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EFFECT OF ENVIRONMENTAL AND CULTURAL FACTORS ON THE DWARF DISEASE OF ALFALFA [1]

By J. L. WEIMER

Senior pathologist, Division of Forage Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture

INTRODUCTION

In an earlier article (*14*)[2] the writer has described briefly, under the name "dwarf", a previously unreported disease of alfalfa (*Medicago sativa* L.), the cause of which is unknown. The fact that the dwarf disease is limited to the southern half of the State of California suggests the possibility that there may be some climatic conditions which tend to limit its distribution or some cultural factors which affect its severity. Temperature, soil moisture, soil fertility, and cutting in an immature stage are factors that appear to be worthy of consideration. It has been suggested by some that the disease might be caused by one or more of these factors.

It is the object of this paper to report experiments and observations designed to show what effect, if any, certain cultural and environmental factors may have on the development of the dwarf disease and on the longevity of alfalfa stands in southern California.

METHODS AND MATERIAL

For these investigations, 16 plots, each 1 by 4 rods in area, were laid out in a 1-year-old alfalfa field on the experimental farm of the University of California at Riverside, Calif. Although this field had been dry-farmed to cereal crops for a number of years, it had never grown alfalfa. The alfalfa used was the so-called Chilean variety, which is most commonly grown in southern California. When the plots were laid out, on July 1, 1929, the stand was in excellent condition in regard to both number and growth of plants. Since the ground was only fairly level, the distribution of water had never been quite even; however, neither the stand nor the vigor of the plants was in any way impaired. This semidrought condition was easily remedied by a revised system of irrigation instituted for the plots, which were so arranged that each could be irrigated separately whenever desired. Figure 1 shows the arrangement of the plots in two series, of eight plots each, separated by an irrigation ditch and bordered on the east by another irrigation ditch. In each series border checks, each 4 feet wide, separated the plots into four groups of two each; the individual plots in each group were separated by an embankment. The two plots of each group were always irrigated alike. Since the "run" was only 4 rods long, it was possible to cover

[1] Received for publication Mar. 14, 1933; issued October, 1933. Cooperative investigations of the Division of Agronomy, California Agricultural Experiment Station, and the Division of Forage Crops and Diseases, Bureau of Plant Industry, U.S. Department of Agriculture.

[2] Reference is made by number (italic) to Literature Cited, p. 367.

any plot quickly and evenly. Usually the water was allowed to remain on the plot for 4 hours after the ground had been entirely covered. By means of a soil auger it was found that this was sufficient time to soak the soil to a depth of 3 feet or more. Plots 1 to 4 and 9 to 12, inclusive, were irrigated once a month, and the remaining plots twice a month. However, plots 1, 2, 5, 6, 11, 12, 15, and 16 were allowed to go without irrigation during the seed-producing period each summer (about 3½ months).

EFFECT OF SOIL MOISTURE

Early in these investigations field observations indicated that soil moisture exerted a very decided influence on the development of the

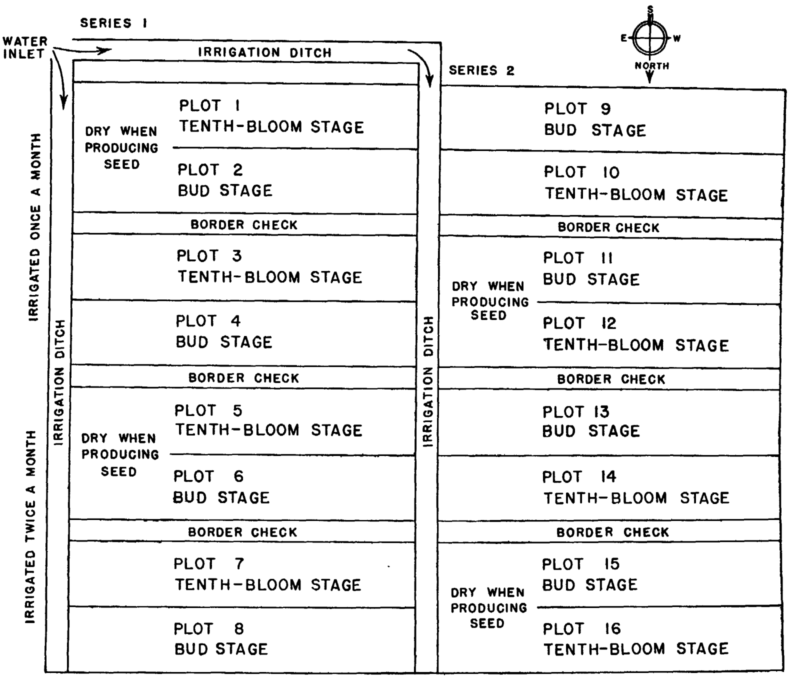

FIGURE 1.—Diagram showing arrangement of plots used in experiments.

dwarf disease and consequently on the length of life of the alfalfa stands. It was noted that the alfalfa stands which died out first were those that received the most irrigation water or those in low spots where the water collected. Often a stand was very good in the high spots of a field, where water reached only with difficulty or sometimes not at all, but elsewhere it was quite thin. Likewise, in certain small valleys where growers do not irrigate their alfalfa but depend entirely on winter rainfall for their moisture supply, dwarf is practically nonexistent and the stands continue for many years.

Having been convinced from field observations that soil moisture is a factor in the development of dwarf, the writer sought confirmatory experimental evidence based on the stands in plots given various irrigation treatments.

The stand was determined by counting the plants in three 3-foot-square quadrats in each plot, one at the center and the others about a third of the distance from each end. These quadrats were permanently located at the beginning of the experiment by driving a stake at each corner. Although the quadrats for the most part were fairly representative of the conditions, in a few cases, where the plants on one side or corner of the plots died more rapidly than those in the quadrat, the count taken was too high. This was especially true of plots 1 and 9, in which the plants died more rapidly along the south side than elsewhere; in fact by the end of the third season the stand in these plots was so poor that the yield figures were considered valueless.

TABLE 1.—*Effect of irrigation treatments on alfalfa stands from September 1929 to October 1931*

[Data represent averages from three 3-foot-square quadrats in each plot]

Number of irrigation treatments per month	Plot no.	Average number of plants					Percentage of plants (October 1931)—	
		September 1929	April 1930	September 1930	March 1931	October 1931	Dead	Living
1	[a][b] 1	45	49	35	24	14	69	31
	[c][b] 2	76	68	56	44	35	54	46
	[a] 3	51	55	47	44	40	22	78
	[c] 4	54	53	40	38	13	76	24
	[c] 9	69	63	42	46	10	86	14
	[a] 10	62	58	47	48	41	34	66
	[c][b] 11	68	58	41	46	40	41	59
	[a][b] 12	57	52	49	40	39	32	68
2	[a][b] 5	67	69	52	52	53	21	79
	[c][b] 6	68	62	47	48	45	34	66
	[a] 7	73	57	50	48	12	84	16
	[c] 8	60	45	37	40	0	100	0
	[c] 13	84	58	54	52	6	93	7
	[a] 14	80	54	48	44	14	83	17
	[c][b] 15	89	59	65	58	55	38	62
	[a][b] 16	76	55	55	50	43	43	57

[a] Plants cut in tenth-bloom stage.
[b] Plants dry when producing seed.
[c] Plants cut in bud stage.

The number of plants in the different plots, as represented by the average of the three quadrats, is given in table 1. The difficulty involved in making accurate counts of alfalfa plants is appreciated by those who have attempted it. Sometimes two or more plants are growing so close together that it is impossible to tell how many are present without removing considerable soil from about the crowns. In the present instance the soil was not removed, but every quadrat was counted by two men, each counting the entire quadrat, and the average of the two counts was used. In case the counts differed by more than a few plants, a recount was made by one or both men. Counts were made in the spring and in the autumn of each year. The results of these counts are presented in table 1. The number of plants per square foot in September 1929 ranged from 5 in plot 1 to 9⅘ in plot 15. For the most part the figures show that there was a gradual thinning of the stand, varying in rapidity in different plots, so that by October 1931 some plots were still quite good while others had few or no plants left. At that time the stands in plots 1, 3, 4, 7, 8, 9, 13, and 14 were very thin, appearing even thinner than the percentage of living plants recorded in the table would indicate.

As is often the case, the stands did not always thin out uniformly; frequently there were more than the average number of plants in a quadrat, thus making the average higher than it would have been had it been possible to count all the plants in the plot. For example, table 1 shows 78 percent of a stand left in plot 3 in October 1931, while estimates made at the same time indicated that there was about 20 percent of a stand at one end and 70 percent at the other end of the plot, or an average of about 45 percent for the plot as a whole. On the other hand, certain quadrats thinned out more than the average of the areas they represented.

In view of the fact that a gradual decrease in the number of plants in each plot took place during the 3 years the experiment was in progress, it becomes of interest to consider the reasons for the unequal rate of thinning. As already stated, some plots (1 to 4 and 9 to 12, inclusive) were irrigated once a month during the growing season, whereas the others were irrigated twice a month, and plots 1 and 9 thinned out more rapidly along the south side than did the others; but since other factors, especially a difference in soil type, were involved in plots 1 and 9, these two plots are not strictly comparable with the rest and are therefore omitted from the present discussion. The remaining figures show an average loss of 43 percent for the plots irrigated once a month and 62 percent for those irrigated twice a month. Another factor is involved, however, the fact that plots 2, 5, 6, 11, 12, 15, and 16 were not irrigated during the seed-growing period. For the plots similarly irrigated the following averages were obtained: The average percentage of loss in stand for the plots irrigated once and for those irrigated twice a month throughout the season was 44 and 90, respectively, as compared with 42⅓ and 34, respectively, for the plots similarly treated but left unirrigated during the seed-producing period. These figures show that there was a decidedly more rapid thinning of the stand in the plots irrigated twice a month, which, however, was counteracted when the stands were kept dry during the seed-producing season (figs. 2, 3, and 4). The difference in the rate of thinning of the two groups of plots that were allowed to go to seed is probably not significant.

Figures 2, 3, and 4 show the condition of certain of the plots in October 1931, when the experiment was discontinued. There seems to be a discrepancy between the data for plot 3 given in table 1 (78 percent of plants in quadrats living in October 1931) and the appearance of the plot in figure 2. This is probably due, at least in part, to the fact that the number of plants in the quadrats was not truly representative of the condition of the plot as a whole. Plot 3 was one of the best plots throughout the experiment and yielded well (table 3). However, during the late summer and autumn of 1931 the plants died out quite rapidly.

The conclusion seems justified that under the conditions of this experiment the rate of thinning of the alfalfa stand was greatly increased, in fact was practically doubled, by doubling the number of irrigations, provided the stands were not allowed to go without irrigation during the summer months. This experiment, therefore, seems to confirm the field observations indicating that soil moisture is an important factor in the longevity of the stands of alfalfa in southern California.

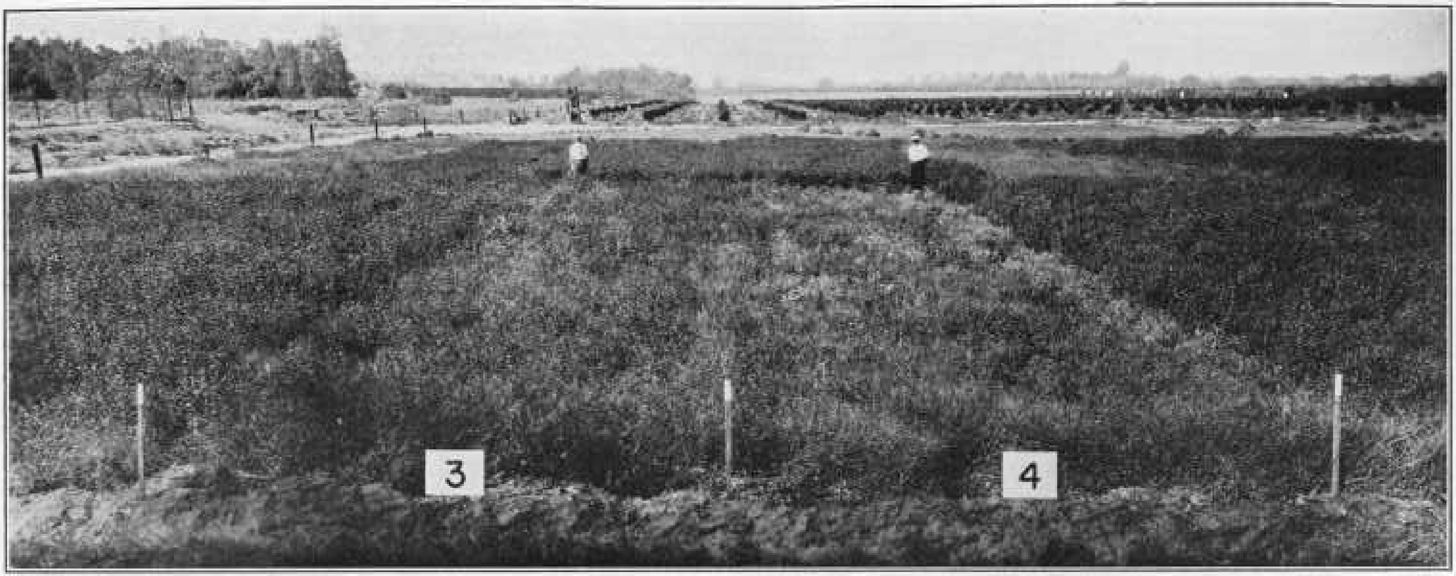

FIGURE 2.—Several alfalfa plots, showing the effect of different cultural treatments. In foreground, plots 3 and 4, irrigated once a month and cut regularly for hay; vegetation mostly weeds. At left, part of plots 1 and 2; at right, part of plots 5 and 6. In background, several plots of second series (9 to 16, inclusive); the two men shown are standing on bank of irrigation ditch separating the two series of plots. Just back of plots 3 and 4 are plots 11 and 12. Plots 1, 2, 5, 6, 11, 12, 15, and 16 were left unirrigated each summer during growth of seed crop. To right of plots 11 and 12, plots 13 and 14; still farther to right, plots 15 and 16. (For details of arrangement and for treatment given each plot, see figure 1.) Photographed in October 1931.

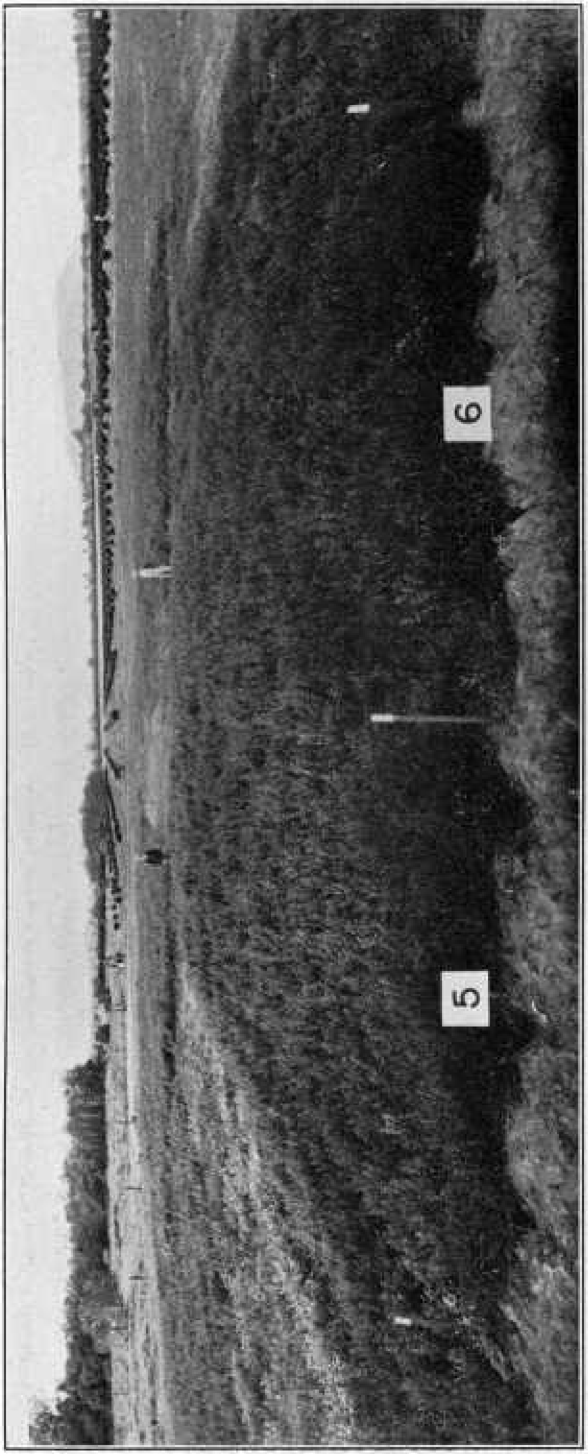

FIGURE 3.—Closer view of plots 5 and 6, showing condition of stand in plots irrigated twice a month except when growing seed. Photographed in October 1931.

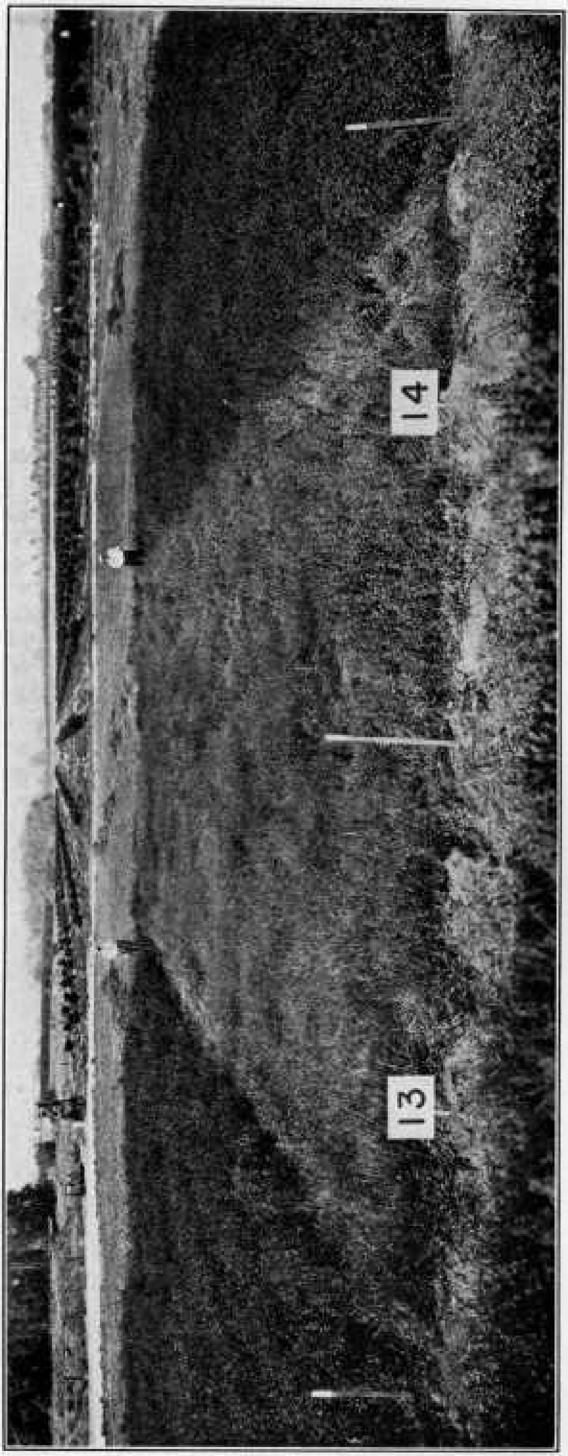

FIGURE 4.—Closer view of plots 13 and 14, showing condition of stand in plots irrigated twice a month and cut regularly for hay. Vegetation mostly weeds; only a few scattered alfalfa plants. Compare with stand of alfalfa in plots 11 and 12 (left) and 15 and 16 (right), where seed was produced each summer. Photographed in October 1931.

EFFECT OF FREQUENCY OF CUTTING

In southern California it is a common practice to cut alfalfa before the blossoms open, in order to meet the market demand for such hay to supply cattle and rabbit feed. This practice is believed by some to be responsible for the rapid thinning of the stand. Several investigators have shown (*3, 8*) that cutting alfalfa when too immature shortens the life of the stand somewhat, at least under certain conditions. An experiment was therefore designed to ascertain whether cutting in the bud stage, as compared with cutting in the tenth-bloom stage, makes any appreciable difference in the longevity of the stand. This part of the experiment was undertaken in conjunction with the study of soil moisture recorded herein, and the discussion must be based on the figures given in table 1. In this experiment, as shown in figure 1, every other plot was cut in the tenth-bloom stage and the alternate ones in the bud stage, except when the stands were allowed to go to seed. In the first series (fig. 1) the odd-numbered plots were cut in the tenth-bloom stage and the even-numbered plots were cut in the bud stage; in the second series the order was reversed.

As already stated, plots 1 and 9 are not strictly comparable with the rest; hence they and their companion plots (2 and 10) are omitted from this discussion. Since the plots run in groups of two, perhaps the best way to consider them is in that order. For example (table 2), plot 3, cut in the tenth-bloom stage, and plot 4, cut in the bud stage, have lost 22 and 76 percent, respectively, of their original stands. In like manner, plots 5, 7, 12, 14, and 16 may be compared with their companion plots, 6, 8, 11, 13, and 15, respectively. Such a comparison indicates that for the most part there is a slightly greater loss of plants in plots cut in the bud stage than in the other plots. The reverse is true for plots 16 and 15; however, the small difference is probably not significant. It is also noticeable that (omitting plots 16 and 15) the differences, though always in the same direction, are not large, except that between plots 3 and 4. The wide difference between these two plots is probably due to the fact that the figure for plot 3 is not representative of the plot as a whole, as previously explained. A further study of table 1 shows that the plots which thinned out so completely did so largely during the summer of 1931. Further light on just when this rapid dying of the plants occurred is given by the yield data in table 3, which show that all the plots, except plot 1, yielded fairly well for the first three cuttings. A falling off in yield is noticeable in plots 4, 7, and 9, in the fourth cutting, and a decided reduction is evident in plots 4, 7, 8, 9, 10, 13, and 14, in the fifth cutting, which was made between June 19 and July 29. It seems evident from these data, as well as from many field observations, that the rapid reduction in stand starts about the middle of June and, if conditions remain favorable for the development of the disease, continues until the stand is nearly or entirely depleted. Doubtless the most rapid dying of the plants takes place during July and August.

Just why the yields of plots 3 and 10 should have increased so greatly at the fourth cutting is not evident from the data at hand. These plots, as well as several of the others, showed more or less decrease in yield at the third cutting, followed by an increase at the fourth cutting. It seems to the writer most probable that soil moisture was at least one of the major factors involved in these fluctuations. This is suggested by the fact that the greater variations occurred in the plots irrigated only once each month. Occasionally the water was not available when needed, so that the plots irrigated only once a month suffered somewhat from drought.

TABLE 2.—*Effect of cutting plants at different stages of maturity on percentage of loss in stand*

Stage when cut	Plot no.	Percentage of plants dead	Stage when cut	Plot no.	Percentage of plants dead
Tenth bloom	3	22	Bud	4	76
	5	21		6	34
	7	84		8	100
	12	32		11	41
	14	83		13	93
	16	43		15	38

The total yields for the year are not of much value, since they are influenced by two inseparable factors, namely, thinning of the stands and weakening of the plants, the latter due, no doubt, to the reduction of root reserves as described by Graber and his coworkers (*3*). This weakening, which was evident as a shortening of top growth, was quite noticeable at times, especially during the latter part of the season, even before the stand started to thin so rapidly. However,

TABLE 3.—*Yield (in pounds) of weed-free hay for each cutting and the total yield for 1931*

Plot no.	Pounds of weed-free hay from indicated cutting							
	1	2	3	4	5	6	7	Total
1	3.3	(a)	(a)	(b)	(b)	c 52.57	27.47	83.34
2	23.8	50.46	58.17	(b)	(b)	c 78.47	66.66	277.56
3	32.1	86.00	52.26	96.96	85.00	52.52	(d)	404.84
4	21.8	38.25	43.53	34.84	16.36	0	3.73	158.51
5	39.7	104.19	93.93	(b)	(b)	c 75.15	62.71	375.68
6	36.1	75.48	60.05	(b)	(b)	c 70.19	48.20	290.02
7	31.5	93.12	71.08	21.81	1.99	0	0	219.50
8	20.6	34.77	34.10	40.29	3.00	0	0	132.76
9	14.2	51.07	51.26	39.23	17.59	0	0	173.35
10	27.1	91.64	58.01	86.10	43.84	55.35	(d)	362.04
11	18.3	64.94	61.94	(b)	(b)	c 86.88	63.67	295.73
12	31.7	92.37	66.35	(b)	(b)	c 97.53	67.34	355.29
13	23.7	36.54	49.98	54.28	2.50	0	0	167.00
14	28.3	83.70	66.63	75.41	38.08	0	0	292.12
15	33.3	69.37	66.75	(b)	(b)	c 112.67	62.18	344.27
16	44.1	115.46	90.04	(b)	(b)	c 120.74	63.48	433.82

[a] Not weighed, owing to large quantity of weeds.
[b] Plots allowed to go to seed.
[c] Weight of straw from seed crop.
[d] There was no seventh tenth-bloom cutting.

table 4, which gives the total yields by plots and, like table 2, is so arranged that the adjacent plots of each group can be compared readily, shows that in every case the plots cut in the tenth-bloom stage yielded considerably more hay than the adjacent plots cut in the bud stage. The total yield for all the plots cut in the tenth-bloom stage is approximately one third greater than that for the plots cut in the bud stage.

TABLE 4.—*Total yields (pounds) of weed-free hay in 1931 from plants cut in the tenth-bloom stage and from those cut in the bud stage*

Stage when cut	Plot no.	Yield	Stage when cut	Plot no.	Yield
Tenth bloom	3	404.84	Bud	4	158.51
	5	375.68		6	290.02
	7	219.50		8	132.76
	12	355.29		11	295.73
	14	292.12		13	167.00
	16	433.82		15	344.27
Total		2,081.25	Total		1,388.29

DWARF AS A FACTOR IN RAPID THINNING OF STANDS

It has been pointed out how soil moisture and possibly to a certain extent frequency of cutting may tend to shorten the life of the alfalfa stands. The chief object of the present experiment, however, was to determine, if possible, what effect these factors may have on the rate of spread and on the severity of dwarf. The percentage of diseased plants in each plot was determined in the spring and autumn of each year of the experiment; the figures thus obtained are given in table 5. For the first three counts 25 plants, irrespective of whether they were diseased or healthy, were dug from each corner of the plot. It was then decided that a more representative sample could be obtained by digging all the plants in two strips, each 1 foot wide, extending across the plots and located about one third of the distance from either end of the plots. Since the strips in which the counts were made in November 1931 were adjacent to those used in February 1931 they were comparable in every way. The number of plants obtained from each plot by this method ranged from 50 to 125, depending upon the thickness of the stand. Every root was peeled and examined, so that the early stages as well as the late stages of the disease were observed.

TABLE 5.—*Percentage of diseased alfalfa plants in each of the 16 plots on various dates*

Plot no.	Percentage of diseased alfalfa plants on indicated date				
	October 1929	April 1930	September 1930	February 1931	November 1931
1	53.1	36.2	36.0	44.6	([a])
2	21.9	10.3	33.0	16.4	17.7
3	13.3	10.5	20.0	12.4	63.0
4	4.0	10.9	30.0	22.1	26.0
5	0	5.1	4.0	3.0	37.0
6	4.4	4.8	24.0	11.7	36.0
7	8.5	16.2	64.0	65.3	([a])
8	0	16.0	50.0	77.5	([a])
9	6.2	17.0	42.0	52.3	([a])
10	0	6.9	15.0	16.3	31.5
11	2.5	1.0	6.0	13.4	25.5
12	1.2	1.0	7.0	6.8	30.0
13	5.3	3.0	31.0	50.1	41.7
14	5.3	6.0	19.0	36.6	40.0
15	2.6	2.9	3.0	4.1	10.4
16	0	1.0	7.0	12.7	25.0

[a] Stand so depleted that there were not enough plants left to make any reliable counts.

The data in table 5, column 2, show the amount of disease present in October 1929, when the stand was a little less than 2 years old. It will be observed that there was considerable disease in plots 1 to 3. The presence of the disease can be explained by the fact that these plots were nearest to the source of water and had received considerably more water than the others at each irrigation before the experiment was started. It is interesting to note that as high as 53 percent of diseased plants were present in plot 1 in the second year of the stand on soil which had never before grown alfalfa and which was several miles from any other field of growing alfalfa. It should be stated, however, that another alfalfa field, about half a mile away, had been plowed in the autumn after the plots under discussion were seeded. Nevertheless, it is difficult to see how this could have been of much importance as a factor, for the irrigation water did not come in contact with the old stand on its way to the new one and the prevailing winds blew in another direction.

Except in plots 1 to 3, there was comparatively little disease in October 1929. The following spring more diseased plants were found; yet, with the exception of plot 9, they were confined largely to the east end of the series on the east, including plots 1 to 8. From that time the disease spread so rapidly that by November 1931 some plots had only an occasional plant left.

From the data in table 5 it may be determined whether a correlation existed between either soil moisture or frequency of cutting and the development of the disease. It must be borne in mind that plots 1 to 4 and 9 to 12, inclusive, were watered once a month and the others twice, and that plots 1, 2, 5, 6, 11, 12, 15, and 16 were without irrigation during the seed-growing period each summer. As noted previously, plot 1 had a high percentage of diseased plants at the beginning (table 5); and, as indicated by the yield data in table 3, the stand died out rapidly. Although the northwest corner remained fairly good throughout, for the most part plot 1 did not show any noticeable response to the treatments given it; it seems best, therefore, to omit plot 1 from the comparisons that follow. It should also be pointed out that some of the figures for November 1931 may be misleading. For example, plot 4 seems to have had less disease in November than plot 3, although the reverse had been true previously. This difference is due to the fact that not enough plants were left in plot 4 in November 1931 to make a representative sample; hence this figure had little or no significance. A comparison of each group of companion plots (3 and 4, 5 and 6, etc.) shows few very striking differences. The outstanding difference apparent between plots 9 and 10 can be explained by the fact that in plot 9, as in plot 1, the plants died more rapidly from the start than in the plot adjacent to it. In many cases the plots cut in the bud stage had a higher percentage of dwarf than the corresponding plots cut in the tenth-bloom stage. There were several instances, however, where the disease was equally prevalent in both plots or where the plot cut in the tenth-bloom stage was the more seriously affected. In February 1931 plots 4, 6, 8, 11, and 13, which were cut in the bud stage, had higher percentages of disease than did the adjacent plots (3, 5, 7, 12, and 14). The reverse is true of plots 15 and 16. In September 1930 plot 7 had more disease than plot 8, and plot 16 had more than plot 15. These figures fail to give convincing proof that the disease is very greatly influenced by the stage of maturity of the plants when cut; hence it is difficult to see how cutting in the bud stage could be responsible for the dwarf disease.

The correlation between soil moisture and the prevalence of dwarf may be determined from the counts made in February 1931. These counts seem to be as suitable as any, if not the most reliable of all, since the samples were taken in two uniform strips across the plots at a time when the disease was very prevalent but when the stands, except that of plot 1, were not too thin. For the plots (except 1 and 9) of the series irrigated once a month, the average percentage of disease was 14.6; and for those irrigated twice a month, 32.6, a difference of 18 percent. This difference is even greater when the plots allowed to go to seed are excluded, the averages being 16.9 and 57.4 percent for the plots irrigated once and twice a month, respectively, or a difference of 40.5 percent. If those plots which had exactly the same treatment are compared, the respective percentages of diseased plants will be found to be as follows: Plots 2 and 11, 16.4 and 13.4 percent; plots 3 and 10, 12.4 and 16.3 percent; plots 5 and 16, 3.0 and 12.7 percent; plots 6 and 15, 11.7 and 4.1 percent; plots 7 and 14, 65.3 and 36.6 percent; and plots 8 and 13, 77.5 and 50.1 percent. These figures show a fairly consistent amount of disease in the duplicate plots. They also emphasize the great increase caused by the added amount of water when the applications were made throughout the growing season, and show the effect on the wet series of the summer drought, which seemingly had no effect on the dry series.

Although only one experiment is involved, the results with respect to the effect of soil moisture on dwarf are so striking and consistent and check so closely with field observations that the following conclusions seem to be justified: (1) That the alfalfa dwarf disease is greatly influenced by soil moisture; (2) that high soil moisture during the summer months is conducive to the spread of dwarf; and (3) that the reverse is true of low soil moisture. The exact degree of soil moisture conducive to the increase or decrease of dwarf has not been determined. Seed production, with the attendant dry period, has a tendency to retard the spread of the dwarf disease, especially if the soil moisture has been high at other times.

The question now arises as to whether soil moisture caused the decrease in stand through its effect on the development of dwarf; that is, whether dwarf was the sole or at least the major cause of the premature thinning of the stands in these alfalfa plots. Probably this question can best be decided by comparing tables 1 and 5. The percentage of plants lost in plot 3, as given in table 1, was rather low; the percentage of disease in the same plot, as given in table 5, was comparatively low until November 1931. Nearly all the plants indicated as diseased in November 1931, however, had an early stage of dwarf; hence they would not have died until the following year. The correlation does not seem to hold for plot 4, in which the percentage of plants lost was high (table 1) and the percentage of disease was comparatively low (table 5). In most of the other plots there seems to be a fairly close correlation between the plants lost and the amount of dwarf. Owing to errors in sampling, which may be fairly high in some cases, a considerable variation must be expected. Furthermore, it seems probable that some of the plants that died were not affected by dwarf. In fact, it is known that some plants were so severely affected with a crown rot that no tops were formed, although the roots still appeared to be healthy. On the other hand, the roots of a considerable number of plants made little growth. Although such plants were hardly ever affected with dwarf, many no doubt eventually died. In general, however, it is thought that the majority of the plants that were lost died from dwarf.

EFFECT OF TEMPERATURE

No definite experiments have been conducted to determine the influence of temperature on dwarf. Field observations, however, tend to refute the supposition that temperature is an important factor in the spread or the severity of the disease. Dwarf has been found to be as severe in places near the coast, where the temperatures are comparatively low, as in the interior valleys, where they are considerably higher. For example, temperatures recorded during June, July, August, and September, for 42 years in Los Angeles and for 23 years in Riverside (*12*), show that the mean and the mean maximum temperatures for Los Angeles were 5° and 10° F. lower, respectively, than those for Riverside. With respect to both the mean and the mean maximum temperatures more extreme conditions doubtless exist in many alfalfa fields, since alfalfa dwarf is found in places much nearer the ocean than Los Angeles, as well as in places where the mean temperatures are higher than those officially recorded for Riverside. That seasonal temperatures do affect the development of dwarf in the plant is indicated by the fact that the diseased wood in an affected plant is commonly overgrown during the winter months. As early as the 1st of December a thin white layer of new wood covering the yellow diseased area may be found in many plants. New wood continues to develop during the winter, so that by spring it may be a millimeter or more in thickness. When hot weather returns the disease again becomes active, involving the new wood, and the plant eventually dies.

Further knowledge of the effect of temperature on the development of dwarf must await a better understanding of the cause of the disease. So far as can be determined from a study of the records of the areas where dwarf is known to exist, temperature is probably not a imiting factor in the spread of the disease. Neither can temperature be considered a causal factor, since in localities where dwarf does not occur temperatures are found that are higher or lower than temperatures in localities where dwarf is known to be most destructive.

EFFECT OF SOIL FERTILITY

Many investigations have been conducted to determine what effect soil fertility has on the susceptibility of plants to disease. The review of the literature on one small group of diseases, by Stakman and Aamodt (*11*), shows the consensus of opinion to be that nitrogenous fertilizers increase the susceptibility of cereals to rusts whereas potassium and phosphorus salts tend to decrease it. These writers state that there is no very close agreement among investigators as to the exact way in which fertilizers effect a change in the resistance of a plant to rust. Stakman and Aamodt consider the effect to be largely indirect, through changes in the growth rate, density of stand, date of maturity, and yield. Much has been written regarding the correlation between the rapidity of growth of fruit trees and their susceptibility to fire blight. Hoffer and Carr (*6*) have shown how the susceptibility of corn to root rot is influenced by the accumulations of iron and aluminum in the nodes, and how the availability of these compounds in the soil may be influenced by soil moisture and the presence of sufficient amounts of other salts such as calcium and phosphorus. It has also been shown in recent years (*1, 2, 4, 7, 9, 13*) that many soils are deficient in certain elements, such as copper, manganese, zinc, and boron, which are needed in very small amounts by plants but which may be quite toxic, producing conspicuous symptoms, if excessive amounts are present in the soil. The results of such investigations serve to emphasize the fact that soil fertility may affect disease in plants by increasing or decreasing the growth rate or by weakening the tissue, as in the case of iron and aluminum, and that a deficiency or an excess of certain elements may produce a condition in plants resembling that caused by micro-organisms.

In 1929 experiments were initiated to determine whether the addition of certain commonly used fertilizers would influence the severity of the dwarf disease or whether the affected plants would outgrow the disease when supplied with certain elements that might be lacking.

The first experiment was designed to show whether the affected plants would outgrow the disease when they were removed from the field and planted in cans containing soil to which manure or commercial fertilizers had been added. For this experiment subsoil was taken from a mountain side where no cultivated crop had ever grown. Six 16-gallon garbage cans were used; two of them, containing only the soil, served as controls; two others were filled with soil mixed with a nearly equal amount of fresh horse manure; and the remaining two received an application of a complete fertilizer (consisting of ammonium sulphate, nitrate of soda, blood, triple superphosphate, and sulphate of potash), which supplied 7.5 percent nitrogen, 9.25 percent P_2O_5, and 4.75 percent K_2O, at the rate of 250 pounds per acre. The soil that was used supported vigorous growth without the application of any fertilizer. Eight 2-year-old alfalfa plants having an early stage of the disease were planted in each can. The experiment was set up in October 1929.

The plants used would normally have died during the summer of 1930. Observations made on October 22, 1930, showed that three of the control plants were alive but that their top growth was only about one third as tall as that of healthy plants growing in nearby cans and cut at the same time. A like number of plants in the cans to which manure had been added were alive and these too were very much dwarfed. Although the top growth was little if any better, the plants in the soil to which commercial fertilizer had been added did not die quite so rapidly, a total of seven plants being alive after 1 year. After 2 years one plant still remained alive in one of the cans treated with manure and one was alive in the soil to which commercial fertilizer had been applied. Just how long some of the control plants might have lived was not determined, as these plants were removed on December 2, 1930, and the cans used for another experiment.

It was concluded from this experiment that none of the treatments appreciably affected the rate of dying or the growth of the plants.

It is of course true that the experiment was carried out on a very limited scale; therefore one would probably not be justified in drawing any conclusions from it if the results had not been confirmed by field observations and other experimental data.

Although no fertilizer tests were conducted in the field, the writer had the privilege of observing and taking notes on such a test conducted during the years 1929–31, inclusive, by M. M. Winslow, farm adviser, of Riverside County, Riverside, Calif. In this experiment there were eight plots, each 50 by 80 feet in area, representing in duplicate three different treatments and a control. The rate per acre and the fertilizers applied were (1) 750 pounds of superphosphate, (2) 200 pounds of sulphur and 600 pounds of lime, and (3) 750 pounds of superphosphate and 500 pounds of potassium chloride. Since no difference in the vigor of the plants was observed, no yield data were taken.

TABLE 6.—*Number of healthy and diseased alfalfa plants in plots receiving different fertilizer treatments*

Fertilizer treatment		Alfalfa plants in—						Average percentage of diseased plants
		Plot 1			Plot 2			
Plant food	Quantity per acre	Healthy	Diseased	Total	Healthy	Diseased	Total	
	Pounds	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Percent*
Superphosphate	750	226	64	290	199	65	264	23.4
Sulphur Lime	200 600	145	66	211	141	54	195	29.5
Superphosphate Potassium chloride	750 500	186	64	250	216	54	270	22.8
Control	----------	214	46	260	204	44	248	17.7

The conclusion reached by Mr. Winslow and the writer, namely, that none of the fertilizers had any appreciable effect on dwarf, is supported by the data presented in table 6, which were obtained in February 1931 by digging all the plants in two 6-inch strips extending across all the plots and located about one third of the distance from either end. Further counts were to have been made in the autumn, but the stand was so thin by that time that it was not deemed worth while. Table 6 gives the number of healthy and diseased plants and the average percentage of diseased plants in the duplicate plots. These values show a very small range in the percentages of diseased plants in the plots. There was practically no difference between the plots receiving superphosphate and those receiving both superphosphate and potassium chloride. The value for the lime-and-sulphur plots (29.5) probably is not significantly greater than the values for the other plots. On the other hand, the percentage of disease in both control plots was the lowest of all. In none of the plots was the ground quite level, so that at times there was a difference in soil moisture; this may account for some of the variation. Taking everything into consideration, it seems probable that none of the fertilizers had an appreciable effect on the disease; certainly they did not prolong the life of the stand. By the end of the third season the stand was so uniformly poor that it was no longer worth retaining.

As stated previously, it is known that certain chemicals, ordinarily used by plants in small amounts, may have a profound effect upon them. In order to determine whether such chemicals would affect the susceptibility of alfalfa plants to dwarf, three experiments were conducted in which the following chemicals were tested: Boron, manganese, strontium, bromine, titanium, iodine, aluminum, copper, and zinc. The use of these chemicals was suggested largely by an article by Haas and Reed (*5*) and also by Dr. Haas in a personal consultation. Chemically pure chemicals were used. For the most part these were sulphates or nitrates; boron, however, was applied as sodium borate, and iodine as potassium iodide. Magnesium sulphate and ammonium nitrate were also added to this mixture. Fifty grams of boron, 1 g of titanium, 1 g of iodine, and 454 g of other substances were applied to each of two plots, each 15 by 40 feet in area, in February 1930. In one plot, which was beginning its second year, about 10 percent of the plants were diseased; in the other, which was beginning its fourth year, about 40 percent of the plants were diseased. As a further control, a heavy application of cow manure was made on a portion of the field adjacent to the plot having the older stand. In each case there was plenty of alfalfa growing on adjacent untreated land to serve as a control. In order that the counts of the plants might be made from the same area each time, three permanent quadrats, each 3 feet square, were staked off in the plot having the younger stand. Very early in the season it became apparent that an unfortunate choice of location had been made for the plot having the older stand; hence only general observations were made upon this plot throughout the season. Careful observations throughout the summer showed no apparent difference between the areas to which the chemicals and the manure had been added and the control areas.

In the plot having the younger stand counts of the quadrats showed that an average of one third of the plants had died during the year. The loss of plants was irregular; 50 percent disappeared at one end of the plot and only 7.5 percent at the other. In February 1931 counts made of representative areas in the plot showed that an average of 40 percent of the remaining plants had dwarf. The plants died so rapidly during the summer of 1931 that comparatively few were left by autumn; hence no further counts were made. It was clearly evident that the chemicals had not increased the longevity of the stand. At no time was there sufficient difference between the plot and the surrounding stand to enable one to locate the former except by the stakes at each corner.

At the time that these two plots were laid out a small experiment was begun in which two 16-gallon garbage cans were filled with soil from one badly diseased field and two with soil from another badly diseased field. Two of the cans, one filled with soil from each field, were treated with a proportionate amount of the chemical mixture used on the plots; the other two cans were left untreated and served as controls. In each can 10 alfalfa plants, 5 healthy and 5 having an early stage of dwarf, were set in such a way that healthy and diseased plants alternated. The object of this procedure was to determine whether the healthy plants would become diseased and whether the diseased plants would recover. The plants were set out on February 19, 1930.

Two plants in each of two cans, one treated and one control, and one plant in each of the other two cans failed to recover from the shock of transplanting; the other plants grew nicely. By October 21, 1930, all the diseased plants, except two in one of the control cans, had died; and two of the originally healthy plants, one in a treated can and one in a control can, had typical dwarf. The experiment was discontinued on July 3, 1931, when all the plants either had died from dwarf or had some stage of the disease. In no case did plants affected with dwarf outgrow the disease or healthy plants remain healthy. Although none of these experiments were conducted on a very large scale, the results are in agreement and are quite clear-cut; they indicate that ordinary fertilizers and other chemicals used have little or no effect on the susceptibility of alfalfa plants to the dwarf disease, and prove fairly conclusively that dwarf is due neither to an excess nor to a deficiency of any of these substances.

SUMMARY

Data are presented in this paper which indicate that dwarf, a recently described alfalfa disease whose cause is yet unknown, is largely responsible for the rapid dying of alfalfa plants in southern California.

Plots irrigated twice each month during the growing season and cut regularly were worthless for commercial hay production by the middle of the fourth year, whereas other plots similarly treated but allowed to remain without irrigation during the seed-growing period had fair stands at the end of the fourth year. The experimental evidence obtained has confirmed field observations that soil moisture exerts a marked effect on the severity of dwarf and consequently on the premature dying of alfalfa in southern California. Where soil moisture is kept sufficiently low, dwarf is not a factor in alfalfa culture. It hardly seems probable, however, that it will be commercially practicable to keep the soil moisture low enough to control dwarf and yet to maintain production at a desirable level.

Cutting alfalfa plants in the bud stage hastened the thinning of the stands to some extent, but not sufficiently to be of much commercial importance.

The development of dwarf in the plant is influenced to some extent by seasonal temperature, but its distribution is probably not limited by temperature to the regions in which it now exists.

Soil type does not appear to be much of a factor in the severity of dwarf. Neither manure, superphosphate, lime and sulphur, potassium, boron, manganese, strontium, bromine, titanium, iodine, aluminum, copper, or zinc were effective in controlling dwarf or in prolonging the life of the stand.

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