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Effects of Irrigation and Fertilization on Alfalfa Yield and Quality

Donald J. Brosz

EFFECTS OF IRRIGATION AND FERTILIZATION ON ALFALFA YIELD AND QUALITY

BY

DONALD J. BROSZ

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EFFECTS OF IRRIGATION AND FERTILIZATION

ON ALFALFA YIELD AND QUALITY

This thesis is approved as a creditable, independent investigation by a candidate for the degree, Master of Science, and acceptable as meeting the thesis requirements for this degree; but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser

Head of the Major Department

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D.J.B.

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INTRODUCTION

The quality of agricultural products is a concern of the American farmer. Quality alone often decides the market value of his product and may be the deciding issue in his net profit. So that he may demand top prices, the producer of bread wheat must produce a grain which is high in protein because high protein wheat is required by flour mills for high grade flour. The farmer raising barley, however, may have to aim for low protein grain since this is the most desirable for the malting industry. The shape, size, and cooking quality of potatoes seems to improve as the supply of potassium is increased. High quality forage is often characterized by its protein percentage and high protein forage demands are increasing. With the possible increase in irrigation development and an expanded livestock enterprise in South Dakota, high quality forage demands will develop at an accelerated pace.

The integration of irrigation and livestock feeding could possibly become a great stabilizing factor for agriculture in South Dakota. As the development of irrigation increases, the feeder of livestock will turn his attention to the irrigation farmer for a reliable supply of high quality feeds. The precipitation varies from year to year in South Dakota. As the rainfall varies so do the crop yields and the quality of crop produced. The farmer may supplement rainfall through irrigation, thus more nearly ensuring a crop of uniform quality each year.

The problem is then, "Is the maximum value to be obtained from irrigation only an increase in volume produced, or can a corresponding

increase in quality also be expected?". Since the flour millers demand high protein wheat, the malting industry demands low protein barley, the housewife and restaurants demand high quality potatoes, and the feeder of livestock continues to increase his demand for high quality feeds, the quality of these products can possibly be controlled by irrigation along with other production factors.

The relatively few irrigators in South Dakota are now just getting the "feel" of irrigation farming. Several of the farmers who are irrigating alfalfa are beginning to ask questions concerning the relationship of the quality of irrigated hay to the quality of dryland hay. Most of the hay which is produced for market is sold by the ton. If irrigation produces high quality hay, the irrigation farmer has stated that this hay should be sold on a quality basis. Since a limited amount of study has been made on irrigated crop quality in South Dakota, the request has been made to initiate such a study.

This study will be confined to one crop, that being alfalfa. The main objective of this study will be to compare the quality of irrigated alfalfa hay with the quality of dryland alfalfa hay. Various phosphorus fertilizer rates will also be incorporated into the study to determine the effects on quality of hay produced. In the study, quality will be based only on the percent of protein produced under the moisture and fertilizer treatments. Studies on digestibility of the hay and protein will not be a concern of this study. The data obtained are to be evaluated in terms of alfalfa hay yield, percent protein of the hay, and crude protein produced.

REVIEWING WORK OF OTHER INVESTIGATORS

The study of the relationship of irrigated crop quality to dryland crop quality has been limited. Essentially, very little research work has been conducted on the quality of alfalfa hay produced under irrigation in South Dakota or in other states. Water is recognized by researchers as an important factor in determining the response of the crop to fertilizer treatment and its resulting composition. The editors of the handbook, Forages, make the following statements concerning the response of the forage crops to fertilizer and water:

> There is a fairly intimate response by forage crops to the fertility of the soil or the availability of various plant nutrients in the soil. Crops are affected both in yield per acre and in composition, thus making soil fertility of great importance to the livestock man.
>
> Granted a fertile soil, then weather conditions determine crop growth. Thus the elements of rain, sun, temperature, and wind need to be favorable for maximum possible yield and for a high content of the various nutrients.......Either too much or too little moisture may interfere not only with yield but also with the composition and nutritive value of a hay crop.[1]

An extensive amount of quality study has been done in comparing sugar content of sugar beets grown under dryland and irrigated conditions. This type of study has been brought about principally because of the influence of beet quality at market-time on price. A study at Logan, Utah, was conducted on sugar beets to determine the sugar produced using four moisture levels along with four fertilizer levels. The four moisture studies consisted of controlling the moisture content of the top six

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[1]H. D. Hughes; M. E. Heath; and D. S. Metcalfe; Editors, Forages, pp. 538-540, The Iowa State College Press: Ames, Iowa, 1952.

inches of soil; the lowest moisture available was held near the wilting point during the entire growing season of the beet along with intermediate moisture levels with the highest level near field capacity at all times. The four fertilizer treatments used with the four moisture levels were as follows: no fertilizer; phosphorus treatment; nitrogen treatment; and a combined treatment of phosphorus and nitrogen. The writer is including the following table to more clearly indicate the effects on yield and quality of sugar beets due to the various moisture and fertilizer treatments:

TABLE I. YIELD AND QUALITY OF SUGAR BEETS AS INFLUENCED BY IRRIGATION AND MOISTURE LEVEL CONTROL, LOGAN, UTAH[2]

Irrigation Treatment	Yield of Sugar Beets (tons/acre) with Various Fertilizers				Mean	Sugar Percentage of Beets with Various Fertilizers				Mean
	O	P	N	NP		O	P	N	NP	
1-S	8.66	8.89	7.70	8.35	8.40	15.6	15.6	15.3	15.5	15.5
2-S	9.32	10.03	9.23	11.06	9.91	16.2	16.7	16.3	16.3	16.4
3-S	12.51	13.59	12.14	13.94	13.04	17.1	17.0	17.0	16.9	17.0
4-S	11.03	12.08	12.75	14.02	12.54	17.1	17.2	17.2	17.2	17.2
MEAN	10.45	11.15	10.46	11.84	10.97	16.5	16.6	16.4	16.5	16.5

This study indicates that permitting the soil to dry too near the wilting point (1-S) materially reduces the yield and the sugar content of

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[2]Sterling Taylor, Vaughen E. Hansen, and Jay L. Haddock, "Irrigation, Fertilization and Soil Management of Crops", 1952 Annual Progress Report, pp. 154, Utah Agricultural Experiment Station: Logan, Utah.

the sugar beets. The 1-S moisture treatment produced an average of 8.40 tons of beets per acre with an average of 15.5 percent sugar content for the various fertilizer treatments. Comparing the 1-S results with the moisture level which was held near field capacity (4-S), the average yield for moisture treatment 4-S is 17.1 tons of beets per acre with an average of 17.2 percent sugar content. This is an increase of 4.14 tons of beets per acre and 1.7 percent in sugar content. This seems to refute the often expressed theory that sugar beets should be forced to obtain moisture from lower depths in the soil to develop the tap root.

The various fertilizer treatments had very little effect on the yields and quality of sugar beets produced. The average yields and sugar percentages are very similar for all fertilizer treatments. The increase in yield and quality of the sugar beets was apparently due to the increased water that was available for plant use.

In comparing the Utah sugar beet data with data from California, one finds contradictory results. Figure 1 is used to illustrate the differences in yield and quality observed by the two stations under similar irrigation treatments.

The widely divergent results lead to opposing conclusions. Both dry treatments closely approached the wilting points, but yield was not affected at Davis and markedly decreased at Logan. At Logan, yield was highest with the wettest treatment; at Davis, yield was not significantly affected by the various moisture treatments. The figure indicates that sugar percentage of the beets also behaves in a different manner. The sugar content was approximately 15 percent at the dry soil condition at

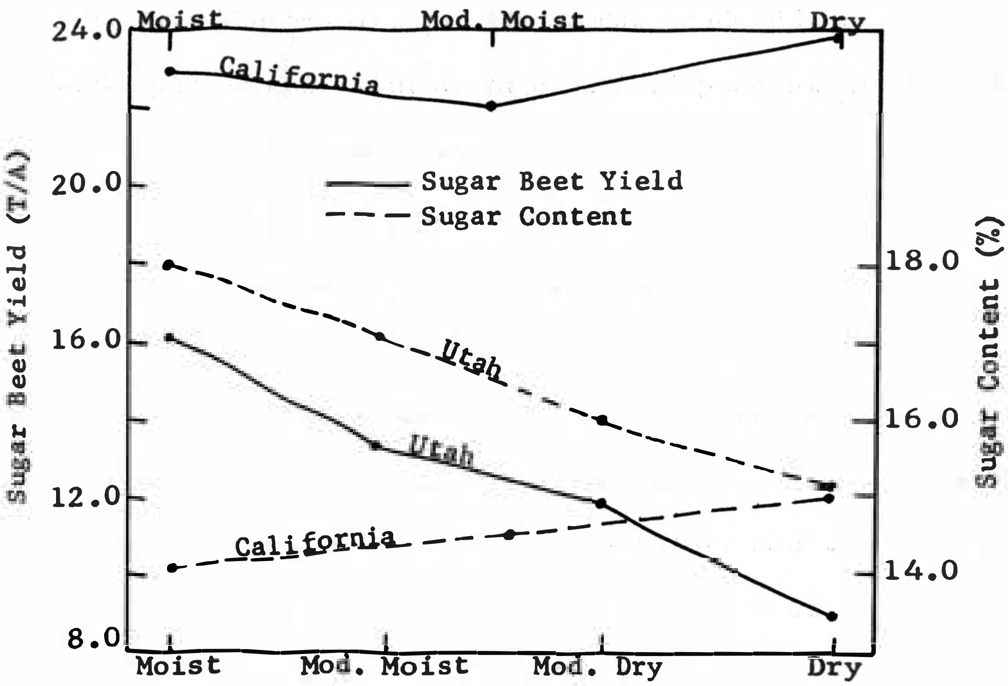

Figure 1. Yield and Quality of Sugar Beets as Influenced by Moisture Level Control at Logan, Utah and Davis, California[3]

both stations, but at the moist soil condition the Utah beets contained approximately 18 percent sugar compared to 10 percent for the California beets. The divergence may have resulted from differences in fertilizer levels and differences in moisture stress that developed within the plant after the last irrigation.[4]

From 1950 through 1953 a study was conducted in Colorado to investigate the effects of improved irrigation practices, application of commercial fertilizers, seeding legumes into meadows, and improved harvest

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[3]R. M. Hagan, Y. Vardia, and M. B. Russell, Editors, Advances in Agronomy, Volume XI, pp. 93-94, Academic Press, New York and London, 1959.

[4]Ibid, pp. 93-94.

management practices in relation to the yield and quality of hay. The practices included four irrigations, two sod management methods, eight fertilizer treatments, and two harvest management systems which were investigated on high altitude mountain meadows.[5]

In many of the mountain meadows, where irrigation water is available, the water is turned onto the meadow at the beginning of the growing season and not shut off until a few days before cutting time. Many Colorado ranchers who have meadows in the mountainous areas stated that the yields of hay had been declining for a period of years. Excessive use of water was believed to be an important factor in the decline of yields. This is what prompted the studies in Colorado.

Intermittent irrigation practices were found to produce hay of better quality with much less water being applied than was used during continuous irrigation. However, the intermittent irrigation practice did not result in significant increases in yield over the continuous irrigation except in the second cutting. No significant differences were found in yields or quality of hay among the various intermittent irrigation practices, namely, sprinkler irrigation at the short interval and flood irrigation at short and long intervals of time. Flood irrigation at the short interval required application of more than three times as much water per ton of hay than did sprinkler irrigation at short intervals.

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[5]H. R. Rouse, F. H. Willhite, and D. E. Miller, "Effects of Irrigation on Hay Yield and Quality", Agronomy Journal, Volume 47, No. 1, January, 1955.

Under intermittent irrigation, the application of nitrogen fertilizers at rates of up to 160 pounds of nitrogen per acre resulted in lower percentage of crude protein than where no nitrogen had been applied. Under continuous irrigation, the protein percentages were not greatly influenced by the rates of application of nitrogen. Under intermittent irrigation, yields of crude protein per acre were increased only when nitrogen fertilizers were applied at rates in excess of 160 pounds per acre. Under continuous irrigation, yields of crude protein per acre were increased over the check treatment with all rates of nitrogen fertilizer.

A similar experiment was conducted in several areas of Wyoming. The experiment consisted of controlled irrigation and timely application of fertilizer on native grasses and introduced species with the objective of increasing production of forage in mountain meadows.[6] Similar irrigation practices on mountain meadows are used by Wyoming ranchers as by Colorado ranchers. Irrigation water is applied onto the meadows by continuous wild flooding methods from the beginning of the growing season until ten days before the crop is harvested. By this method several acre feet of water are applied in excess of the crop needs.

Two moisture levels, excessive or continuous irrigation and controlled irrigation, were used in the study made in Wyoming. The rates of nitrogen studied along with the irrigation practices were 0, 80, and

[6] Rulon D. Lewis, "The Increased Production of Forage in Mountain Meadows Brought About by Controlled Irrigation and Timely Application of Fertilizers on Native and Introduced Species", Report given at Regional Research Reviews Conference, Billings, Montana, April 20-22, 1959.

160 pounds per acre. As the nitrogen rate was increased, the yield of hay per acre increased under both excessive and controlled irrigation. When no nitrogen was used, the controlled and excessive irrigation resulted in the production of approximately one ton of hay per acre for the season. When 160 pounds of nitrogen per acre was applied, controlled irrigation produced 4.5 tons of hay per acre compared to 3.5 tons per acre under excessive irrigation. The greatest response of nitrogen and water was shown by differences in yield of crude protein, especially at the 160 pound rate. With the use of fertilizer at this rate, controlled irrigation produced 1155 pounds of crude protein per acre compared to 540 pounds under excessive irrigation. The excessive amount of irrigation water caused a reduction in yield amounting to 615 pounds of crude protein per acre.

Dryland research in Missouri clearly showed the effects which water had on the quality of lespedeza hay that was produced. In 1942 the plots received sufficient rainfall during the growing season and crude protein production of lespedeza hay amounted to 335 pounds per ton. The 1943 growing season was short of rainfall and crude protein production amounted to only 285 pounds per ton of lespedeza hay. This indicates that moisture shortage severly reduces the quality as well as the total production of lespedeza hay.[7]

Dryland studies such as those made in Missouri have shown that the quality of a crop will vary as rainfall amounts vary.

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[7]H. D. Hughes, M. E. Hath, and D. S. Metcalfe, Editors, Forages, p. 540, The Iowa State College Press: Ames, Iowa, Second Printing 1942.

Fertilizers also show a response on percent protein produced. Table II clearly illustrates the effect of increasing rates of nitrogen fertilizer upon yield and protein percent of corn.

TABLE II. EFFECT OF INCREASING RATES OF NITROGEN FERTILIZER UPON YIELD AND PROTEIN PERCENT OF CORN[8]

N (lbs/acre)	Yield (Bu/acre)	Percent	Protein (lbs/acre)
0	64.6	6.92	211
40	90.4	7.27	310
80	118.2	7.86	439
100	132.4	8.06	504
120	140.7	8.45	562
140	141.0	8.46	564
160	146.8	8.74	606
180	141.2	9.00	602
200	147.1	9.30	647
240	145.8	9.17	632
280	147.8	9.55	665
320	143.6	9.58	650

In this study the protein content of the corn continues to increase even when the effect of the fertilizer upon yields becomes negligible.

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[8]R. M. Hagen, Y. Vardia, and M. B. Russell, Editors, Advances of Agronomy, Volume XI, p. 95, Academic Press, New York and London, 1959.

It appears that at the 120 pound rate of nitrogen, yield no longer increases with each increment increase in nitrogen; but the percent protein and protein content continue to increase. The pounds of crude protein produced varies from 211 pounds per acre using no nitrogen to 650 pounds per acre using 320 pounds of nitrogen. The percent protein continues to increase by .3 to .4 percent with each increment increase of nitrogen.

Neither moisture level nor phosphorus fertilizer had any appreciable effect on percent protein in the forage of brome-grass and brome-alfalfa mixture in an experiment conducted at Upham, North Dakota.[9] An increase in protein percentage was brought about by the various nitrogen fertilizer treatments (six nitrogen treatments). Each increase in the rate of nitrogen fertilization resulted in an increase in percentage protein in the forage harvested. The range was from nine percent to over 18 percent for material cut at hay stage and from 12 percent to over 25 percent for material clipped more frequently to simulate grazing. In some cases, the first 40 or even the first 80 pounds of nitrogen produced little or no increase in percent protein. The yield was stimulated, thus producing more pounds of protein per acre for the treatments than was produced by the check. The percent protein in the forage was higher in the frequently clipped simulated pasture system than in the treatments cut at hay stage. This resulted in as much protein produced per

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[9]R. J. Lorenz, G. A. Rogler, C. W. Carlson, H. Holmen, "Consumptive Use and Fertilizer Studies on Bromegrass and Brome-Alfalfa Mixture Grown Under Irrigated and Dryland Conditions", Report given at Regional Research Review Conference, Billings, Montana, April 20-22, 1959.

acre from the pasture treatments as was produced by the hay treatments, although the pounds dry forage produced per acre were much greater for the hay treatments. Seasonal total production of protein per acre in 1955 reached 1470 pounds from the irrigated treatments receiving 200 pounds of nitrogen compared with about 300 pounds protein from the irrigated check treatments.

ANALYSIS OF THE PROBLEM

Irrigation agriculture permits control of numerous production factors which help to stabilize the farmer's income through more stable crop production. Nature is often bountiful, but she is not always dependable. The farmers who produce consistently high yields are those who leave the fewest production factors to chance. Superior varieties of crops have been developed, mineral fertilizers have been introduced to supplement soil reserves, and insects and disease are being brought under control. In most areas of South Dakota the great unpredictable and uncontrollable factor is the weather. With irrigation it is possible to control some phases of the plant climate. Where soil moisture is maintained near maximum, the maximum value can be obtained from other production factors.

A potential of over 1.5 million acres for development of irrigation lies in the future of South Dakota.[10] To accelerate the development many questions must first be answered. One of the foremost questions is, "Is the maximum value to be obtained from irrigation only an increase in volume produced, or can a corresponding increase in quality also be expected?". Many researchers have proven that by the use of irrigation crop yields can be increased and stabilized over dryland yields. Is this the maximum value which can be obtained from irrigation? Possibly the quality of the crop produced under irrigation is such, whether it be

[10]Martin M. Fogel, Extension Irrigation Specialist, South Dakota Extension Service; Estimate presented in private conversation.

higher or lower in quality than dryland crops, that a revised means of marketing the crop may be essential. If the quality of the irrigated crop is significantly higher than dryland crop quality, this crop possibly can be sold more profitably on a quality basis rather than by the ton or bushel.

Many feeders of livestock are beginning to demand feeds which have a high protein content. Feeds having high protein available in its composition will mean the farmer may have to purchase less supplemental protein to have a balanced feeding program for his livestock.

South Dakota raises large numbers of cattle on its western range. But it is reported there are counties in the state that ship 85 percent of their cattle out of the county to be finished. If irrigation should develop in South Dakota, the irrigated areas could possibly become a reliable source of feed for the range cattle. These areas could also become the wintering feed-lots for these cattle. As the integration of irrigation and livestock continues to progress, demands for high quality feeds will also increase.

In examining the future of South Dakota, it would appear evident that the quality of feed produced will become increasingly important, if and when, the 1.5 million acres of potential irrigation agriculture are developed. A closely integrated irrigation and livestock enterprise may be logically expected to develop if abundant amounts of high quality feeds can be expected every year.

EXPERIMENTAL PROCEDURE

The alfalfa hay quality study was conducted on the Agricultural Engineering Research Farm (Figure 2), eight miles southwest of Brookings, South Dakota. The soils on the farm are alluvial soils varying from sandy clay loam to a sandy loam. The static water table is in the vicinity of seven feet below the soil surface and the thickness of the water table varies between 30 and 40 feet.

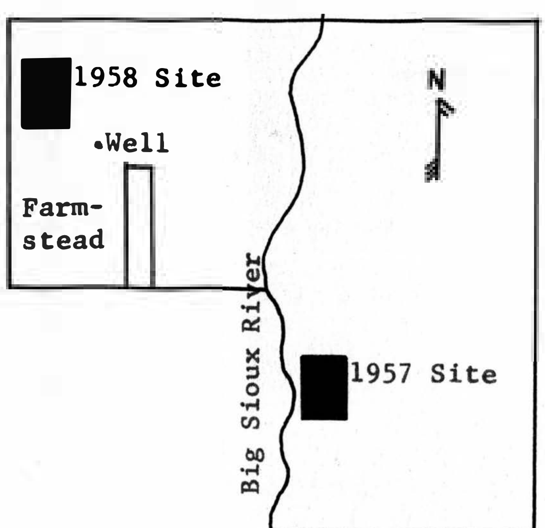


Figure 2. Location of the Experimental Plots on the Farm

Figure 3 illustrates the randomized moisture levels consisting of the irrigated plots as one level and dryland plots as the second level. The dryland plots received no supplemental moisture. The irrigated plots received only one irrigation per cutting, at which time the root zone was filled to field capacity. This was done at the early stages of growth in the spring and immediately after each cutting. With a sandy clay loam textured soil, the water holding capacity would be approximately two inches of available water per foot. A sandy loam soil will hold

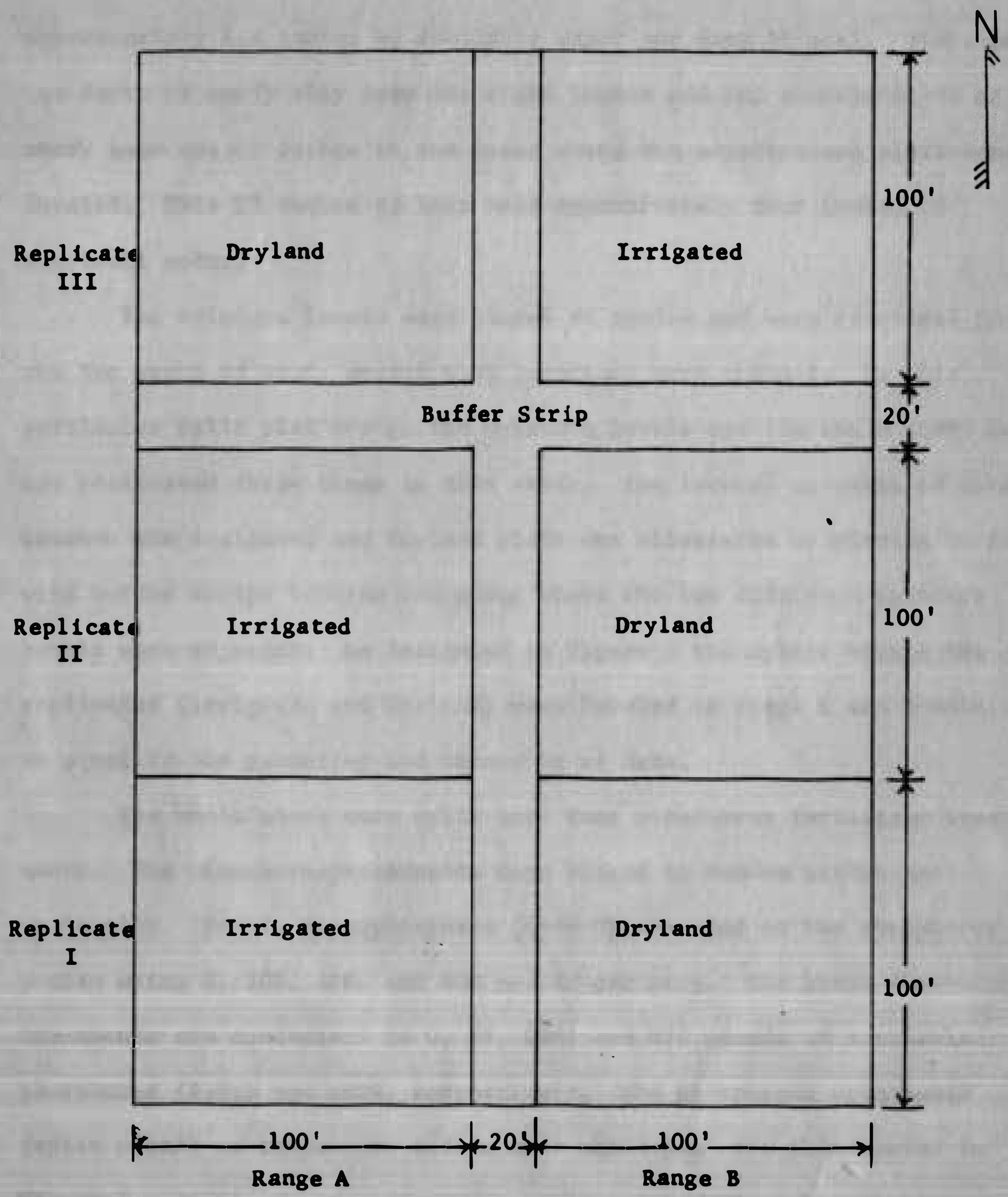


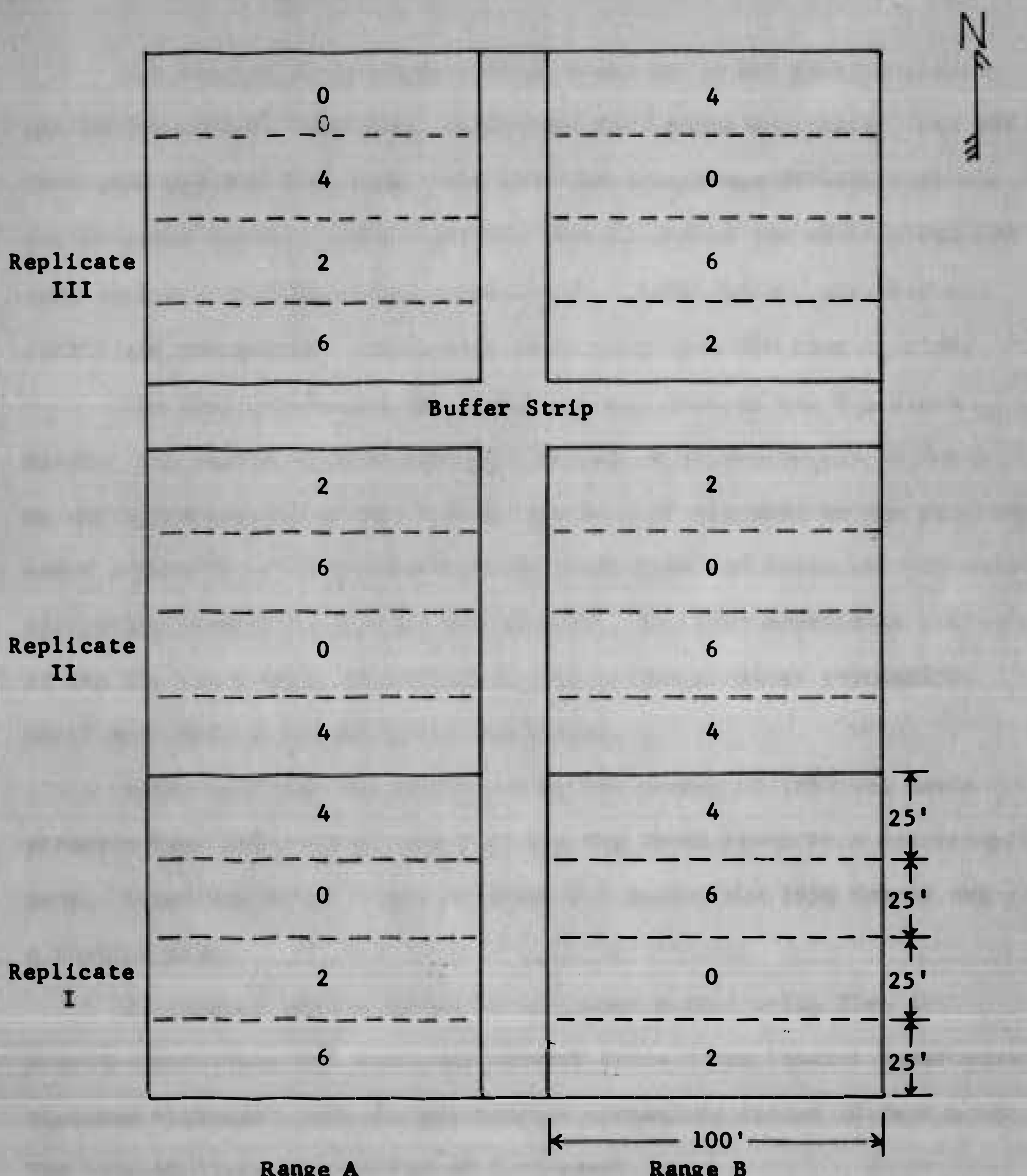
Figure 3. Moisture Level Whole Plots Randomized Within Replicates

approximately 1.4 inches of available water per foot of soil. The average depth of sandy clay loam was eight inches and the average depth of sandy loam was 20 inches in the areas where the experimental plots were located. This 28 inches of loam held approximately four inches of available water.

The moisture levels were placed at random and were identical for the two years of study except that locations were changed. In this particular split plot design the moisture levels are the whole plots and are replicated three times in this study. The lateral movement of water between the irrigated and dryland plots was alleviated by placing 20 foot wide buffer strips between the plots where the two different moisture levels were adjacent. As indicated in Figure 3 the splits within the replicates (irrigated and dryland) were labeled as range A and B mainly to simplify the gathering and recording of data.

The whole plots were split into four phosphorus fertilizer treatments. The phosphorus treatments were placed at random within each whole plot. Treble superphosphate (0-46-0) was used as the phosphorus source using 0, 200, 400, and 600 pounds per acre. The above phosphorus treatments are equivalent to 0, 92, 184, and 276 pounds of available phosphorus (P_2O_5) per acre, respectively. The phosphorus treatments (split plots) as randomized within each whole plot are illustrated in Figure 4.

The fertilizer was spread in the early spring of each year before plant growth had started for the season. The fertilizer was weighed out in the laboratory and spread by hand crossing the split plot both lengthwise and crosswise to ensure nearly even application.



Treble Superphosphate (0-46-0) Treatment:
Treatment 0 = 0 lbs/acre = 0 lbs/acre P_2O_5
Treatment 2 = 200 lbs/acre = 92 lbs/acre P_2O_5
Treatment 4 = 400 lbs/acre = 184 lbs/acre P_2O_5
Treatment 6 = 600 lbs/acre = 276 lbs/acre P_2O_5

Figure 4. Randomized Split Plots (Phosphorus Fertilizer Treatments) Within the Whole Plots

The size of the experimental plot was 200 x 300 feet, excluding the buffer strips. The area, as divided into three replicates, was 100 feet wide and 200 feet long. The 200 foot length was divided into the two moisture levels. Each replicate thus contained two whole plots 100 feet square. The whole plot contained four split plots, phosphorus fertilizer treatments, making each split plot 25 x 100 feet in size.

The 1957 experiment was along the east bank of the Big Sioux River. The entire alfalfa acreage (Vernal) of approximately 50 acres on which the experiment was located had been established by the previous owner of the farm for dryland growing conditions and later was put under irrigation without replanting the alfalfa. The 1958 experiment was west of the Big Sioux River on a field having a heavier plant population which was planted for irrigated conditions.

Water used for irrigation during the summer of 1957 was drawn directly from the surface waters of the Big Sioux River by a centrifugal pump. Water was drawn from a 40 foot well during the 1958 summer using a turbine pump.

Irrigation was performed by sprinkler method using five inch aluminum main line and four inch lateral lines. The lateral lines were equipped with both full and part-circle sprinklers spaced 30 feet apart. The lateral lines were spaced 50 feet apart.

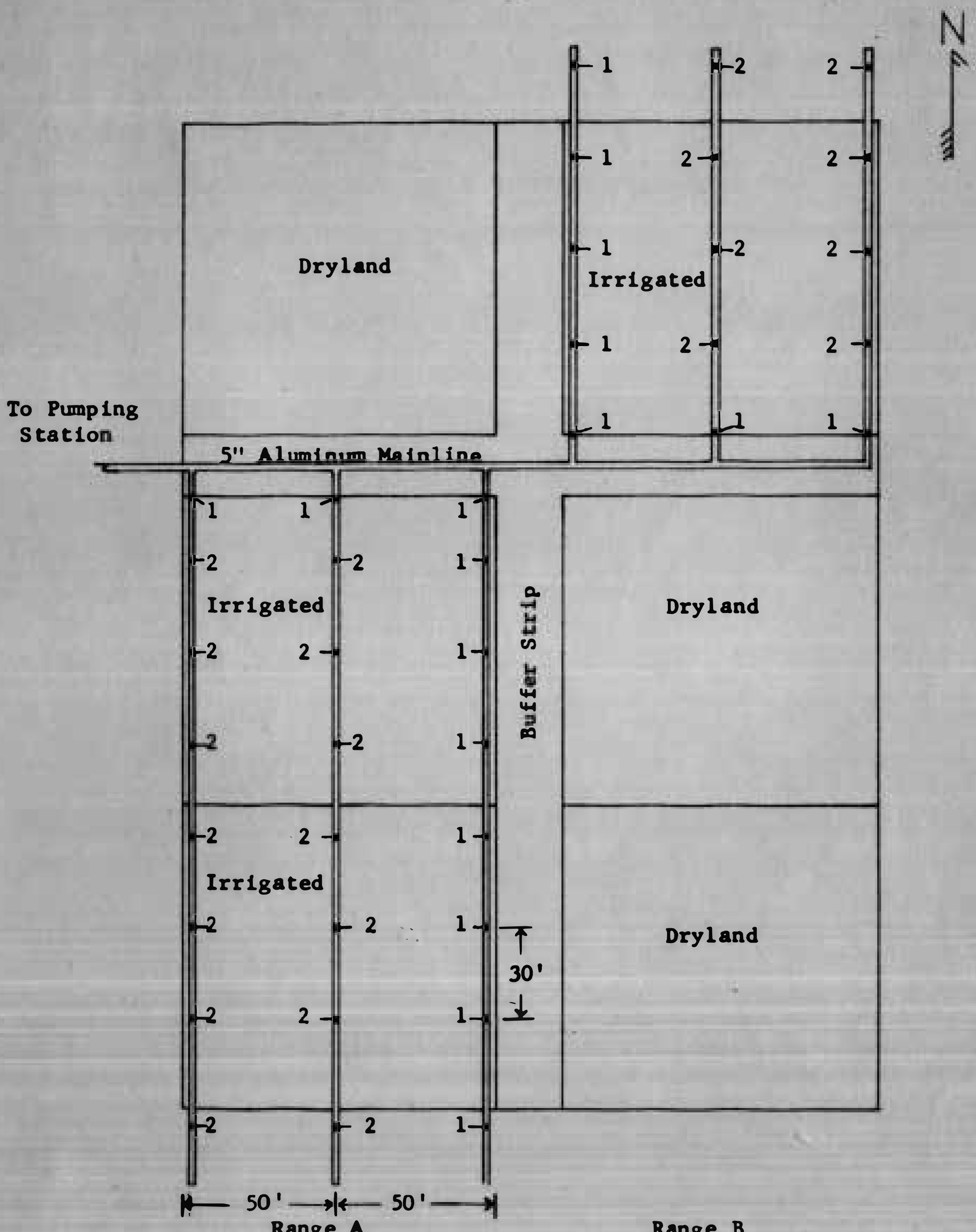
Full-circle sprinklers were used wherever there was no danger of irrigating any portion of the dryland whole plots. The full-circle sprinklers were fitted with 1/4 inch nozzles, operating at 40 pounds per square inch pressure. The 1/4 inch nozzle operating at 40 psi discharges

11.4 gallons per minute. For the 30 x 50 foot spacing, the precipitation rate is equivalent to 0.72 inches per hour.

In areas near the dryland whole plots, part-circle sprinklers were used. These sprinklers can be set to rotate through any portion of a circle from 0 to 360 degrees. The experimental layout was such that all the part-circle sprinklers could be set to rotate through 180 degrees. All the part-circle sprinklers were fitted with 3/16 inch nozzles. The 3/16 inch nozzle operating at 40 psi pressure discharges 6.8 gallons per minute. For the 30 x 50 foot spacing, the precipitation rate is equivalent to 0.40 inches per hour for 360 degree rotation or approximately 0.80 inches per hour for the 180 degree rotation.

The combination of the full and part-circle sprinklers made it possible to achieve a near uniform moisture application. The full-circle sprinklers were applying approximately 0.72 inches per hour while the part-circle sprinklers applied approximately 0.80 inches per hour. To apply four inches of water per irrigation meant a seven hour setting. This is assuming a 75 percent application efficiency.

The harvesting of alfalfa was started when approximately 10 to 15 percent of the plants were in bloom. This was determined by visual observation only. It was first thought that one may encounter some difference in the stages of growth between the two moisture levels. However, even though the dryland plots did not have as much growth as the irrigated plots, the two moisture levels still seemed to bring the alfalfa into bloom at the same rate and time.



1. Part Circle Sprinkler Heads with Single Nozzle - 3/16" Diameter
2. Full Circle Sprinkler Heads with Single Nozzle - 1/4" Diameter

Figure 5. Irrigation System Layout

Figure 6. Dryland Alfalfa Plot Near Harvest Stage, July 16, 1957

Figure 7. Irrigated Alfalfa Plot Near Harvest Stage, July 16, 1957

Two samples of alfalfa hay were taken at random from each phosphorus fertilizer treatment or split plot. The alfalfa samples were cut with a small power mower having a 38 inch wide cutting bar. A sample area of 38 inches wide and 165 inches long was taken giving a sample area of 0.001 of an acre. Two samples from each split plot gave a total sample area of 0.002 acre out of a total of 0.057 acre. The entire cut sample was gathered and placed in a cloth wrap. This sample was weighed immediately in the field for determination of tonnage produced per acre. From this larger sample, a small sample of approximately 500 grams (wet weight) was taken and placed in a bag and its weight recorded in the field. This sample was taken to the laboratory for moisture and protein content determination. The large sample was weighed in the field by a spring scale which read to the nearest ounce. The smaller sample was weighed in the field with a balance scale which read to the nearest hundredth of a gram. This same balance scale was used in the laboratory analysis. With four split plots per whole plot and two alfalfa hay samples per split plot, eight samples were taken per whole plot. Two whole plots per replicate and three replicates gave a total of (8x2x3) 48 samples per cutting. The third cuttings were not taken on the dryland plots either year because no growth resulted due to drought conditions.

In the laboratory, the alfalfa hay samples were oven dried in a Despatch oven. After determining the moisture content of the hay, the tonnage per acre then was calculated on 15 percent moisture basis from the weights obtained in the field.

Figure 8. A 0.001 Acre Sample Being Cut
Using a Small Power Mower

Figure 9. The Alfalfa Hay Sample as
Gathered into a Cloth Wrap
to be Weighed

Figure 10. Weighing the Alfalfa Hay Sample which was Gathered from the Sampling Area

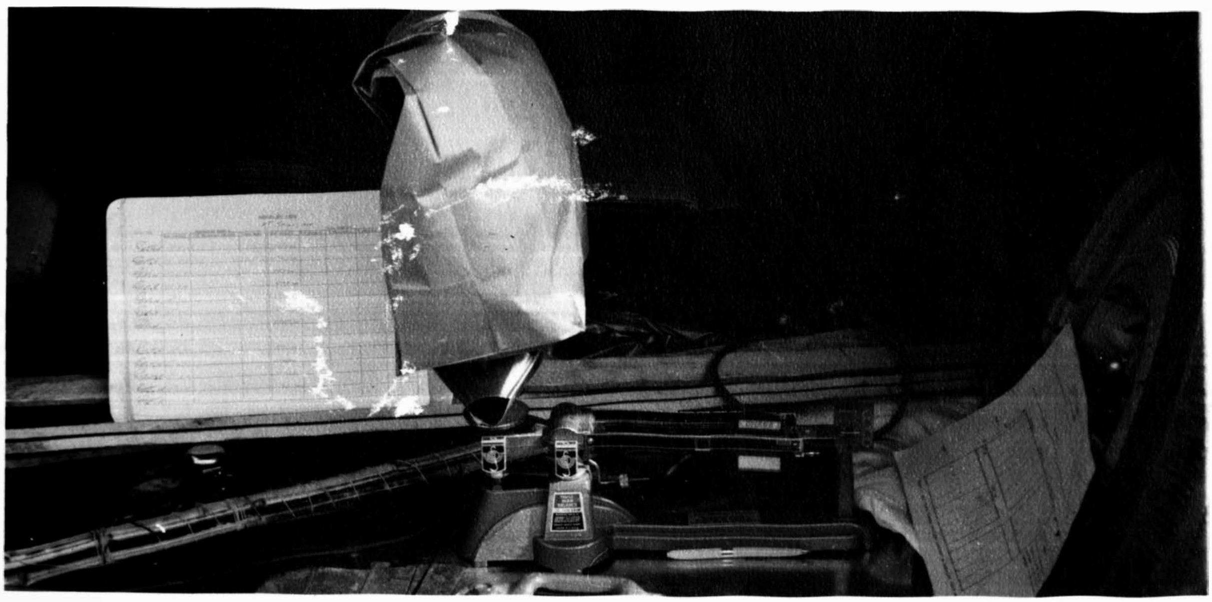


Figure 11. Field Weighing of the Smaller Sample to be Used for Laboratory Analysis

After the moisture content was determined in the laboratory, the same samples were taken to the Station Biochemistry Department on the South Dakota State College campus. The Biochemistry personnel conducted analysis (Modified Gunning Method) on the alfalfa hay samples to determine protein content.

Soil moisture samples were taken immediately before and approximately 48 hours after irrigation to determine whether the root zone had been brought back to field capacity.

RESULTS

The summer growing seasons of 1957 and 1958 were years with very limited rainfall. Figure 12 shows the recorded precipitation amounts received at the Brookings weather station located one mile east of the South Dakota State College campus for the periods of April 1, 1957 through August 31, 1957, and April 1, 1958 through August 31, 1958. The rainfall received in 1957 from April through August was 12.5 inches for the five month period. During the month of April, rainfall amounted to a little over one inch while during May and June rainfall amounted to 4.5 and 4.0 inches, respectively. This was sufficient moisture to produce a good first cutting of dryland alfalfa hay. After June, rainfall was very limited but there was still enough reserve moisture to produce a second cutting of dryland alfalfa. There was not sufficient rainfall or reserve moisture to produce a third cutting of alfalfa worth cutting.

The 1958 rainfall amounts from April through August were even less than for the same period in 1957. As may be noted, the total rainfall amount for the period was 9.5 inches. A little less than two inches of rain fell during the month of April. The month of May was extremely dry with only 0.1 inch of precipitation. On the third of June almost an inch of precipitation fell which brought the first crop of alfalfa along to a fairly good dryland yield. The month of June had many drizzly days which eventually brought a total of 3.5 inches of precipitation. Again in 1958, the dryland plots produced only two cuttings of alfalfa while the irrigated land produced three cuttings.

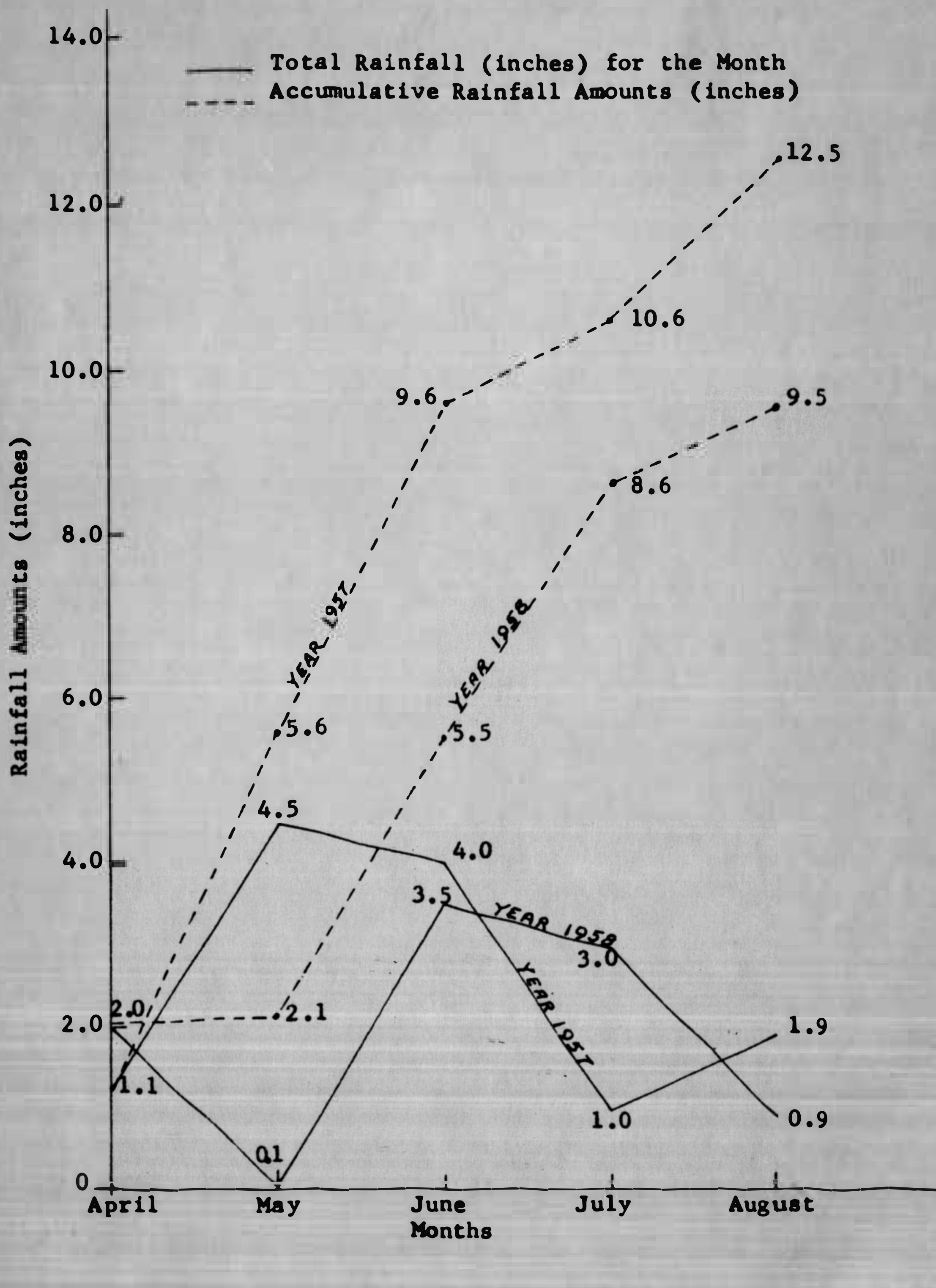


Figure 12. Rainfall Amounts (inches) Received During the Month at the Weather Station Located One Mile East of the South Dakota State College Campus 1957-1958

A split plot design was used for the experiment and the analysis of variance of the data was calculated by the least squares method.

Yield data for the 1957 alfalfa hay crop may be found in Table III and the analysis of variance of the yield data in Table IV. The analysis of variance in Table IV indicates that there was no significant difference between the three replicates and between the average irrigated yields of 3.6 tons and average dryland yields of 2.5 tons. It was expected that there be no significant difference between replicates, but one would expect a significant difference between the tons of alfalfa hay produced under irrigated and dryland conditions, especially in a year of limited rainfall. As stated in the experimental procedures, the 1957 experimental plots were located on a field which was established for dryland conditions. Plant population was low in all the experimental plots. Comparing the 1957 average yields, irrigated yields under all fertilizer treatments were approximately a ton per acre more than the dryland yields for the year. The analysis of variance indicates this was not a significant difference. This brings forth the point that must be recognized by an irrigator that plant population is very important. Not only is it necessary to carefully manage the water and fertilizer, but a suitable plant population must also be carefully maintained.

The analysis of variance indicates a significant difference at the five percent level between phosphorus fertilizer treatments and no significant difference between the interaction of fertilizer treatments and moisture levels. Yield data indicates that a response to phosphorus fertilizer was limited. The average irrigated yield of 3.0 tons per acre and average dryland yield of 2.3 tons per acre using 0 pounds of

TABLE III. AVERAGE ALFALFA HAY YIELDS (TONS/ACRE) FOR 1957-1958

Moisture Level	Replicates	Fertilizer Treatments (lbs/acre)* 0 (T/A)[1]	92 (T/A)[1]	184 (T/A)[1]	276 (T/A)[1]	Total
	I	3.3	3.6	3.9	3.4	14.2
Irrigated	II	2.8	3.4	3.9	3.6	13.7
1957	III	3.0	4.5	3.3	4.4	15.2
	Total	9.1	11.5	11.1	11.4	43.1
	Average	3.0	3.8	3.7	3.8	3.6
	I	4.4	4.5	4.5	4.5	17.9
Irrigated	II	4.3	4.2	5.2	4.9	18.6
1958	III	5.0	4.7	5.3	5.3	20.3
	Total	13.7	13.4	15.0	14.7	56.8
	Average	4.6	4.5	5.0	4.9	4.7
	Two Year Total	22.8	24.9	26.1	26.1	99.9
	Two Year Average	3.8	4.1	4.3	4.3	4.1
	I	2.6	3.2	2.7	3.1	11.6
Dryland	II	2.3	2.5	2.4	2.9	10.1
1957	III	2.0	2.2	2.0	2.2	8.4
	Total	6.9	7.9	7.1	8.2	30.1
	Average	2.3	2.6	2.4	2.7	2.5
	I	2.4	2.1	1.9	2.3	8.7
Dryland	II	2.1	1.8	1.9	2.2	8.0
1958	III	2.2	1.9	2.0	1.8	7.9
	Total	6.7	5.8	5.8	6.3	24.6
	Average	2.2	1.9	1.9	2.1	2.0
	Two Year Total	13.6	13.7	12.9	14.5	54.7
	Two Year Average	2.3	2.3	2.2	2.4	2.3

*Pounds of available phosphorus (P_2O_5) applied per acre.
[1]Alfalfa hay produced - tons per acre based on 15 percent moisture. Dryland (two cuttings) and irrigated (three cuttings).

TABLE IV. ANALYSIS OF VARIANCE OF 1957 ALFALFA YIELDS[1]

Source	DF	SS	MS	F
Moisture Levels	1	7.05	7.05	11.19
Replicates	2	0.33	0.16	0.25
Error (a)	2	1.27	0.63	
Fertility Levels	3	1.42	0.47	3.92*
Fertility X Moisture	3	0.31	0.10	0.83
Error (b)	12	1.42	0.12	

*Indicates significance at the five percent level.
[1]Statistical analysis based on original field data (lb/acre).

phosphorus are yields slightly lower than the yields of all the other fertilizer treatments. The irrigated plots having phosphorus rates of 92, 184, and 270 pounds per acre had approximately identical alfalfa hay yields; all were around 3.8 tons per acre. Similar conditions held true for the dryland yields as all were around 2.6 tons per acre using 92, 184, and 270 pound rates of phosphorus. Thus, a response was realized on 92 pounds of phosphorus per acre but no additional response for the higher levels. This indicates that the significance comes about only between the 0 and 92 pounds per acre rate of fertilizer application. An effort has been made to keep fertility high on the research farm. The experimental data indicate that this had been successfully accomplished. Soil samples were analyzed before phosphorus treatments were applied. The analyzed samples indicated a relatively high soil fertility. It was thought that even so, a response could be expected from the phosphorus fertilizer treatments used. The available phosphorus in the soil was

determined by taking composite samples from within each whole plot. The available phosphorus in the soil before fertilizer was applied in 1957 is shown in the following table.

TABLE V. PHOSPHORUS IN THE SOIL BEFORE APPLICATION OF FERTILIZER TREATMENTS IN 1957

REPLICATE	PROFILE DEPTH (inches)	DRYLAND - PLOTS PHOSPHORUS (P) (lb/acre)	IRRIGATED - PLOTS PHOSPHORUS (P) (lb/acre)
I	0-6	19.7	8.1
	0-12	19.7	8.1
	12-24	5.3	7.4
II	0-6	11.3	6.2
	0-12	11.9	8.1
	12-24	7.1	6.6
III	0-6	10.8	11.9
	0-12	18.9	7.6
	12-24	5.9	8.8

The non-significance of the interaction, fertilizer treatment times moisture levels, means that there was no special combination of moisture and phosphorus which can be expected to be better than another. This again may come about due to the relatively high fertility program carried on during the previous years.

The 1958 alfalfa hay yield data may also be found in Table III and the analysis of variance of the yield data is in Table VI.

The relationship between moisture level and yield for 1958 was highly significant, as should be expected when comparing irrigation to dryland in a dry year such as 1958. The average yield of 4.7 tons per acre for irrigation compared to the average yield of 2.0 tons per acre

TABLE VI. ANALYSIS OF VARIANCE OF 1958 ALFALFA YIELDS[1]

Source	DF	SS	MS	F
Moisture Levels	1	42.98	42.98	130.24**
Replicates	2	0.23	0.11	0.33
Error (a)	2	0.67	0.33	
Fertility Levels	3	0.60	0.20	4.54*
Fertility X Moisture	3	0.19	0.06	1.36
Error (b)	12	0.53	0.04	

**Indicates significance at the one percent level.
*Indicates significance at the five percent level.
[1]Statistical analysis based on original field data (lb/acre).

for dryland was significant to the one percent level. This means that significantly higher yields can be expected from irrigated plots than from the dryland plots in 99 out of 100 trials. In studying the alfalfa hay yield data for 1958 it was observed that the irrigated hay yields were approximately double the dryland yields in all replicates. Some of the irrigated hay yields were above five tons per acre while dryland yields were around two tons per acre. During the second year the plant population was high in the field where the studies were conducted and the response to irrigation water showed up significantly.

Fertility treatments again showed a significance at the five percent level as was indicated in the 1957 data. It appears that the 184 pounds of phosphorus per acre was the breaking point in the fertility yield response curve under irrigated conditions. Using 0 and 92 pound rates of phosphorus, 4.6 and 4.5 tons of alfalfa were produced

respectively and at the 184 pound rate, 5.0 tons of alfalfa were produced. Comparing the average yields of the irrigated hay there was only about a half ton per acre difference between the various phosphorus treatments which may not make it economically feasible to even add fertilizer in this case. Dryland plots with no added phosphorus produced 2.2 tons of alfalfa compared to 1.9, 1.9, and 2.1 tons for rates of 92, 184, and 276 respectively, thus showing no benefits due to added fertilizer. Not much of a trend in yield can be detected for the dryland condition. The initial soil samples showed that the available phosphorus in the soil before fertilizer was added again was relatively high for the 1958 experimental field.

As in 1957, the interaction of fertilizer treatments times moisture levels did not indicate significance. As before, this indicates that there was no particular combination of moisture level and phosphorus treatment which yielded more than another.

Combining the two years of alfalfa yield data into the analysis of variance brings about a factorial analysis. The factorial analysis of variance of the two years' data is shown in Table VII. The discussion of the degrees of freedom and interactions may be found in Appendix A.

For the two years of study, moisture levels indicate a significance at the one percent level, while moisture times years, fertilizer treatments, and fertilizer treatments times years, all show a five percent level of significance. The moisture level yield differences are more obvious when studying the two year average yields. The two year average

TABLE VII. ANALYSIS OF VARIANCE OF THE COMBINED 1957-1958 ALFALFA YIELDS[1]

Source	DF	SS	MS	F
Years	1	1.51	1.51	3.15
Moisture Levels	1	42.43	42.43	88.40**
Replicates (in each year)	4	0.56	0.14	0.29
Moisture X Years	1	7.61	7.61	15.85*
Error (a)	4	1.93	0.48	
Fertility Levels	3	0.78	0.26	3.25*
Fertility X Years	3	0.94	0.31	3.87*
Fertility X Moisture	3	0.69	0.23	2.87
Fert. X Moist. X Years	3	0.10	0.03	0.37
Error (b)	24	1.96	0.08	

**Indicates significance at the one percent level.
*Indicates significance at the five percent level.
[1]Statistical analysis based on original field data (lb/acre).

yield for irrigation was 4.1 tons per acre compared to 2.3 tons per acre for dryland average yield. The significance for interactions, moisture levels times years, and fertilizer times years was due to the difference in plant populations for the two year study. The significance for fertilizer treatment was still hard to identify, as explained in the single year analysis of variance. A small response to phosphorus fertilizer treatments under irrigated conditions was shown by the average yields for the two years with very little response shown in the yields under dryland conditions. Under irrigated conditions, the rates of 92, 184, and 276

pounds of phosphorus produced average yields of 4.1, 4.3, and 4.3 tons per acre respectively, while the use of no fertilizer produced 3.8 tons per acre. The rates of 0, 92, 184, and 276 pounds of phosphorus under dryland conditions produced average yields of 2.3, 2.3, 2.2, and 2.4 tons per acre, respectively.

The line graph, Figure No. 13, illustrates the average alfalfa yields for the two years of study under the various phosphorus treatments. The graph indicates that there was not much spread between the irrigated and dryland yields in 1957. The 1958 alfalfa hay yields have a definite spread between the two moisture levels indicating a substantial difference in yields. The relatively flat or horizontal lines for all moisture levels indicate that there was not much response to the various phosphorus fertilizer treatments.

From the alfalfa hay yield data it can be concluded that most of the increase in hay yield was brought about by the water that was added by irrigation. This probably will not hold true in all soils, especially those of low fertility. However, water was the only highly significant factor in the relatively fertile soil on which this study was conducted.

The two year study indicates that the quality of irrigated alfalfa hay did differ from that of dryland alfalfa hay. According to data in Table VIII, the protein percentage of irrigated alfalfa was in the order of 19.6 percent to 20.7 percent in both 1957 and 1958. Dryland alfalfa hay appears to be in the order of 18.5 percent to 19.3 percent protein. The analysis of variance for 1957 and 1958 shown in Tables IX and X indicates that moisture levels were significant at the one percent level in

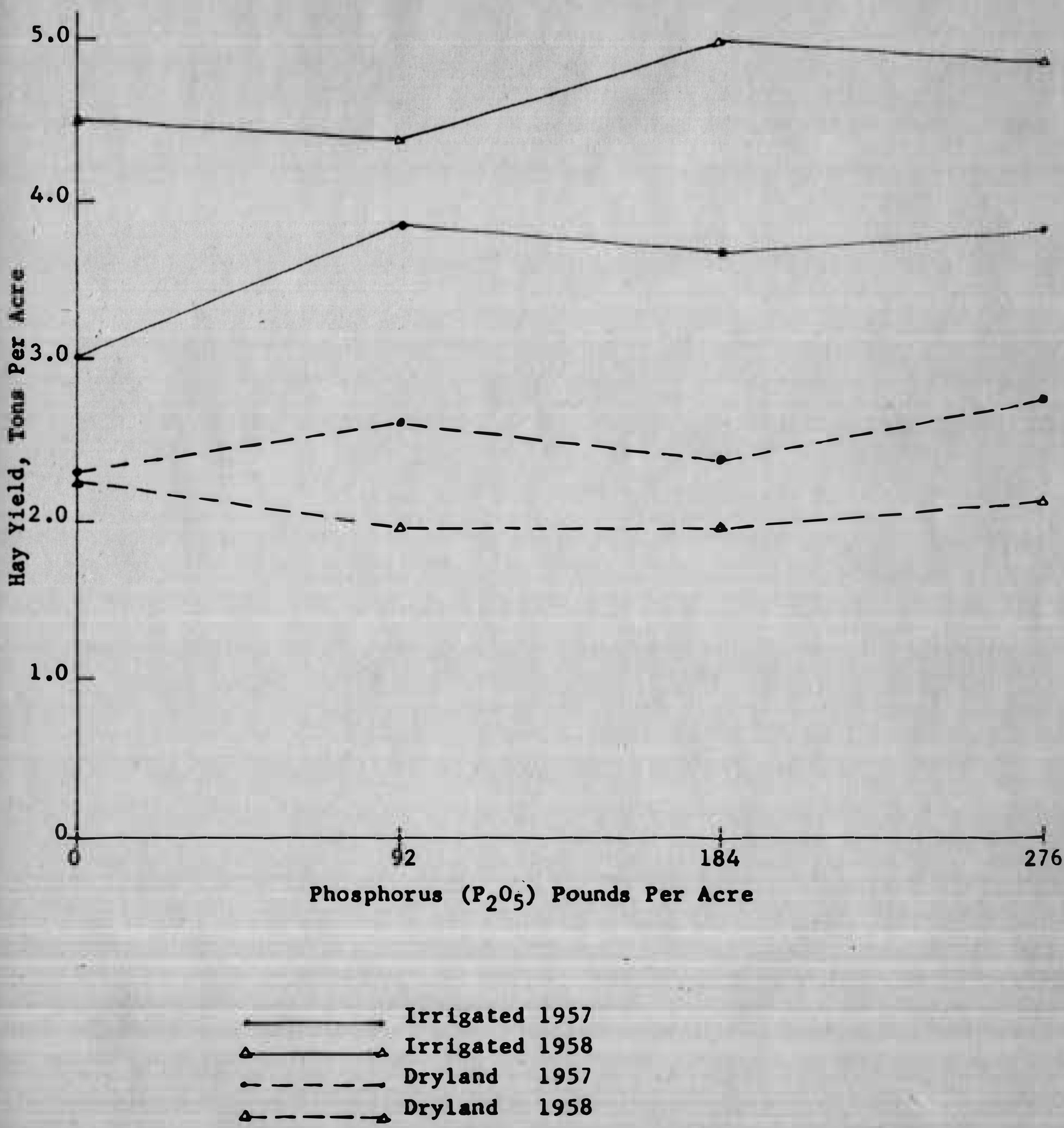


Figure 13. Average Yield of Alfalfa Hay from Three Replicates on Dryland (Two Cuttings) and Irrigated (Three Cuttings)

TABLE VIII. AVERAGE PROTEIN PERCENTAGE OF THE ALFALFA HAY FOR 1957-1958

Moisture Level	Replicates	Fertilizer Treatments (lbs/acre)* 0 (%)[1]	92 (%)[1]	184 (%)[1]	276 (%)[1]	Total
	I	19.84	21.63	20.63	20.68	82.78
Irrigated	II	19.55	19.47	19.96	20.67	79.65
1957	III	19.43	18.60	19.43	20.75	78.21
	Total	58.82	59.70	60.02	62.10	240.64
	Average	19.61	19.90	20.01	20.70	20.05
	I	19.93	20.03	20.16	20.05	80.17
Irrigated	II	19.84	20.03	20.36	19.92	80.15
1958	III	20.00	19.71	20.62	19.95	80.28
	Total	59.77	59.77	61.14	59.92	240.60
	Average	19.92	19.92	20.38	19.97	20.05
	Two Year Total	118.59	119.47	121.16	122.02	481.24
	Two Year Average	19.77	19.91	20.19	20.34	20.05
	I	20.28	19.36	20.14	19.03	78.81
Dryland	II	18.21	17.65	18.98	20.16	75.00
1957	III	17.22	19.30	18.84	18.26	73.62
	Total	55.71	56.31	57.96	57.45	227.43
	Average	18.57	18.77	19.32	19.15	18.95
	I	19.69	18.88	19.21	19.[illegible]	77.39
Dryland	II	18.54	18.34	18.88	19.66	75.42
1958	III	19.38	19.50	19.03	19.22	77.13
	Total	57.61	56.72	57.12	58.49	229.94
	Average	19.20	18.91	19.04	19.50	19.16
	Two Year Total	113.32	113.03	115.08	115.94	454.37
	Two Year Average	18.88	18.84	19.18	19.32	19.06

*Pounds of available phosphorus (P_2O_5) applied per acre.
[1]Average protein percent from dryland (two cuttings) and irrigated (three cuttings), dry weight basis.

TABLE IX. ANALYSIS OF VARIANCE FOR THE AVERAGE PROTEIN PERCENTAGE OF 1957 ALFALFA HAY

Source	DF	SS	MS	F
Moisture Levels	1	7.27	7.27	363.50**
Replicates	2	6.31	3.15	157.50**
Error (a)	2	0.04	0.02	
Fertility Levels	3	2.42	0.81	1.09
Fertility X Moisture	3	0.57	0.19	0.25
Error (b)	12	8.94	0.75	

**Indicates significance at the one percent level.

TABLE X. ANALYSIS OF VARIANCE FOR THE AVERAGE PROTEIN PERCENTAGE OF 1958 ALFALFA HAY

Source	DF	SS	MS	F
Moisture Levels	1	4.73	4.73	36.38*
Replicates	2	0.31	0.15	1.15
Error (a)	2	0.27	0.13	
Fertility	3	0.39	0.13	1.34
Fertility X Moisture	3	0.64	0.21	2.16
Error (b)	12	1.17	0.10	

*Indicates significance at the five percent level.

1957 and at the five percent level in 1958. Average protein content of the alfalfa hay produced under irrigation for all phosphorus treatments was 20.05 percent for both 1957 and 1958 compared to 18.95 percent in

1957 and 19.16 percent in 1958 for dryland conditions. This study does then indicate that the one to one and a half percent difference in protein percentage between irrigated and dryland hay is significant.

The two year study also indicated that there was no significant difference between the protein percentages due to the various phosphorus treatments as indicated in Table XI. The protein percentage of alfalfa hay did indicate a trend for both moisture treatments. For rates of 0, 92, 184, and 276 pounds of phosphorus, the two year average percent protein for irrigated hay was 19.77, 19.91, 20.19, and 20.34, respectively. As the increment of phosphorus increased, the percent protein of irrigated alfalfa hay also increased. A similar trend can be noted in the two year average protein percentage of dryland alfalfa hay. As the rate of phosphorus was increased from 0 to 276 pounds per acre, percent protein of dryland hay was 18.88, 18.84, 19.18, and 19.32, respectively. This finding was not found to be significant. As far as this study is concerned, the increase in protein percentage also was due to the addition of water.

The interaction between phosphorus treatments times moisture was not significant either year. No particular combination of moisture and fertilizer rate was of greater value than any other.

A difference between the protein percentage in the three replicates was indicated in the 1957 data at the one percent level. The writer has no explanation for this and must attribute this to experimental error. In studying the 1957 data, the protein percentages in the order of 20.6 percent to 21.6 percent for replicate I under irrigated conditions are

somewhat higher than in the other two replicates which are in the order of 19.6 percent to 20.7 percent. This also holds true for the dryland conditions where replicate I has a higher protein percentage than replicates II and III. Under similar procedures, this difference between replicates did not appear in the 1958 data. In studying the protein percentages for 1958, it may be noted that there was very little difference in the protein percentages throughout the replicates. The analysis of variance in Table X does indicate a low sum of squares between replicates which is an indication that the protein percentages do not vary much with the mean value.

As stated previously, the average protein percentage for the two year study appears to increase with heavier applications of phosphorus. This appears to hold true for both irrigated and dryland conditions. The analysis of variance, Table XI, does not indicate that this finding was significant. Under irrigated conditions each additional 200 pounds of treble superphosphate per acre seem to increase the two year average protein percentage by 0.2 percent. A similar result was shown for the two year average protein percentage for the alfalfa hay under dryland conditions.

The line graph, Figure 14, illustrates the average protein percentage of the three replicates plotted against the phosphorus treatments per acre. The lines are relatively flat which indicates that there was not much of a protein percentage increase due to the phosphorus. In both 1957 and 1958 the protein percentage was higher for irrigation than dryland thus indicating a response to water. There did appear to be a

TABLE XI. ANALYSIS OF VARIANCE FOR THE AVERAGE PROTEIN PERCENTAGE OF THE COMBINED 1957-1958 ALFALFA HAY

Source	DF	SS	MS	F
Years	1	0.13	0.13	1.73
Moisture Levels	1	11.87	11.87	158.27**
Replicates (in each year)	4	6.62	1.66	22.13**
Moisture X Years	1	0.13	0.13	1.73
Error (a)	4	0.30	0.07	
Fertility Levels	3	2.14	0.71	1.69
Fertility X Years	3	0.68	0.23	0.55
Fertility X Moisture	3	0.06	0.02	0.04
Fert. X Moist. X Years	3	1.14	0.38	0.91
Error (b)	24	10.12	0.42	

**Indicates significance at the one percent level.

questionable phosphorus response at the 276 pound rate for both the irrigated and dryland conditions. During the 1957 study, the protein percentage rose sharply under the irrigated conditions while the dryland protein percentage dropped comparing each moisture level's protein percentage to the 184 pound rate of phosphorus. The 1958 season has this 1957 finding exactly reversed. The irrigated protein percentage dropped off at the 276 pounds per acre compared to the 184 pound rate while the dryland protein percentage took an upward swing. Checking back to the original data on Table VIII, it may be noted that the protein percentages for the 276 pound rate of phosphorus under both the irrigated and dryland

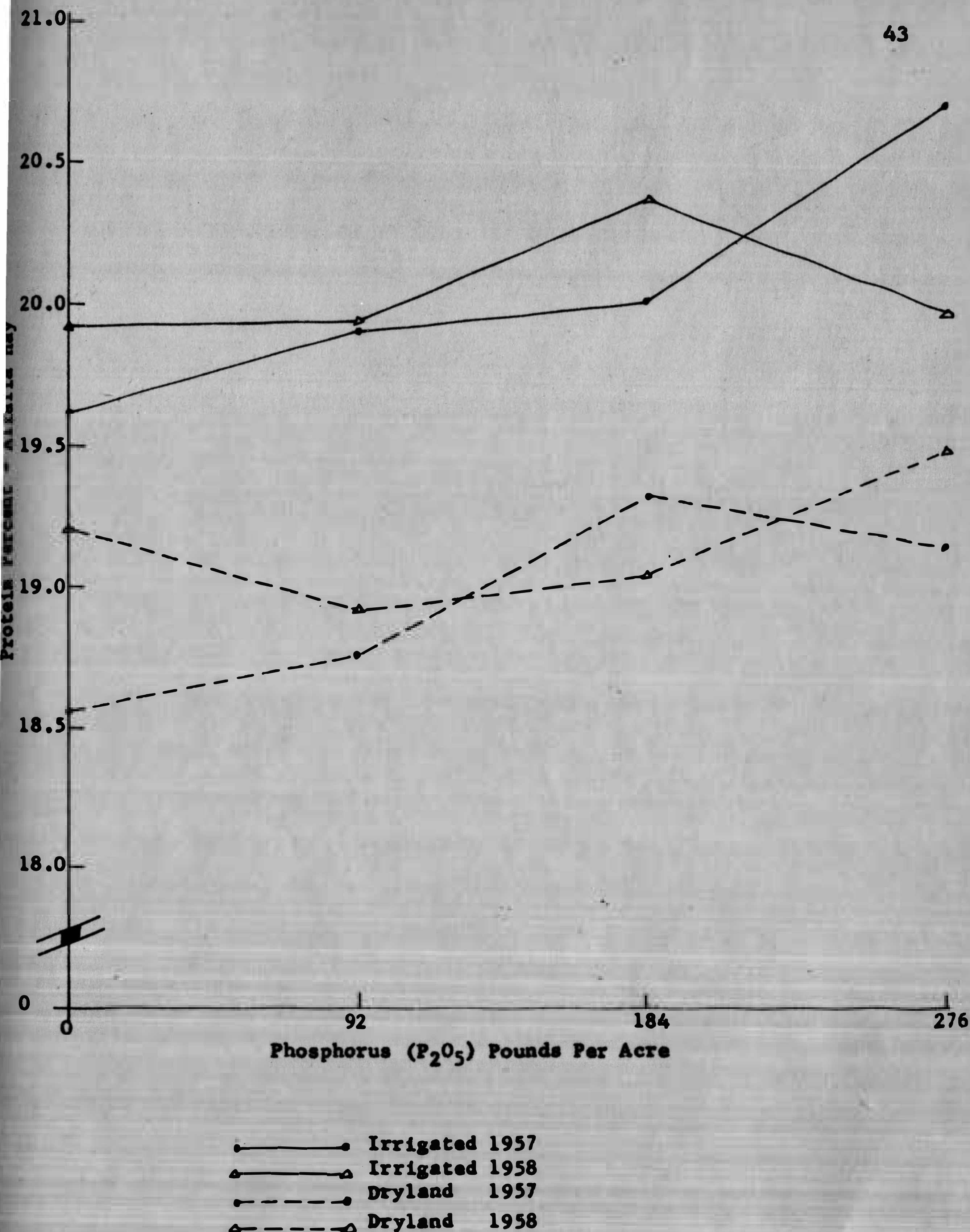


Figure 14. Average Protein Percent in the Alfalfa Hay from Three Replicates on Dryland (Two Cuttings) and Irrigated (Three Cuttings)

conditions did not vary excessively. The reverse in the curves was not brought about by one or two replicates being way "out of line". The only place where there may be a difference between replicates at the 276 pounds per acre treatment is in the dryland plots in 1957. Replicate II had 20.16 percent protein while Replicate III had 18.26 percent protein. This is one high percentage and one low percentage which tends to cancel out the extremes. This finding may have to be attributed to experimental error.

Many times protein percentage of agricultural products may be inversely correlated with yield. When the crop yields are high, protein percentages are low; when crop yields are low, protein percentages seem to be high. In comparing data in Tables III and VIII, this did not seem to be true for this alfalfa study. The findings show that as the alfalfa hay yield increased, protein percentage also increased. The 1958 irrigation data indicates a positive response in yield for phosphorus applications of up to 184 pounds per acre and then drops off for the 276 pound rate which was the same trend obtained for the protein percentage. The same results also appear under dryland conditions, as tonnage increased, protein percentage also increased.

Thus far the study has indicated that irrigated alfalfa hay yields and protein percentages were significantly higher than dryland alfalfa yields. Crude protein produced under irrigation must then also be substantially higher for irrigated alfalfa than for dryland alfalfa.

The data in Table XII illustrates the crude protein as produced in 1957 and 1958 under irrigated and dryland conditions. The increase of

TABLE XII. AVERAGE CRUDE PROTEIN YIELD (LBS/ACRE) FOR 1957-1958

Moisture Level	Replicates	Fertilizer Treatments (lbs/acre)* 0 (Lbs/A)[1]	92 (Lbs/A)[1]	184 (Lbs/A)[1]	276 (Lbs/A)[1]	Total
	I	1075.4	1326.9	1334.7	1193.6	4930.6
Irrigated	II	907.1	1088.2	1261.7	1239.4	4496.4
1957	III	975.9	1402.3	1083.8	1573.4	5035.4
	Total	2958.4	3817.4	3680.2	4006.4	14462.4
	Average	986.1	1272.5	1226.7	1335.5	1205.2
	I	1490.0	1537.3	1556.2	1558.9	6142.4
Irrigated	II	1447.3	1443.9	1821.0	1669.7	6381.9
1958	III	1721.6	1592.6	1865.5	1812.1	6991.8
	Total	4658.9	4573.8	5242.7	5040.7	19516.1
	Average	1553.0	1524.6	1747.6	1680.2	1626.4
	Two Year Total	7617.3	8391.2	8922.9	9047.1	33978.5
	Two Year Average	1269.6	1398.5	1487.2	1507.8	1415.8
	I	919.2	1044.7	945.7	1034.3	3943.9
Dryland	II	698.5	719.1	786.1	1024.5	3228.2
1957	III	564.0	701.6	639.2	683.9	2588.7
	Total	2181.7	2465.4	2371.0	2742.7	9760.8
	Average	727.2	821.8	790.3	914.2	813.4
	I	790.0	661.3	610.4	761.6	2823.3
Dryland	II	655.5	558.3	614.3	734.7	2562.8
1958	III	729.7	610.9	643.0	576.7	2560.3
	Total	2175.2	1830.5	1867.7	2073.0	7946.4
	Average	725.1	610.2	622.6	691.0	662.2
	Two Year Total	4356.9	4295.9	4238.9	4815.7	17707.2
	Two Year Average	726.2	716.0	706.5	802.6	737.8

*Pounds of available phosphorus (P_2O_5) applied per acre.
[1]Average crude protein yield from dryland (two cuttings) and irrigated (three cuttings), dry weight basis.

crude protein due to irrigation over dryland was significant to the one percent level for the combined two year study as shown in the analysis of variance, Table XIII.

TABLE XIII. ANALYSIS OF VARIANCE OF THE CRUDE PROTEIN YIELD FOR THE COMBINED YEARS, 1957-1958

Source	DF	SS	MS	F
Years	1	218,605	218,605	3.84
Moisture Levels	1	5,515,733	5,515,733	96.94**
Replicates (in each year)	4	150,379	37,595	0.66
Moisture X Years	1	982,726	982,726	17.27*
Error (a)	4	227,591	56,898	
Fertility Levels	3	158,001	52,667	5.00**
Fertility X Years	3	126,332	42,111	4.00*
Fertility X Moisture	3	88,281	29,427	2.79
Fert. X Moist. X Years	3	18,999	6,333	0.60
Error (b)	24	253,012	10,542	

**Indicates significance at the one percent level.
*Indicates significance at the five percent level.

The combined two year study also showed that there was a one percent level of significance in the relationship between the various phosphorus levels and production of crude protein. The largest increase of crude protein per acre was between rates of no phosphorus and 92 pounds of phosphorus per acre where the yields were 1269.6 and 1398.5 pounds per acre, respectively, under irrigation. There was also a continued increase

in crude protein produced under irrigation for 184 and 276 pound rates of phosphorus per acre from 1487.2 pounds to 1507.8 pounds per acre. The average crude protein produced under dryland conditions in 1957 seems to indicate a trend in that as the increment of phosphorus was increased the crude protein produced also increased. The plots with no fertilizer produced an average of 727.2 pounds of crude protein while the plots with an application of 276 pounds of phosphorus produced 914.2 pounds of crude protein. The second year data indicates that the plots with no phosphorus fertilizer applied produced an average of 725.1 pounds of crude protein which was the highest amount of protein produced under all phosphorus treatments. This may be an indication that moisture was an essential factor in determining the response of alfalfa to fertilizer. This in turn seems to determine the quality of hay produced. As pointed out in the rainfall records, 1958 had very limited precipitation. This appeared to affect the amount of crude protein produced on the dryland during 1958. Comparing just the 276 pound rate of phosphorus, during 1957 the dryland condition produced 914.2 pounds of crude protein to 691.0 pounds in 1958.

Taking a look at the line graph on Figure 9, one can see the wide spread between the crude protein produced under irrigated and dryland conditions, especially during the 1958 season. The maximum two year average crude protein production under irrigated conditions was 1507.8 pounds per acre in 4.3 tons of alfalfa using 276 pounds of phosphorus per acre. Disregarding the 1957 year due to the poor alfalfa stand and using the 1958 data, one finds that at 184 pounds of phosphorus per acre, an

average of 1747.6 pounds of crude protein was produced in 5.0 tons of alfalfa hay. This compared to 914.2 pounds of crude protein in 2.7 tons under dryland conditions. In 1958, under drought conditions, only 725.1 pounds of crude protein were produced in 2.2 tons of alfalfa hay to which no phosphorus fertilizer had been added.

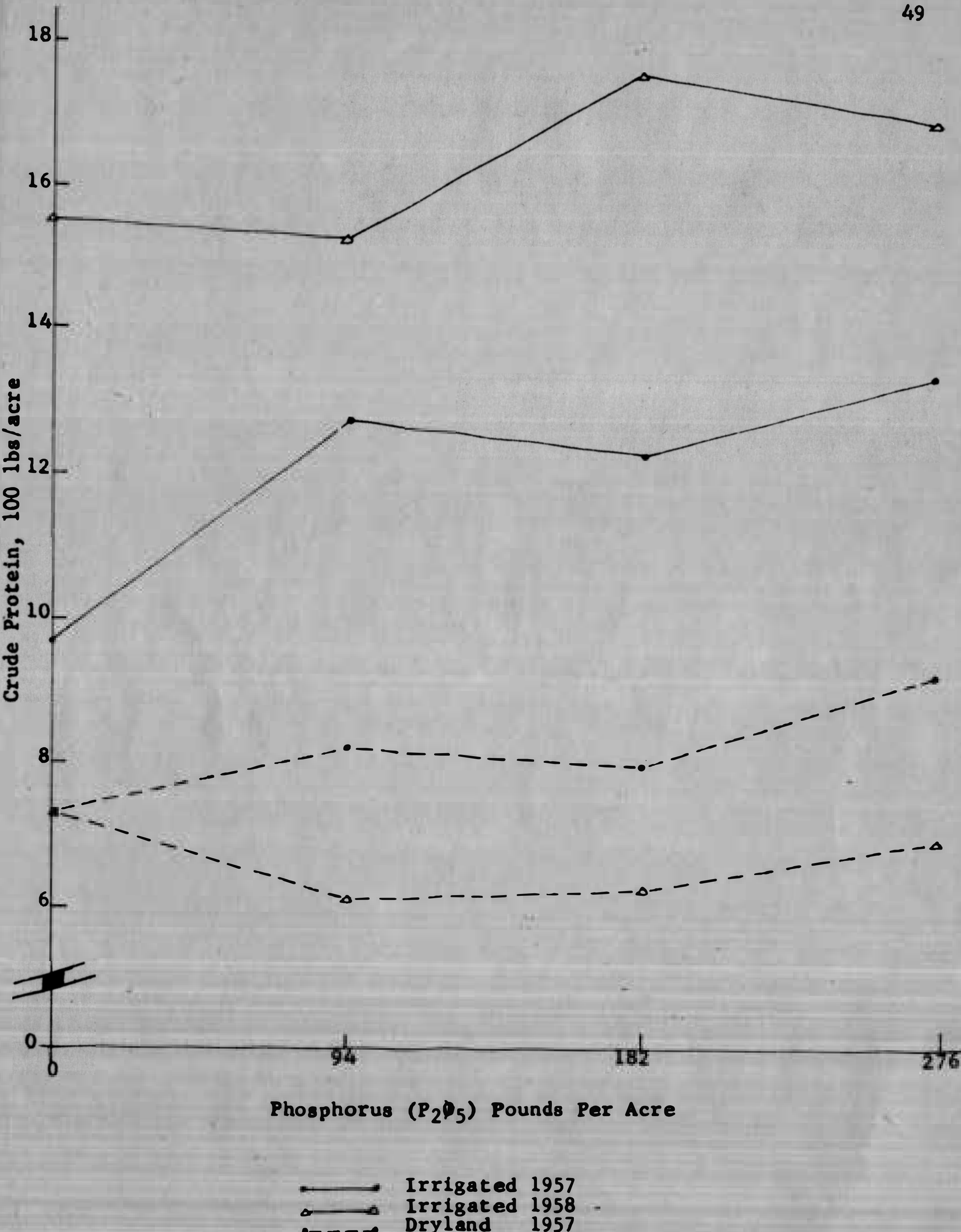


Figure 15. Average Crude Protein Yield from Three Replicates on Dryland (Two Cuttings) and Irrigated (Three Cuttings)

SUMMARY AND CONCLUSIONS

The alfalfa hay quality study was conducted on the Agricultural Engineering Irrigation Research Farm located eight miles southwest of Brookings, South Dakota. Two moisture levels (irrigated and dryland) with four rates of phosphorus fertilizer were the treatments used in the study. The rates of available phosphorus used were 0, 92, 184, and 276 pounds per acre. The data obtained were evaluated in terms of alfalfa hay yield, percent protein of the hay, and crude protein produced.

The study was conducted on soil which was initially rather high in fertility. The study was conducted for two years, plots having been moved to a new location during the second year's study. The first year's study was made where alfalfa plant population was low, while the second year's study was made on an alfalfa field which was established for irrigation thus having a relatively heavy stand.

The following conclusions are offered:

1. Irrigated alfalfa hay yields in 1957 were not significantly different from the dryland hay yields even though below normal rainfall was received. The non-significance between the irrigated and dryland yields may be attributed to the low plant population. Thus, thin alfalfa stands should best be replanted before irrigation can be expected to bring about significant yield differences from that of dryland yields. Having a relatively high plant population in the second year of study, one would conclude that irrigated alfalfa hay yields were larger than dryland yields which were significant to the one percent level.

2. No large responses were experienced for the two year study on alfalfa yields due to the phosphorus fertilizer treatments. This may have been due to the relatively high fertility of the soil even before the phosphorus treatments were applied.

3. The percent protein content in irrigated hay was found to be higher than in dryland hay for both years of study. The average percent protein content (dry weight basis) of irrigated hay in 1957 and 1958 was found to be 20.05 and 20.05 while for dryland hay the percent protein content was 18.95 and 19.16 respectively. The difference between the protein percentage of irrigated hay and dryland hay was significant to the one percent level in 1957 and five percent level in 1958.

4. The two year study indicated no significant difference of percent protein content of the hay due to the various phosphorus treatments under either irrigated or dryland conditions.

5. The increase of crude protein produced by irrigation over dryland was significant to the one percent level for the two years study. In 1958, irrigation produced 5.0 ton of alfalfa hay per acre containing 1747.6 pounds of crude protein using 184 pound rate of phosphorus per acre. The highest average production of crude protein for dryland was in 1957. Two hundred and seventy-six pounds of phosphorus were used which resulted in the production of 2.7 tons of hay per acre. This hay contained 914.2 pounds of crude protein.

6. The two year study also indicated a significant difference to the one percent level for the amount of crude protein produced due to the phosphorus treatments. For irrigation, the two year average crude protein production indicates the largest response to phosphorus at the 92 pound rate. The two year dryland averages of crude protein indicate the largest response to phosphorus at the 276 pound rate.

This study has been limited to one crop. The results obtained and conclusions offered are representative of the alfalfa crop in one locale.

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APPENDIX

FACTORAL ANALYSIS

Source	Degrees of Freedom
Years	1
Moisture Levels	1
Replicates (in each year)	4
Moisture Levels X Year	1
Error (a)	4
Fertility Levels	3
Fertility Levels X Years	3
Fertility Levels X Moisture Levels	3
Fertility Levels X Moisture Levels X Years	3
Error (b)	24

The interactions and degrees of freedom of the above factorial analysis may be explained as follows: The study was conducted for two years which results in one degree of freedom (2-1) for years. There were also two moisture levels, irrigated and dryland, which leaves one degree of freedom (2-1) for moisture levels. Since locations were changed for the second year's study, replicate degrees of freedom must be considered for each year and are pooled for the two years. There were three replicates each year leaving two degrees of freedom (3-1) for replicates. There being two degrees of freedom for replicates for each year gives a total of four degrees of freedom (2+2) for the two years. Since locations were changed for the second year's study, the interaction

of replicates times years is eliminated. The only interaction of the whole plots is moisture levels times years which has one degree of freedom (1x1). Another interaction of moisture levels times replicates is error (a) having four degrees of freedom (4x1).

Interactions and degrees of freedom within the whole plots are as follows: The whole plots were split into four fertilizer treatments which leaves three degrees of freedom (4-1) for fertility levels. The interaction of fertility levels times years gives three degrees of freedom (3x1) and fertility levels times moisture levels also has three degrees of freedom (3x1). The triples interaction within whole plots is fertility levels times moisture levels times years having three degrees of freedom (3x1x1). Error (b) used for testing significance within whole plots has two pooled interactions. The interactions are fertility levels times replicates having 12 degrees of freedom (4x3) and fertility levels times moisture level times replicates also having 12 degrees of freedom. Pooling the two interactions leaves error (b) with 24 degrees of freedom.