets at $10 per ton	Profit an acre
13.0	$100.00	$133.00	$33.00
22.5	114.00	196.00	82.00
31.9	120.00	206.00	86.00
41.7	122.00	196.00	74.00

The above table shows that on the basis of the cost data given, 31.9 inches of water was the most profitable.

The Peterson Farm, on which the 1914 experiments were conducted, was irrigated heavily in 1913, and this in all probability accounts for the relatively high yield with small amounts of irrigation water.

The plats used in 1918 on the R. D. Young Farm were irrigated the same in 1918 as they were in 1917. Cost and profit comparisons for this farm during 1918 are given in Table III.

TABLE III—PROFITS PER ACRE FROM SUGAR-BEETS WITH DIFFERENT AMOUNTS OF WATER ON THE R. D. YOUNG FARM IN 1918

Depth of water applied in inches	Cost of producing beets on 1 acre	Amount received for Beets at $10 per ton	Profit an acre
6	$ 81.00	$ 58.00	-- $23.00 (loss)
18	97.00	105.00	8.00
24	104.00	135.00	31.00
30	109.00	152.00	43.00

Table III shows that 30 inches of water produced the most economical returns under the cost of labor, land, and water above assumed with a sale price of $10 a ton for beets.

An analysis of the cost of production of the 1920 crop on the same basis, i. e., the 1918 costs and sale price of beets, shows that the greatest profit was obtained with the 36 inches of water, but it was only a little greater than the profit obtained with 30 inches.

It is important to remember that the profits reported above with different amounts of water will vary as the cost of labor and machinery vary, together with the value of the land and water-rights and also the maintenance costs of the irrigation system and the interest rates for money. The results of the cost analysis on the basis on which they are made are given for the purpose of illustrating what is believed to be a sound basis for interpreting the results of experiments concerning the duty of water rather than to attempt to show what profit may under all conditions be obtained by using the amounts of water used in these experiments. This analysis of how to assure the individual of the greatest net return is believed to apply to Sevier Valley for the reason that prior rights are entitled under the doctrine of of beneficial use to protection on the basis of the most economical net return to the individual rather than to the entire public.[1]

To compare the yields on the experiment farm with those of the valley as a whole records were obtained giving as nearly as possible the average sugar-beet yield in the valley for the years 1816, 1917, and 1918. These yields were found to be 17½, 14, and 17 tons, respectively, being 15, 53, and 19 per cent, respectively higher than the largest average yields on the experiment farm. Correctly to interpret this comparison, it must be remembered (1) that the largest average yield on the experiment farm represents what may be expected with the same amount of water on similar soil under ordinary farm practice and (2) that the average yields for the valley as a whole are approximations and not the results of accurately kept records. It is also important to remember that the soil surface was greatly disturbed during 1917 for the purpose of leveling and that the yields during 1917 and 1918 were greatly decreased as a result of disturbing the surface soil.

Eliminating these minor disturbances, the observations are considered significant as producing some evidence concerning the net amounts of water needed for sugar-beets on Sevier Valley farms having similar soil conditions. The results are not considered as being finally conclusive. Further experiments with larger amounts of water are necessary. The work does suggest, however, that 27 to 33 inches of water for sugar-beets on soil

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[1]For a detailed mathematical analysis explaining how to ascertain, from any given set of irrigation experiments, what amount of water is most economical under different conditions the technically-trained reader is referred to a paper entitled, "The Economical Use of Irrigation Water", by Harry Clyde, Willard Gardner, and O. W. Israelsen, now in press.

similar to that of the farms on which this work was done is likely to insure economical returns. Be it remembered that this refers to the amount actually retained on the field after the run-off is deducted from the total applied at the head of the farm. Further, the experiments here reported do not include the amount of water lost in conveyance from canal intake to farm, and, therefore, the amount of water necessary at the heads of canals is not fully considered in this discussion.

POTATOES

Irrigation experiments in the production of potatoes were conducted during the years 1914, 1916, 1917, 1918 and 1919.

The Irrigation of Potatoes.—The 1914 experiments were designed to ascertain the effect of many light irrigations compared to the effect of using the same total amount of water applied in a few heavy irrigations. In this the results were not sufficiently accurate to be convincing and are, therefore, not reported. Yields of potatoes during 1914 are reported for one plat to which a 6-inch irrigation was applied before seeding and to one which received two irrigations after seeding.

In 1916 one plat was given nearly four inches of water on June 21 and one was given nearly twelve inches in four irrigations, the first irrigation being on June 21 and the last one on August 29.

In 1917 the Young Farm was divided into fields, A, B, and C, as indicated in Figure 2. The greatest amount of leveling was done on Field B to which potatoes were planted. Four irrigation treatments were applied as follows: (a) no irrigation after seeding, (b) four 2-inch irrigations, (c) four 3.5-inch irrigations, and (d) four 5-inch irrigations—all after planting the potatoes. As with the sugar-beets, the field was divided into twelve plats; therefore, each irrigation treatment was applied to three plats. The first, second, third, and fourth irrigations were begun on July 19, August 16, August 27, and September 19, respectively. Each irrigation required about two days' time. The actual net total amounts of water applied after seeding to the various sets of plats were (a) no irrigation, (b) 8.74 inches, (c) 14.67 inches, and (d) 22.17 inches.

At the beginning of the season of 1918, it was planned to apply the same total amounts of water as nearly as possible as were applied in 1917, but as the season developed it was found desirable to apply only three irrigations instead of four as in 1917. The plats were irrigated on July 18, August 8, and August 28, respectively. The total net amounts of water applied to each set of plats after seeding during the year 1918 were. (a) no irrigation, (b) 6.5 inches, (c) 10.38 inches, and (d) 14.77 inches.

In 1919 each set of plats except the unirrigated ones, was given four irrigations after seeding. It was aimed to give each set the same amounts of water as in 1917. The following net amounts of water were actually applied: (a) no irrigation, (b) 8.02 inches, (c) 13.73 inches, and (d) 20.17 inches.

Potato Yields.—The amounts of water applied during the different years 1914 to 1919 and the potato yields produced with these different quantities of water, together with averages for the three years 1917 to 1919, inclusive, are presented in Figure 4. It will be noted that the yields increased regularly but not proportionally as the water was increased; the smallest average yield, less than 40 bushels, was produced with only the 6-inch irrigation before seeding, and the largest average about 105 bushels with 26 inches total. The remarks made concerning the disturbance of surface soil during 1917 and 1918 in the discussion of sugar-beet yields apply equally to the potatoes since these crops were grown alternately on fields A and B of the Young Farm. Despite considerable care in planting, only a two-thirds' stand of potatoes was secured in 1919, and this contributed to a relatively small total yield on all of the plats.

The results of potato experiments from 1917 to 1919 are more conclusive than the earlier tests, since each yield reported represents an average from three plats, the same as for sugar-beets. It will be noted that the 6-inch application before seeding produced slightly more than 20 bushels an acre in 1917, a little more than 30 in 1919, and only 50 in 1918.

The amounts of water applied to the various plats which were irrigated after seeding, as indicated in Figure 4, include also the 6-inch irrigation before seeding. It will be noted that the yield of potatoes increased with the amounts of water used and that the largest amounts of water, about 25 inches average, produced the largest potato yield. In 1917 the yield was increased from 23.7 to 63.3 bushels an acre; in 1918, from 49.7 to 165.2; and in 1919, from 30.9 to 87.1 bushels an acre.

Eliminating the potato plats, which were not irrigated after seeding, the yields of potatoes for each acre-inch of irrigation water with but one exception decreased as the amount of water increased. Thus in 1917 the yield in bushels for each acre-inch of irrigation water was 3.20, 2.98, and 2.25 produced by the use of 14.7, 20.7, and 28.2 inches of water, respectively. During 1918 the yield was 9.10, 7.65, and 7.98 bushels an acre-inch with the use of 12.5, 16.4, and 20.8 inches of water. The 1919 yields were 5.58, 4.14, and 3.33 bushels an acre-inch for 14.0, 19.7 and 26.2

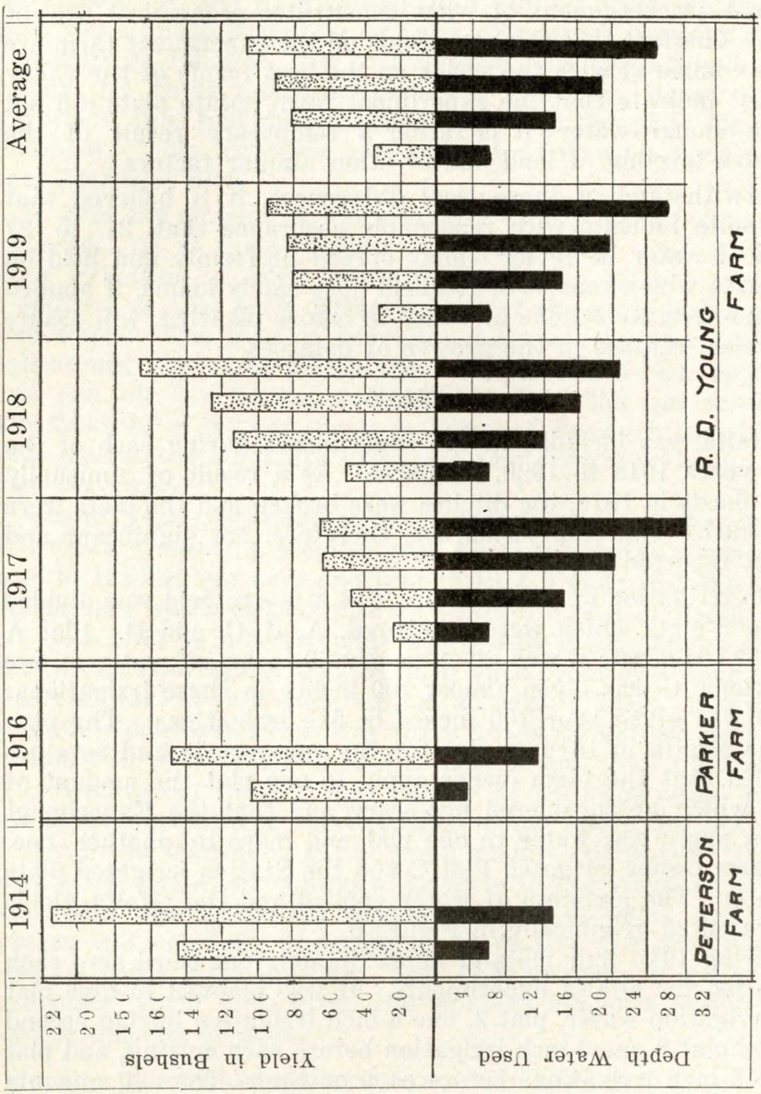

Fig. 4.—Yields of potatoes produced on different farms in Sevier Valley with various amounts of irrigation water.

inches of water. The variation from year to year is in a large measure a result of seasonal differences.

DISCUSSION OF RESULTS WITH POTATOES

As with sugar-beet yields, the amount of water which gives the largest yield to the acre-inch may or may not be the most economical. Other factors, particularly the labor cost of planting, cultivating, irrigating and harvesting the crop, influence the final ascertainment of what constitutes economical use of water. The fact that the best yields on the experiment farm are low as compared with the yields on the best farms of the valley does not indicate that the experiment farm potato plats did not receive enough water; it is rather a temporary result of the extensive leveling of land and of other similar factors.

Notwithstanding these local differences, it is believed that the results indicate with reasonable assurance that 21 to 27 inches of water in Sevier Valley spread uniformly and held on the farms which consist of Redfield deep sandy loams, if applied in 4 or 5 irrigations, one of which is before planting, will assure economical returns in the growth of potatoes.

ALFALFA

Alfalfa was included in the experiments during each of the seven years 1914 to 1920, inclusive. As a result of unusually heavy floods in 1916, the ditches were broken and the plats were all flooded. The crop yields are, therefore, not significant and are not reported here.

The Irrigation of Alfalfa.—In 1914 a 5-acre field was divided into four plats which were numbered, A, B, C, and D. Plat A was not irrigated; B was given nearly 60 inches of water in two irrigations, C was given almost 100 inches in three irrigations; and D was given over 100 inches in five irrigations. The plan for the alfalfa in 1914 as also for the sugar-beets and potatoes provided that the farm owner apply to one plat the amount of water which he considered necessary and that the Experiment Station apply less water to one plat and more to another one. The farm owner irrigated Plat C and the Station irrigated plats B and D. The amounts of water applied and the alfalfa yields are presented graphically in Figure 5.

During 1915 four plats of approximately one-third acre each were used for alfalfa experiments. It was planned to give plat 1 no irrigation water, plat 2, one 6-inch irrigation during second growth, plat 3 one 6-inch irrigation before each cutting, and plat 4, two 6-inch irrigations before each cutting. The net amounts of water actually applied to plats 2, 3, and 4 were 5.91, 18.16, and 32.88 inches depth in 1, 3, and six irrigations, respectively. Plat 2 was irrigated July 13, plat 3 once each month beginning June 15, and plat 4 twice in June, twice in July, once in August, and the last irrigation was applied on September 8.

In the spring of 1917, Field C of the Young Farm was divided into 8 alfalfa plats each having an area of nearly six-tenths of one acre, as shown in Figure 2. The alfalfa having been seeded about eight years previously made leveling of the land impractical. Back furrows were plowed to divide the plats. Each plat was given a 6-inch irrigation in April after which it was planned to irrigate as follows: (a) no irrigation, (b) three 3-inch irrigations, (c) three 6-inch irrigataions, and (d) three 9-inch irrigations, thus making four treatments and two plats for each treatment. This irrigation plan was also followed during the years 1918 and 1919.

In 1920 the amount of water applied to each set of plats was increased. As in the preceding years, each plat was given a 6-inch irrigation in April before the beginning of crop growth. In addition to this early irrigation, all of the plats were given some water. The plan of irrigation follows: (a) two 4.5-inch applications, (b) three 6-inch ones, (c) four 6.75-inch applications, and (d) five 7.5-inch irrigations. This plan was substantially followed in 1920 as shown in Figure 5, in which the alfalfa yields during the other five years are also presented during the other five years.

Alfalfa Yields.—Examination of Figure 5 shows that without irrigation water, a yield of over 4.5 tons of alfalfa was produced in 1914 on one acre and that in 1915 a yield of about 3.25 tons an acre was procured without water. It will be noted also that from 1917 to 1919 the plats which were given only an early 6-inch irrigation rapidly decreased in yield from over four tons an acre in 1917 to less than one ton an acre in 1919. Likewise, the plats which were given only three 3-inch irrigations decreased rapidly in yield from 4.5 tons in 1917 to less than 1.5 tons in 1919. Because of the very low rainfall of 1919 and other unfavorable crop conditions, the decreases noted above are not due entirely to the continued use of small amounts of water. These unfavorable conditions caused a decrease in the yields on those plats which were given the largest amounts of water, and this decrease was not fully overcome by increasing the amounts of water on these plats in 1920. The 1920 increase of water on those plats which were given the smallest amounts previously caused a marked increase.

DISCUSSION OF RESULTS WITH ALFALFA

That moisture can be carried from one season for production of crops the following season is generally known by experimentors in irrigation and also by carefully observing irrigators. The alfalfa yields in 1914 and 1915 without irrigation water and also the yield in 1917 with only one early 6-inch irrigation fully support the foregoing assertion. The relatively high yields of 1914 and 1917 obtained with light irrigations or with no irrigation water at all resulted from late-fall irrigation of the

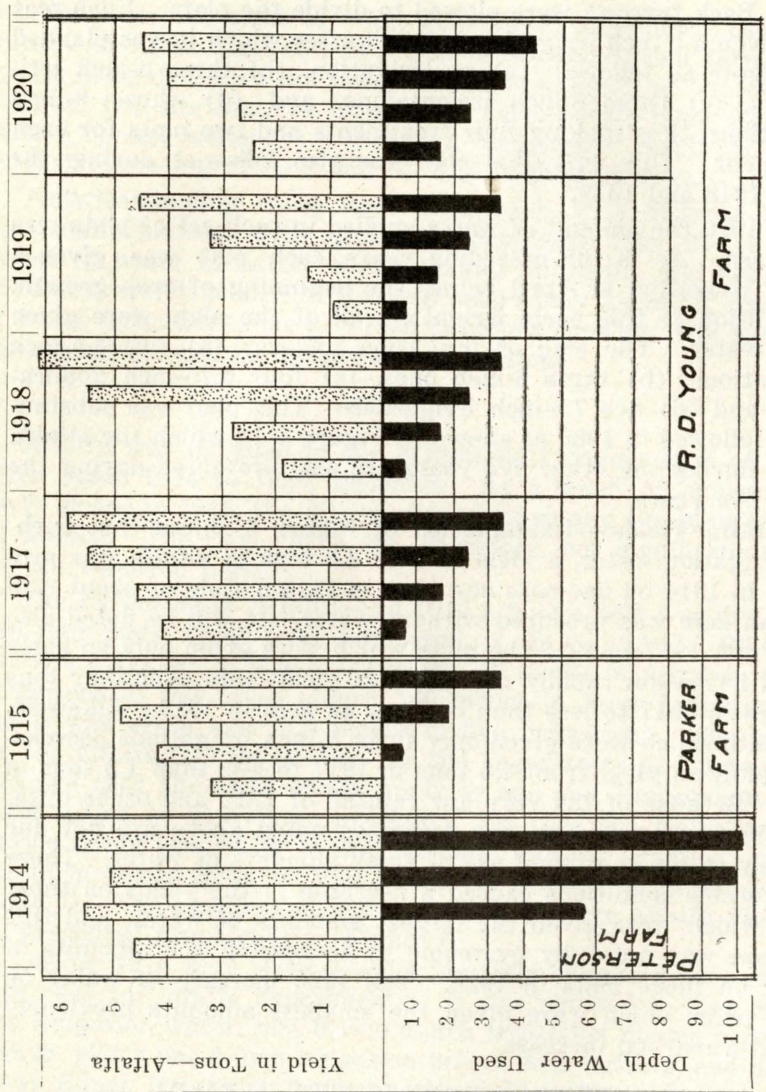

Fig. 5.—Yields of alfalfa produced on different farms in Sevier Valley with various amounts of irrigation water.

Peterson tract in 1913 and from excessive flooding of the Young Farm in 1916. The results of the work from 1918 to 1920 show clearly that alfalfa cannot be profitably produced by the rainfall alone or by the addition of a small amount of water, even though it is possible in a single season as in 1914, 1915 or 1917 to obtain a heavy yield without the use of irrigation water during that season.

It is, however, equally evident from the results presented in

Figure 5 that excessive amounts of water are not needed for alfalfa production in Sevier Valley on soils similar to those of the three farms on which the experiments were made. This figure shows that during the four years 1915, and 1917 to 1919, inclusive, excellent alfalfa yields, averaging more than 5 tons an acre, were produced by the use of approximately 33 inches of water, 6 inches of which were applied before crop growth began. Moreover, these yields during four years were just as high as those obtained in 1914 by the use of three times as much water.

In all probability, 33 inches of water on the Peterson Farm, if spread uniformly over the plats, would have produced just as much alfalfa as was produced by the 100 inches. Undoubtedly the quantities applied to this farm in 1914 were excessive.

An analysis of the cost of producing alfalfa, made on substantially the same basis as heretofore given for sugar-beets, indicates that 33 inches of water brought the largest net returns on the Young Farm. A single irrigation of 6 inches brought the highest net return on the Parker Farm in 1915, but the high yield on the plats of this farm which were given little or no irrigation was no doubt influenced by the moisture stored in the soil from the previous year.

An itemized statement of the values and costs used as a basis for the profit analysis is given below:

Investment Costs and Taxes	
Land value, apart from cost of water	$100 an acre
Water stock value	50 an acre-foot
Interest on land and water investment	7 per cent per annum
Taxes on land and water	1 per cent per annum
Operation and Maintenance of Irrigation System	$1 an acre-foot annually
Machinery and Fertilizer Costs	
Rental of all machinery and equipment	$1 an acre a year
For obtaining and applying manure	$4 an acre a year
Labor Costs	
Labor cost of irrigating	$ .60 an acre each irri.
Labor of harvesting crop	$ 1.70 a ton
Other labor items	$ 2.85 an acre a year

The alfalfa hay produced is valued at $10 a ton in the stack.

It must be remembered that these costs do not represent actual field costs in conducting the experiments. They are intended to represent approximately the cost of alfalfa production in Sevier Valley. However, the actual cost, as well as the sale price of the crop, varies considerably from year to year, and for this reason the above cost analysis is considered valuable as representing a sound method of analysis rather than the actual net profit which may be expected during any given year with the various amounts of water.

The results of the cost analysis for alfalfa are brought together in Table IV. The years 1914 and 1917 are not included in the analysis because of the influence of previous years' irrigation treatment, which caused a large yield during the year of the experiment with little or no irrigation water.

The table shows that during the three years 1918 to 1920, inclusive, 33 inches of water, the maximum amount used in the experiment, was the most profitable. In 1920 the plats which were given 42 inches produced one-half ton more alfalfa, but the value of the extra one-half ton of alfalfa was consumed in the extra cost of additional water and of harvesting the larger crop. It is noteworthy that during the years 1919 and 1920, in which the rainfall and other climatic conditions were unfavorable to crop growth, 33 inches of irrigation water produced very satisfactory growth, and during the favorable year of 1918 an excellent yield of more than six tons an acre was produced with 33 inches of water.

TABLE IV.—ALFALFA PROFITS FOR EACH ACRE WITH DIFFERENT AMOUNTS OF IRRIGATION WATER.

Year	Amount of water used, acre-feet per acre	Total cost of producing the crop	Value of crop at $10 a ton in stack	Net profit per acre
Parker Farm				
	.00	21.40	32.50	11.10
1915	0.50	26.20	42.50	16.30
	1.50	33.30	48.00	14.70
	2.75	42.50	55.00	12.50
Young Farm				
	5.50	22.00	18.00	– 4.00[1]
1918	1.25	29.25	28.00	– 1.25
	2.00	37.60	55.00	17.40
	2.75	43.00	65.00	22.00
	0.50	20.35	9.80	– 10.55
1919	1.25	27.00	14.00	– 13.00
	2.00	33.75	32.50	– 1.25
	2.75	39.65	45.00	5.35
	1.33	27.50	25.00	– 2.50
1920	2.00	33.00	27.00	– 6.00
	2.80	39.80	40.00	0.20
	3.50	44.60	45.00	0.30

[1]The minus (–) sign indicates a loss, not a profit.

Careful examination of Figure 5 and Table IV, together with a study of the crop and soil conditions described above, seems to warrant the conclusion that it is very doubtful if the use of amounts of water in excess of 36 inches net, on soil similar to that of the farms studied would prove economical to the individual irrigator. As water becomes more valuable and land is better prepared for irrigation, it is probable that less than 36 inches will bring the most economical return to the individual farmer in the irrigation of alfalfa on soils similar to those of the experiment farms in Sevier Valley.

SURFACE RUNOFF

Attention is again called to the fact that the amounts of water that were applied to the various crops as above reported are the net amounts actually held on the plats after the surface runoff has been deducted from the amounts turned on to each plat.

The ideal in irrigation practice is to prevent entirely losses of water through surface runoff and thus keep on the land all of the water applied. The nearness to which this ideal can be approached in practice is dependent on a number of factors, important among which are: (1) the slope of the land, (2) the length of irrigation run, (3) the physical properties of the soil, (4) the size of stream used and how it is spread over the surface, and (5) the amount of water applied in a single irrigation. It is also dependent on the use, if any, to which the water that runs off the surface may be put. In some valleys, as in a few places in the Sevier Valley, the runoff water is used over and over again on lower land to such extent that the final loss is reduced to a minimum. The extent of the influence of each of the above factors is difficult to determine. Despite the possibility of using water on low land, and further, regardless of the fact that the prevention of runoff under some conditions is impractical, it is always desirable to know with fair accuracy what amount of water is being lost in this way. Measurements of runoff losses were made, therefore, on nearly every plat irrigated. Particular care was given to the measurement of runoff losses for sugar-beets, potatoes, and alfalfa, the results of which, together with some miscellaneous measurements, are reported below.

Surface Runoff from Sugar-beets.—Measurements of runoff from the sugar-beet plats for the years 1915, and 1917 to 1920, inclusive, are considered first. The measurements for 1914 and 1916 are insufficient in number to be significant and are, therefore, not reported.

In 1915 runoff measurements were made on 12 plats, i. e., a, b, and c, for each of plats C1, C2, C3, and C4. Each plat was irrigated three times, making a total of 36 runoff measurements.

The plats were 28 to 30 feet wide and 290 feet long. The exact slope was not measured, but the field is fairly level.

In 1916, the first year on the Young Farm, the water was applied in a direction running from west to east on a slope of about one foot in 100 feet. The runoff loss, although not measured, was apparently heavy.

In 1917 the part of the Young Farm to be used for sugar-beets and potatoes was carefully smoothed and the ditches so made as to run the water toward the south on a slope averaging about 2 inches in 100 feet. The amount of runoff was beyond a doubt greatly reduced in this way. Nevertheless, the accurate measurements summarized below show a considerable runoff. During the years 1917 to 1920 runoff measurements were made on each of 9 plats for three irrigations. The results, together with those of 1915[1], are presented in Table V.

TABLE V.—SURFACE RUNOFF FROM SUGAR-BEETS ON SEVIER FARM, 1915 AND 1917-1920, INCLUSIVE.

Year	Plat Numbers	Proposed Irrigation Treatment	Acre-inches of water applied to the Acre: Gross	Net	Surface Runoff: Acre-inches	Per cent of Gross
1915	C1a, C1b, C1c	Three 3-inch irrigations	12.2	9.6	2.6	21
1917	3, 7, and 11	Three 4-inch irrigations	8.4	7.4	1.0	12
1918	"	"	13.8	12.0	1.8	13
1919	"	"	15.8	11.7	4.1	26
1920	4, 8, and 12	"	12.1	11.7	0.4	3
Five-year Average			12.7	10.5	2.0	16
1915	C2a, C2b, C2c	Three 6-inch irrigations	18.1	4.4	13.7	24
1917	2, 6, and 10	"	21.7	5.3	16.4	24
1918	"	"	25.2	7.3	17.9	29
1919	"	"	26.3	8.6	17.7	33
1920	"	"	21.7	3.7	18.0	17
Five-year Average			22.6	5.9	16.7	26
1915		Three 10-inch irrigations	32.4	8.8	23.6	27
1917	1, 5, and 9	Three 8-inch irrigations	29.0	7.0	22.0	24
1918	"	"	35.2	12.4	22.8	35
1919	"	"	34.6	10.9	23.7	32
1920	"	"	29.9	5.9	24.0	20
Five-year Average			32.2	9.0	23.2	28

The runoff measurements in Table V are arranged according to the amounts of water applied—the light irrigations of approximately 3-5 inches being presented first, the medium

[1]For convenience in tabulating the 1915 runoff measurements, they are reported with those of 1917 to 1920. Consequently, only 27 of the 36 measurements made in 1915 appear in Table V.

irrigations of approximately 6 inches each, second, and the heavy applications of about 9 inches last. The data presented in the table indicate a runoff of less than one inch from each irrigation for the light irrigations, approximately 2 inches for each of the medium irrigations, and 3 inches for each of the heavy irrigations. The results further show average percentage losses based on the gross amount of water applied ranging from 15 for the light irrigations to 28 for the heavy ones. The proportional losses with respect to the amount of water held on the beets, or the net application, ranges from 19 per cent or nearly one-fifth on the light applications to 39 or approximately four-tenths for the heavy ones. During 1920 all of the plats on Field A were seeded to sugar-beets and irrigated in the same way. Each plat was given four 5-inch irrigations and one 4-inch application, making a total net amount of 24 inches. On four of the 12 plats, 27 per cent of the gross and 38 per cent of the net application was lost by surface runoff, and on the remaining 8 plats 30 per cent of the gross, and 43 per cent of the net application was lost in surface runoff. It appears that surface runoff on the

TABLE VI.—SURFACE RUNOFF FROM POTATO PLATS, 1917-1919, INCLUSIVE.

Year	Plat Number	Proposed Irrigation Treatment	Acre inches applied to the Acre		Runoff	
			Gross	Net	Acre-inches an Acre	Per cent of gross applied
1917	3, 7, and 11	Two 2-inch irrigations	8.8	8.7	0.1	1
1918	"	Three 2-inch irrigations	7.1	6.6	0.5	7
1919	"	Four 2-inch irrigations	9.8	8.1	1.7	17
Three-year Average			8.6	7.8	0.8	9
1917	2, 6, and 10	Four 3½-inch irrigations	16.2	14.7	1.5	9
1918	"	Three 3½-inch irrigations	12.4	8.9	3.5	28
1919	"	Four 3½-inch irrigations	17.7	13.7	4.0	23
Three-year Average			15.4	12.4	3.0	20
1917	1, 5, and 9	Four 5-inch irrigations	25.3	22.2	3.1	12
1918	"	Three 5-inch irrigations	18.4	13.3	5.1	28
1919	"	Four 5-inch irrigations	28.0	20.2	7.8	28
Three-year Average			23.9	18.6	5.3	23

Sevier Farm was largely influenced by the amount of water applied in single irrigations. This will be considered further after presenting the results of runoff measurements for potatoes.

Surface Runoff from Potatoes.—Runoff measurements for potatoes are reported only for the three years 1917 to 1919, inclusive. At the outset it was planned to give the potatoes three irrigation treatments, namely, four 2-inch irrigations, four 3.5-inch irrigations, and four 5-inch irrigations. In 1918 the potato plats were irrigated only three times. The gross amounts of water applied to the various plats, the net amounts, and the runoff are shown in Table VI.

That the runoff losses are distinctly lower in 1917 than in later years is a result partly due to the fact that the soil of field B settled to a great extent the first year after leveling, and thus left many uneven places which retarded the flow of the water and made uniform lateral distribution very difficult. The data for both the sugar-beets and the potatoes support the conclusion that the surface runoff is relatively large with single irrigations. This is more clearly seen by arranging the percentages of runoff loss in the order of the amount applied in each irrigation as presented in Table VII.

TABLE VII.—INFLUENCE OF DEPTH OF SINGLE IRRIGATIONS ON THE PERCENTAGE OF RUNOFF.

Crop	Depth Water Applied in each irrigation inches	Runoff in percentage of gross amount of water applied
Potatoes	2	9
Potatoes	3.5	20
Sugar-beets	4	16
Potatoes	5	23
Sugar-beets	6	26
Sugar-beets	8	28

Fields A and B of the Young Farm, on which were made most of the runoff measurements given above for sugar-beets and potatoes, were smoothed and leveled for irrigation with special care. Before the farm was first used for experimental purposes it was customary to run water from the west to the east, in which direction the fall is more than one foot to 100 feet. Likewise, on neighboring farms, water is run down the steepest slope. In order to reduce runoff losses to a minimum and also to obtain the greatest possible uniformity in lateral distribution of water on the experimental plats, the irrigation water was run from north to south, in which direction the fall ranges from 2 to 3 inches to 100 feet. It is significant that despite the precaution in land leveling and reducing the fall in the direction that the water was run, large percentages of runoff losses accompany small unit applications of water. With a range of 2 to 8 inches of water in a single irrigation, the average percentage runoff varied from 9 to 28 per cent and averaged 20 per cent.

These observations emphasize the necessity for Sevier Valley irrigators occasionally to measure their runoff losses. The results would doubtless be alarming, notwithstanding the fact that in many cases the runoff is used to meet, in part, the irrigation requirements of lower lands. The runoff from the alfalfa plats was less than from the sugar-beet and potato plats, as may be seen from the results of runoff measurements from alfalfa presented below.

Surface Runoff From Alfalfa.—There was no special preparation made of the land comprising the plats used for the study of irrigation of alfalfa. Runoff measurements were made during six of the seven years' work.

In 1914 the runoff was relatively small. Table VIII shows that with a heavy irrigation of more than 36 inches, the runoff was only 9 per cent. With four of the five irrigations of the heavily irrigated plat, the runoff was 9 per cent.

On the Parker Farm, during the year 1915 with an average gross application of 7.1 inches, the runoff was 16 per cent; with an average depth of 22.0 inches, it was 17 per cent; and with an average depth of 41.6 inches, it was 21 per cent.

The experimental tract on the Young Farm containing alfalfa in 1917 was divided into eight plats, each 85 feet long and 300 feet wide. As the alfalfa was seeded before the experiments began, the land was not leveled as was that of the beet and potato plats. It was necessary in irrigating the alfalfa to continue to run the water from west to east down the heaviest slope, which varies every 100 feet from ¾ to 1 2/3 feet.

The runoff measurements during the four-year period, 1917 to 1920, inclusive, are presented in Table VIII. The greater variation of the runoff from the alfalfa is due to the fact that the land could not be properly leveled. Moreover, because of the large variation in the different measurements, the averages for alfalfa are less accurate than those for the sugar-beets and potatoes.

It will be noted in Table VIII that the average percentage runoff during the 4-year period is practically as high for the light irrigations in which an average net depth of 9.4 inches was applied each year as for the heavy irrigations in which the average net irrigation was 27 inches. From the average medium net application of 16 inches, the percentage runoff was also

TABLE VIII.—SURFACE RUNOFF FROM ALFALFA PLATS, 1917-1920, INCLUSIVE.

Year	Plat Number	Irrigation Treatment	Acre-inches applied to the Acre		Runoff	
			Gross	Net	Acre-inches an Acre	Per cent of Gross applied
1917	2 and 7	Three 3-inch irrigations	14.5	10.4	4.1	28
1918	"	"	10.2	9.6	0.6	6
1919	"	"	10.2	8.9	1.3	13
1920	1 and 8	Two 4.5-inch irrigations	10.0	8.9	1.1	11
Four-year average			11.2	9.4	1.8	15
1917	3 and 6	Three 6-inch irrigations	24.1	18.2	5.9	24
1918	"	"	19.2	18.0	1.2	6
1919	"	"	21.9	18.0	3.9	18
1920	2 and 7	"	21.3	18.0	3.3	15
Four-year average			21.6	16.0	3.6	16
1917	4 and 5	Three 9-inch irrigations	36.5	27.5	9.0	25
1918	"	"	30.1	26.8	3.3	11
1919	"	"	30.2	26.5	3.7	12
1920	"	"	31.4	27.0	4.4	14
Four-year average			32.0	27.0	5.1	16

16, the same as for the heavy irrigations, and practically the same as for the light irrigations. It is significant, however, that the average actual amount of runoff from the plats given light irrigations was only 1.8 inches, or about one-third of the 5.1 inches from the heavily irrigated plats.

The runoff measurements in general show that large amounts of runoff do occur in the irrigation of staple crops in Sevier Valley even when small amounts of irrigation water are carefully applied. They further emphasize the desirability of farmers making occasional measurements of the water lost as surface runoff in order more fully to understand the importance of reducing such losses to the greatest extent practicable.

SUMMARY AND CONCLUSIONS

(1) Seven years' experiments on the *net* duty of water for staple crops on typical soils in Sevier Valley are reported in this bulletin.

(2) The Sevier River is one of the most important sources of irrigation water in Utah, but the total water supply is insufficient for the irrigable lands to which Sevier River water may economically be conveyed.

(3) According to the 1920 census there are now included in irrigation projects in five counties more than 580,000 acres, most of which must be irrigated by the Sevier River. The stream measurements of the United States Geological Survey show an average discharge at the town of Sevier of less than 300,000 acre-feet.

(4) The mean annual rainfall at Richfield (8.34 inches) is approximately one-half that at Logan in Cache Valley and two-thirds that of the state as a whole.

(5) The soils on which the experiments were conducted, which are classed by the United States Bureau of Soils as Bingham gravelly sandy loam and Redfield fine sandy loam, comprise, according to the Bureau, nearly 55 per cent of the arable soils of the valley.

(6) Apparent specific gravity tests of the soil in its natural condition show its average weight to a depth of six feet when oven-dry to be 83 pounds a cubic foot; also that nearly 52 per cent of the soil bulk is pore-space, occupied by air and water.

(7) The average permeability of the soil is 0.7 inch depth of water an hour, i. e., free water standing on the surface of the soil will disappear at the rate of 0.7 inch an hour.

(8) Determination of the maximum capacity of the soil to absorb and retain water showed that one day after irrigation it held nearly 1.5 inches to the foot of soil in excess of the amount held before irrigation, whereas 20 days after irrigation the soil held less than one inch for each foot of soil in excess of the amount contained before irrigation, notwithstanding the fact that evaporation had been prevented. It is, therefore, likely that one inch of water for each foot of soil that needs moistening is ample in a single irrigation, provided that it is spread uniformly over the surface. Furthermore, any amount in excess of 1.5 inches of water for each foot of soil is likely to result in waste through deep percolation.

(9) The experiments here reported concern only the *net* duty of water, or the amount needed at the farm headgate. The investigations do not include a study of conveyance losses, which must of course be included in the ascertainment of amounts of water needed at storage works or at canal intakes.

(10) Sugar-beets, potatoes, and alfalfa are the crops which have been given major consideration. During the greater part of the time, the beet and potato plats were run in triplicate, and the alfalfa plats in duplicate; in a few cases, only single plats were studied.

(11) The experimental work suggests that 27 to 33 inches of water applied in four or five irrigations, and retained on the

farm, will insure economical returns for sugar-beets on the type of soils that comprise the experiment farms.

(12) For potatoes, on the soils studied, the results indicate that a net amount of 21 to 27 inches of water will assure economical returns.

(13) The observations on alfalfa indicate that 30 to 36 inches, if uniformly distributed, will bring economical results.

(14) The amounts of water for the three crops above suggested include the early irrigation before seeding but do not include the water lost from the farm through surface runoff.

(15) Measurements of surface runoff indicate that large percentages of water are lost in spite of careful preparation of land for irrigation and making the slope more gentle than that which is ordinarily used. The amount of water applied in a single irrigation seems to be the most important single factor in the control of runoff, the loss for sugar-beets and potatoes varying from 9 per cent with 2-inch irrigations to 28 per cent with 8-inch applications. The runoff measurements for alfalfa were smaller than for sugar-beets and potatoes.

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