PHOSPHORUS UPTAKE BY ALFALFA AS AFFECTED BY DEPTH OF FERTILIZER PLACEMENT AND SUPPLEMENTAL IRRIGATION

Thesis for the Degree of M. S.

MICHIGAN STATE COLLEGE

Herbert R. Metzger

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thesis entitled

Phosphorus Uptake by Alfalfa as Affected
by Fertilizer Placement and Supplemental Irrigation

presented by

Herbert R. Metzger

has been accepted towards fulfillment
of the requirements for

Master's degree in Science

R L Cook

Major professor

Date May 19, 1955

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By

Herbert R. Metzger

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Soil Science

Year 1955

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ABSTRACT

Phosphorus uptake by established alfalfa as affected by depth of fertilizer placement and supplemental irrigation was studied. Fertilizer was placed at various depths that ranged from surface applications to depths of twenty four inches. The rates of irrigation were; none, low irrigation and high irrigation. These tests were conducted on Hillsdale sandy loam and Brookston clay loam.

During the months of July and August the moisture level in the surface six inches of soil dropped to two to four percent available moisture. The percent of fertilizer derived phosphorus in the alfalfa was generally higher for the broadcast and one inch placements on the irrigated plots than from the non-irrigated plots. In addition higher moisture levels increased the uptake of labelled phosphorus placed at the lower soil depths.

Feeder roots of alfalfa within the three inch depth of soil on an established alfalfa sod were very active in absorbing fertilizer phosphorus. The activity or number of these feeder roots apparently decreased with an increase in depth as a reduction in the percent of phosphorus in the hay was noted as the depth of fertilizer placement increased. The data presented implies that alfalfa does not derive as large a share of its nutrients from the sub-soil as has been suggested by some earlier workers. The idea of a surface pattern of active feeding roots on established alfalfa plants is supported by this work.

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INTRODUCTION

Considerable experimental evidence has been obtained in many of the states in the past twenty years indicating surface applications of phosphorus and potassium are very effective in establishing and maintaining stands of legumes and grasses. Notably, alfalfa and clovers are able to make effective use of phosphorus applied in bands at planting time and as topdressings of the established legume.

Since it is known that phosphorus undergoes very limited downward movement in all soils except extremely sandy types, it is logical that absorption of fertilizer phosphate by legumes and grasses occurs largely in the upper layers of soil. Gross morphological studies of alfalfa plants have shown that many small lateral roots are present within the surface six to eight inches. In recent experiments with radioactive phosphate fertilizers, it has been shown that legume and grass roots close to the soil surface are able to absorb relatively large amounts of fertilizer phosphorus.

Little information is available concerning the influence of soil moisture on the absorption of fertilizer phosphorus by plants. Since moisture affects root extension and uptake of nutrients as well as movement of phosphorus by diffusion, it is important that such a relationship be better understood. It is the purpose of this paper to study the effect of depth of fertilizer placement and soil moisture levels on the yield and absorption of fertilizer phosphorus by established alfalfa.

REVIEW OF LITERATURE

Morphology of Alfalfa Roots

The alfalfa plant has both a tap and lateral roots. Although the tap root is the most evident and makes up the largest part of the dry root weight, the smaller lateral roots near the surface are believed to be very important in the absorption of nutrients.

Upchurch and Lovvorn (16) noted that approximately fifty percent of all the lateral roots of alfalfa plants grown on two North Carolina soils were found to occur within the top three inches of soil. Futhermore, these workers found that the maximum depth of tap root penetration was evident by the end of the first year. These roots penetrated to a depth of 24 to 48 inches in a Cecil clay soil and from 48 to 72 inches in a Norfolk sandy soil.

Phosphorus Movement and Availability As Related to Soil Moisture

Numerous studies have shown that because of chemical reactions resulting in fixation of soluble phosphorus, the movement of phosphate ions from source concentrations is greatly retarded. The results of topdressed superphosphate experiments by Stanford and McAuliffe (14) indicated that with few exceptions ninety percent or more of the applied phosphorus remained within an inch of the point of application even after long periods of contact. They concluded that high rainfall should make for somewhat greater downward penetration of the phosphorus dissolve

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dissolved in the soil solution. These workers were not able to fully explain the high utilization of broadcast phosphate by alfalfa and clover grown under semi-drought conditions.

Using granular superphosphate, Lawton and Vomocil (8) were able to show that phosphorus migration away from the granules was very limited. One of the factors having the greatest effect on this movement was soil moisture.

McAuliffe, Bradfield and Stanford (9) found that by mixing radio active superphosphate in the 1 to 3 inch layer of Ontario loam and Wooster, Erie and Canfield silt loams, about twenty to thirty percent of the applied phosphate moved out of the zone of incorporation within three months. However, only a small proportion of this phosphorus penetrated more than two inches below the zone of application. Some upward movement of phosphate was also noted. For some soils it has been found by McAuliffe et al. (9) that the phosphorus concentration in the soil solution is nearly independent of the quantity of water present due to the comparatively low solubility of phosphorus compounds.

Metzger (10) in 1940 found that a large proportion of the easily soluble phosphorus, which accumulated in the soil following the top-dressing of various phosphates on alfalfa for twenty-seven years, remained in the surface four inches of soil.

Experiments by Jordan et.al. (6) showed that the amount of water influences the downward movement of fertilizer phosphorus in the soil. The more supplemental water applied, the greater was the movement of tagged phosphate ions. However, these workers found that potatoes absorbed more fertilizer ans soil phosphorus at low moisture tensions than when soil moisture contents were high.

Satchell (12) studied the movement of phosphates in soil systems. His work showed that phosphate movement was predominately upward from the fertilizer band in the Norfolk soil in a dry season. In a Bladen soil the phosphate movement was predominately downward with some lateral movement during a wet season. Phosphate movement was increased when the rate of application was increased.

Analysis of samples taken from the Bladen soil fifty-one days after placement indicated considerably more movement of phosphates than did samples taken thirty days after placement. There was also greater movement of phosphate in a soil with a low phosphorus content than in soils high in available phosphorus. Satchell's work indicated that the phosphorus from superphosphate exhibited the greatest movement when compared with di-calcium phosphate, calcium metaphosphate, and fused rock phosphate. However, the mobility in soils varied and in some soils the movement was negligible.

Absorption of Surface Applied Phosphate by Alfalfa and Clovers

With the use of P^{32} labeled fertilizers, it has recently been possible to determine the relative amounts of soil and fertilizer phosphorus taken up by plants from different fertilizer sources and placements.

Stanford and Nelson (15) found that from twenty to fifty percent of the phosphorus in alfalfa, ladino clover, and orchard grass was derived from topdressed phosphate. They concluded that this high utilization of fertilizer phosphorus was due to a large number of active roots near the surface. More than one half of the total root growth of these forage plants was found in the surface eight inches of soil. The utilization of applied phosphorus was much the same for the three crops despite marked differences in the general characteristics of their root systems.

Similar experiments by Blasser and McAuliffe (1) with radioactive fertilizer have proven that Ladino clover and orchard grass have very active feeding roots in the surface six inches of soil.

Lawton, Tesar, and Kawin (7) also obtained relatively high absorption of fertilizer phosphorus by alfalfa and alfalfa-bromegrass crops from topdressed superphosphate. Depth placement with P^{32} studies by these workers have shown that the absorption of applied phosphate falls off rapidly with depth. With placements below six inches for bromegrass and below twelve inches for alfalfa, little fertilizer phosphorus was taken up by these plants.

EXPERIMENTAL MATERIALS AND METHODS

Description of Experimental Areas

Experiment I

This experiment was located in the SW 1/4 of SW 1/4 of Section 25, Lansing township, Ingham County, Michigan. The soil was Hillsdale sandy loam, which is a well drained glacial till soil. The area chosen had third year alfalfa. This field was seeded with oats in 1951. The alfalfa stand in the field was good containing 95 percent alfalfa and 5 percent weeds and grasses. Soil samples were collected at various depths prior to laying out the experiment. Values for soil reaction, phosphorus and potassium extractable in 0.13 N HCl according to Spurway and Lawton (13) and exchangeable calcium by the method of Cheng and Bray (2) of these samples are reported in Table I. Rainfall records for this area which were obtained from a weather station about a mile distant are presented in Table 2.

Experiment II

This experimental area was located in the NW 1/4 of Section 33, Saginaw County, Michigan. The soil was a Brookston clay loam, a naturally poorly drained soil, which was well tiled. The field had first year alfalfa which had been seeded with oats in 1953. There was a good stand of alfalfa with ninety percent alfalfa and ten percent weeds and grasses. Before fertilizers were applied, soil samples were collected at different depths up to 18 inches for analysis of soil reaction, available phosphorus and potassium, and exchangeable calcium. These results are presented in Table I. Rainfall figures for this experiment were obtained from daily records obtained at the farm area, and are listed in Table 2.

Experiment III

This plot area was also third year alfalfa on Hillsdale sandy loam closely adjacent to that of Experiment I and located in the same field. Soil samples were taken in June for the specific chemical analysis as reported in Table I. The source of rainfall records was the same as for Experiment I.

Plan of Experiment

Experiment I

Plots nine square feet in area were placed in a randomized block design with two replicates of each fertilizer and irrigation treatment, note Figure 12. Concentrated superphosphate (0-48-0) tagged with P^{32} and having a specific activity of 0.3 millicures per gram of P_2O_5, was broadcast and placed at depths of 1, 3, 6, 12 and 24 inches in a grid pattern. The holes were drilled for the fertilizer placement in a 6 inch by 6 inch pattern over the 3 by 3 foot plots by using a 5/8 inch soil auger. To prevent contamination along the sides of the holes, the dry fertilizer was placed at the bottom of the auger holes by using a glass tube and a funnel. These holes were then refilled with dry soil.

TABLE 1. PARTIAL CHEMICAL ANALYSIS OF SOILS IN DEPTH OF FERTILIZER PLACEMENT EXPERIMENTS

Sampling Depth Inches	pH	Pounds Per Acre P*	K*	Ca**
		Experiment I		
0-2	6.4	13	41	2440
2-4	6.1	4	16	2440
5-7	6.2	3	13	2392
11-13	6.6	5	13	2576
22-24	7.4	90	13	3056
		Experiment II		
0-2	5.9	25	50	5000
2-4	6.2	26	52	6000
5-7	6.5	11	21	4592
11-13	6.8	25	18	3624
16-18	6.9	150	16	3360
		Experiment III		
0-2	6.1	31	42	3968
2-4	6.2	6	16	3104
5-7	6.4	3	20	3424
11-13	6.6	5	17	3832
22-24	7.7	60	11	3088

* Extracted with 0.13N HCl solution

** Extracted with 23% $NaNO_3$ solution

TABLE 2. RAINFALL AND IRRIGATION DATA FOR ALL EXPERIMENTAL AREAS FOR THE PERIOD ONE WEEK PRIOR TO FERTILIZER APPLICATION UNTIL FINAL HAY HARVEST

Experiment I			Experiment II		Experiment III			
	Inches of Water					Inches of Water		
Date	Rain	Irrigation	Date	Rain	Date	Rain	Irrigation Low	Irrigation High
4/16	.02		4/27	1.26	6/19	1.10		
*4/19	.08		5/1	.24	6/20	.61		
4/20	.34		5/3	.09	***6/21	.15		
4/24	.23		**5/5	.03	6/24	.57		
4/26	.15		5/8	.02	6/28	.20		
4/27	.20		5/9	.08	7/3	.59		.58
5/2	.16		5/11	.03	7/5	.42		
5/8	.33		5/31	.48	7/8	.22		
5/9	.08		6/1	.80	7/14	.03	.39	.58
5/19	.08	.77	6/3	.96	7/19	.20	.19	.39
5/23	.16		6/10	.06	7/22	.22	.39	.58
5/24		.77	6/16	.34	7/26	.34	.39	.77
5/27	.07		6/19	1.67	7/28	.14	.39	.96
5/28	.11	.77	6/20	.30	7/30	.10		.19
5/31	.98		6/22	1.01				
6/1	.43							
6/12	1.13							
6/15	.04							
Total	4.59	2.31		5.78		3.18	1.75	3.86

* Fertilizer applied April 17
** Fertilizer applied May 5
*** Fertilizer applied June 21

The superphosphate was placed in the ground on April 17th. To insure that a potassium deficiency would not affect the results muriate of potash was applied with the superphosphate at the rate of 131 pounds per acre of K_2O. The triple superphosphate was applied at the rate of 171 pounds of P_2O_5 per acre.

A gypsum moisture block was buried at the same depth as the fertilizer, but six inches adjacent to each plot. Measurements of percent available moisture were made using a Bouyoucos moisture meter usually twice weekly or 12 hours after precipitation occured. Supplemental water was applied to the irrigated plots over a 5 by 5 foot area in an attempt to maintain a continuous level of about sixty percent available soil moisture.

Three samples of alfalfa plants were taken on May 29th, June 7th, and June 15th respectively. For each sample three square feet was cut. The plant material was weighed, dried, ground and 2 gram pellets were pressed at 14,000 pounds per square inch for radioactive assay. Phosphorus analysis was made of the pelleted plant material.

Experiment II

Three feet square (square yard) plots were placed in a randomized block design, using two replicates of each fertilizer depth placement. The P^{32} labeled concentrated superphosphate (0-48-0) and muriate of potash were applied on May 5th, as described in Experiment I, except that the depths of placement were changed to those of 1, 3, 6, 12 and 18 inches. At the start of the experiment gypsum moisture blocks were placed at each of the above depths. No supplemental irrigation was made on these plots. Moisture readings for available soil water were taken about once a week.

Plant samples were cut from three square foot areas of each plot on May 28th, June 7th, and on June 26th; in addition the first area was recut on July 16th. Dry plant weights were recorded and samples prepared for specific activity and total phosphorus analysis as in Experiment I.

Experiment III

The experimental design used in this experiment was a radomized block utilizing two replications of each fertilizer and soil moisture level, note Figures 13 to 22. Triple superphosphate (0-48-0) tagged with P^{32} and muriate of potash was applied broadcast and at depths of 1, 3, 6, 12, and 24 inch depths on June 21st. The labeled fertilizer had a specific activity of about 0.3 millicurie per gram of P_2O_5 when the material was applied. The rates of application were equivalent to those described in Experiment I. One set of plots was not irrigated, while supplemental water was added to another set in moderate amounts in an attempt to keep the available moisture level at approximately forty to sixty percent. In the third group of plots in the experiment using the normal precipitation plus a high level of supplemental water an attempt was made to keep the moisture content of the soil at approximately sixty to eighty percent.

Plant samples were cut on July 9th, July 20th, and August 1st and dry weights recorded. The plant material was prepared for radio-

active and total analyses as in Experiment I and II.

Two standards were made from the labeled fertilizer received during the first of the season and two standards were made from the labeled fertilizer received during the middle of the summer.

The same pellets used for radioactive assay were used in the total phosphorus analysis. The plant material was wet ashed using nitric, sulfuric and perchloric acids as described by Piper (11). The residue remaining after ashing was taken up in 0.2 N. hydrochloric acid and made to volume. Phosphorus in these plant ash solutions was determined as molybdenum blue using a Coleman Spectrophotometer with transmission values of unknown and standard solutions compared at 650 millimicrons.

Methods for Soil and Plant Analysis

All soil samples used for chemical analyses were air dried and screened through a two mm. sieve. Soil reaction determinations were made on a 1:1 soil to water suspensions by weight, using a Beckman H-2 pH meter. Available soil phosphorus and potassium were extracted and determined according to the reserve procedure by Spurway and Lawton (13) A Coleman spectrophotometer was used to make comparative transmission measurements between standards and unknowns for both elements. Exchangeable calcium was determined according to the procedure of Cheng and Bray (2) in which exchangeable calcium is extracted with a twenty three percent sodium nitrate solution. An aliquot of this extract is titrated with 0.4 percent versenate solution(disodium-dihydrogen ethylenediamine tetraacetic acid) using a murexide indicator.

Plant material was prepared for specific activity measurements by pressing two grams of dry, ground tissue into a one inch diameter pellet under 14,000 pounds per square inch for one minute. Using a Geiger-Muller tube in conjunction with a Decade Scaler, the activity of the pellet was determined and compared with a standard pellet containing a known amount of radioactive superphosphate. A uniform distribution of P^{32} in the standard pellet was obtained by dissolving a given quantity of the labeled fertilizer in dilute hydrochloric acid solution and thoroughly moistening a given weight of dry plant material. After drying at 60° centigrade, two grams of this standard material was pressed into a pellet.

RESULTS AND DISCUSSION

Experiment I

From Table 3 it is apparent that irrigation did not influence the percent of phosphorus in the alfalfa cuttings. However, the phosphorus content of the cuttings declined with the lower depths of fertilizer placement. The phosphorus content of the alfalfa was highest for the first sampling and successively lower for the second and third samplings. It is probable that the early spring growth of established alfalfa plants is higher in phosphorus largely because of a dilution of this element with a rapid increase in dry weight production toward the harvest period.

The relationship between the depth of the fertilizer placement and the percent of phosphorus derived from the fertilizer is given in Table 4. The percent of plant phosphorus derived from the fertilizer declined with the deeper placement of the labeled superphosphate. There was as shown in Table 4, a slight difference between the irrigated and the non-irrigated plots for the May 29 and the June 7 cuttings. The reason the irrigated plots did not show a higher absorption of fertilizer phosphorus when compared with the non-irrigated plots was no doubt due to the high rainfall so that the soil moisture level was similar in both plots. The June 15 cutting showed an appreciable difference in the absorption of phosphorus from the labeled superphosphate. The amount absorbed from all but the three inch depth was increased by irrigation. The moisture might have stimulated more feeder root development.

TABLE 3. THE EFFECT OF FERTILIZER PLACEMENT AND IRRIGATION ON THE PHOSPHORUS CONTENT OF ALFALFA FROM A HILLSDALE SANDY LOAM. (Experiment I)

Depth of fertilizer placement in inches	Percent phosphorus in alfalfa cuttings at sampling dates May 29*	June 7	June 15
	No Irrigation		
Surface***	0.46**	0.34	0.36
1	0.43	0.31	0.30
3	0.44	0.32	0.30
6	0.46	0.33	0.29
12	0.42	0.31	0.28
24	0.44	0.31	0.26
Check	----	0.30	0.33
	Irrigated		
Surface***	0.46	0.33	0.33
1	0.45	0.32	0.30
3	0.46	0.32	0.30
6	0.38	0.31	0.30
12	0.42	0.30	0.24
24	0.42	0.29	0.26
Check	----	0.33	0.25

* Plots put in April 17th and 18th

** All values are averages of two replicates.

*** Broadcast application

TABLE 4. THE EFFECT OF FERTILIZER PLACEMENT AND IRRIGATION ON THE ABSORPTION OF FERTILIZER PHOSPHORUS BY AN ESTABLISHED ALFALFA STAND ON A HILLSDALE SANDY LOAM. (Experiment I)

Depth of fertilizer placement in inches	Percent plant phosphorus derived from fertilizer at sampling dates May 29*	June 7	June 15
	No Irrigation		
Surface***	17.9**	32.2	14.7
1	17.2	20.5	14.1
3	10.6	31.0	19.5
6	7.2	15.3	12.7
12	2.5	6.5	5.4
24	1.9	5.3	2.1
	Irrigated		
Surface***	25.1	36.7	54.6
1	14.7	27.9	23.8
3	8.7	27.4	17.5
6	7.4	24.2	18.8
12	2.3	8.1	10.9
24	0.7	3.7	4.8

* Plots put in April 17th and 18th

** All values are averages of two replicates.

*** Broadcast application; other placements localized

[illegible]

In 1953 Lawton et al. (7) worked with the uptake of fertilizer phosphorus placed at different depths. Their plots were not irrigated. The uptake of fertilizer phosphorus from the non-irrigated plots was similar to that reported by Lawton and Tesar. However, in the present study the percent of plant phosphorus derived from the surface applied fertilizer was lower, possibly indicating less contamination of P^{32} on the plant surfaces.

With one exception the percent of fertilizer derived phosphorus in alfalfa from plots having surface applied or one inch placements was higher where supplemental water was applied. It can also be noted from Table 4 that absorption of fertilizer phosphorus was greater in plants from the irrigated areas on June 7 and June 15 from plots where fertilizer was placed at the 6 and 12 inch depths. No explanation can be given for the reversal of this trend for the 3 inch depth placement.

Examination of the available soil moisture data in Figures 1, 2 and 3 show that the surface six inches of the non-irrigated areas contains less than twenty percent available water from May 24 to May 30. The very dry period represented here may account for a higher content of plant phosphorus derived from fertilizer in alfalfa from some of the irrigated plots. It should be noted, however, that plant material from non-irrigated plots receiving fertilizer at the 1, 3, 12 and 24 inch depths was slightly higher in fertilizer phosphorus than alfalfa from corresponding irrigated plots at the May 29 sampling. A similar instance was noted for alfalfa cut from 3 inch depth fertilizer placement plots on June 7.

It is evident from the data in Table 1 that there are some important differences in pH and "available" phosphorus and potassium than

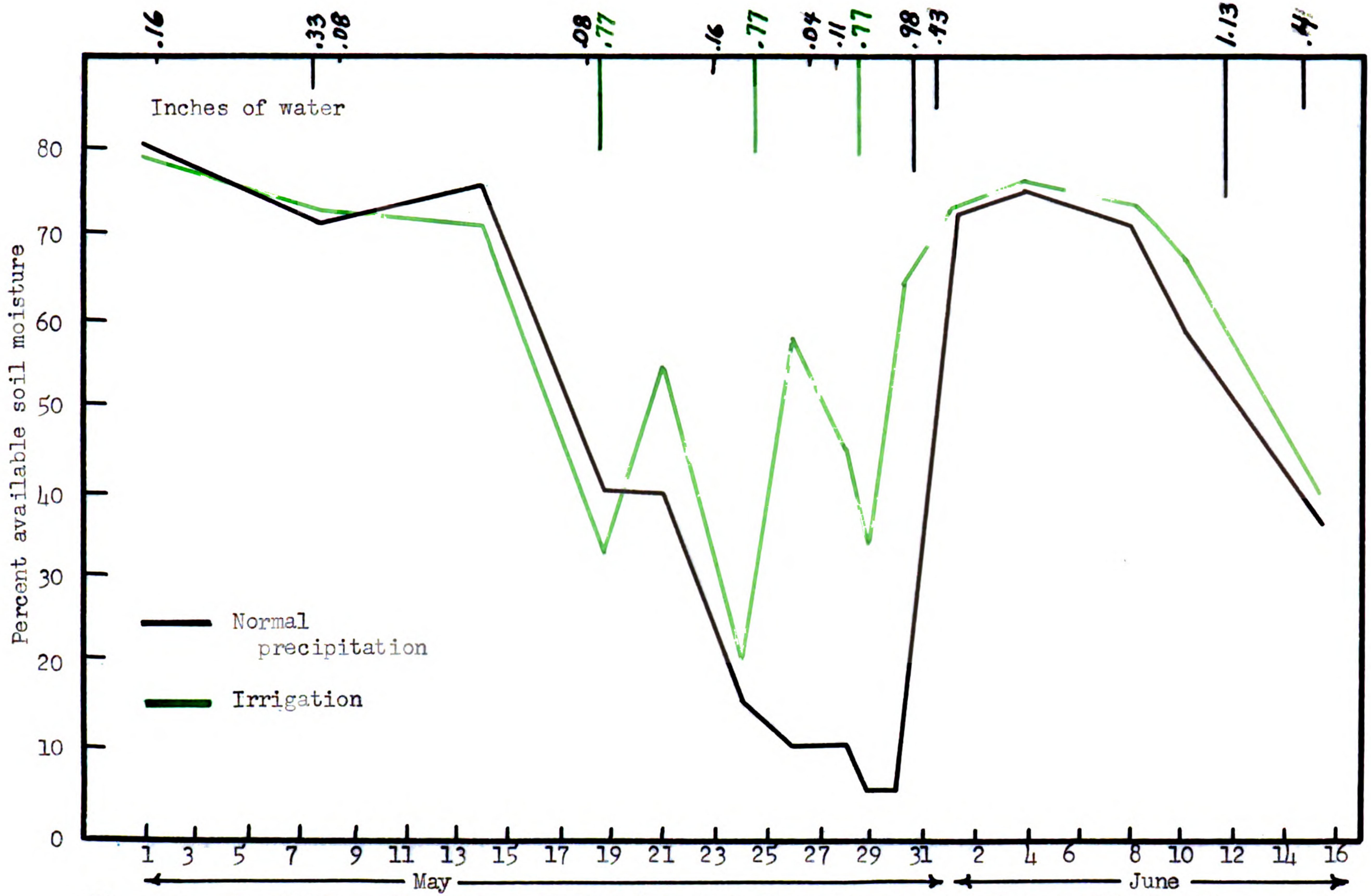


Figure 1. Available soil moisture at the 1 inch depth under an established alfalfa sod as affected by normal precipitation and irrigation. (Experiment I)

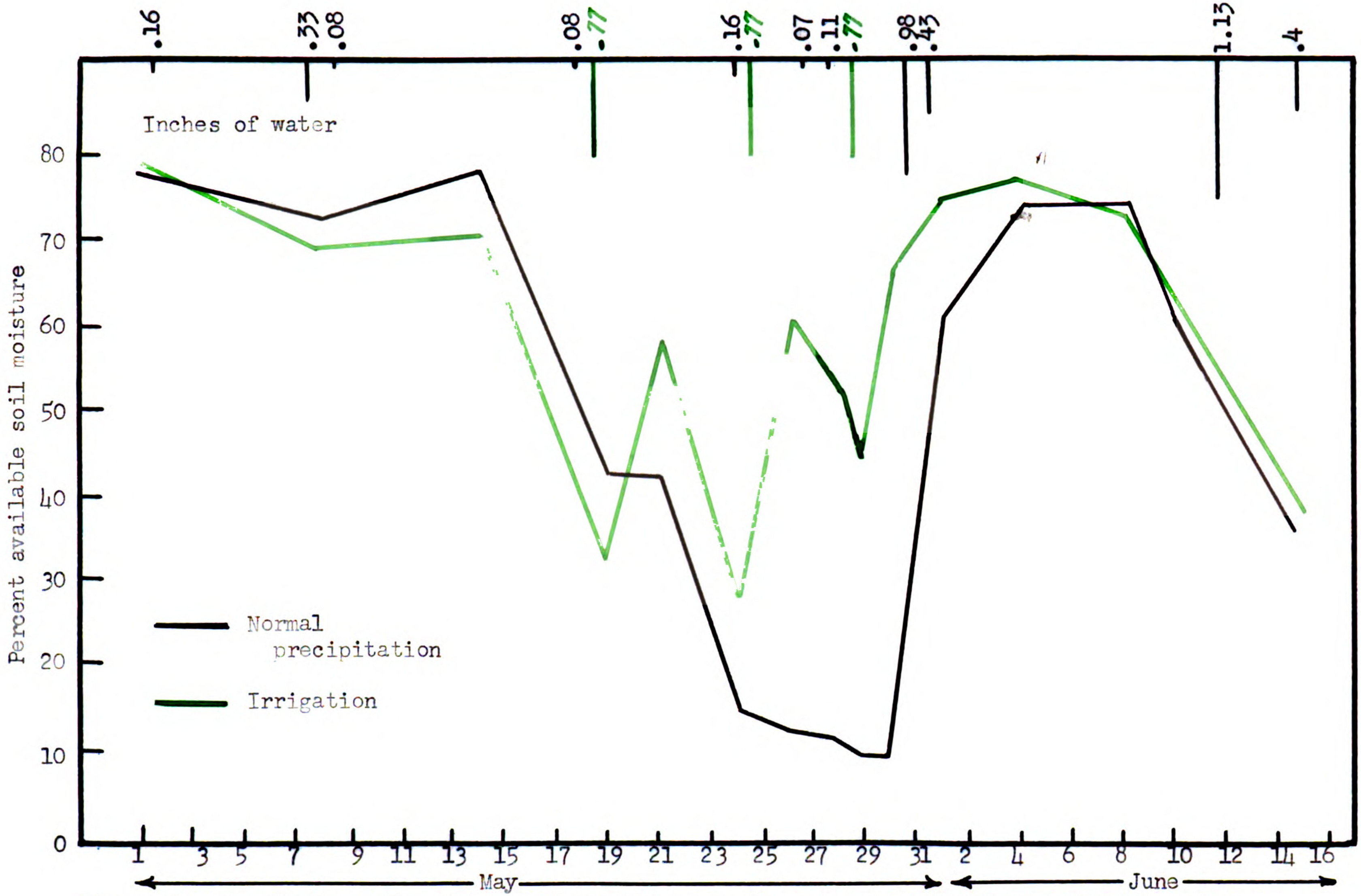


Figure 2. Available soil moisture at the 3 inch depth under an established alfalfa sod as affected by normal precipitation and irrigation. (Experiment I)

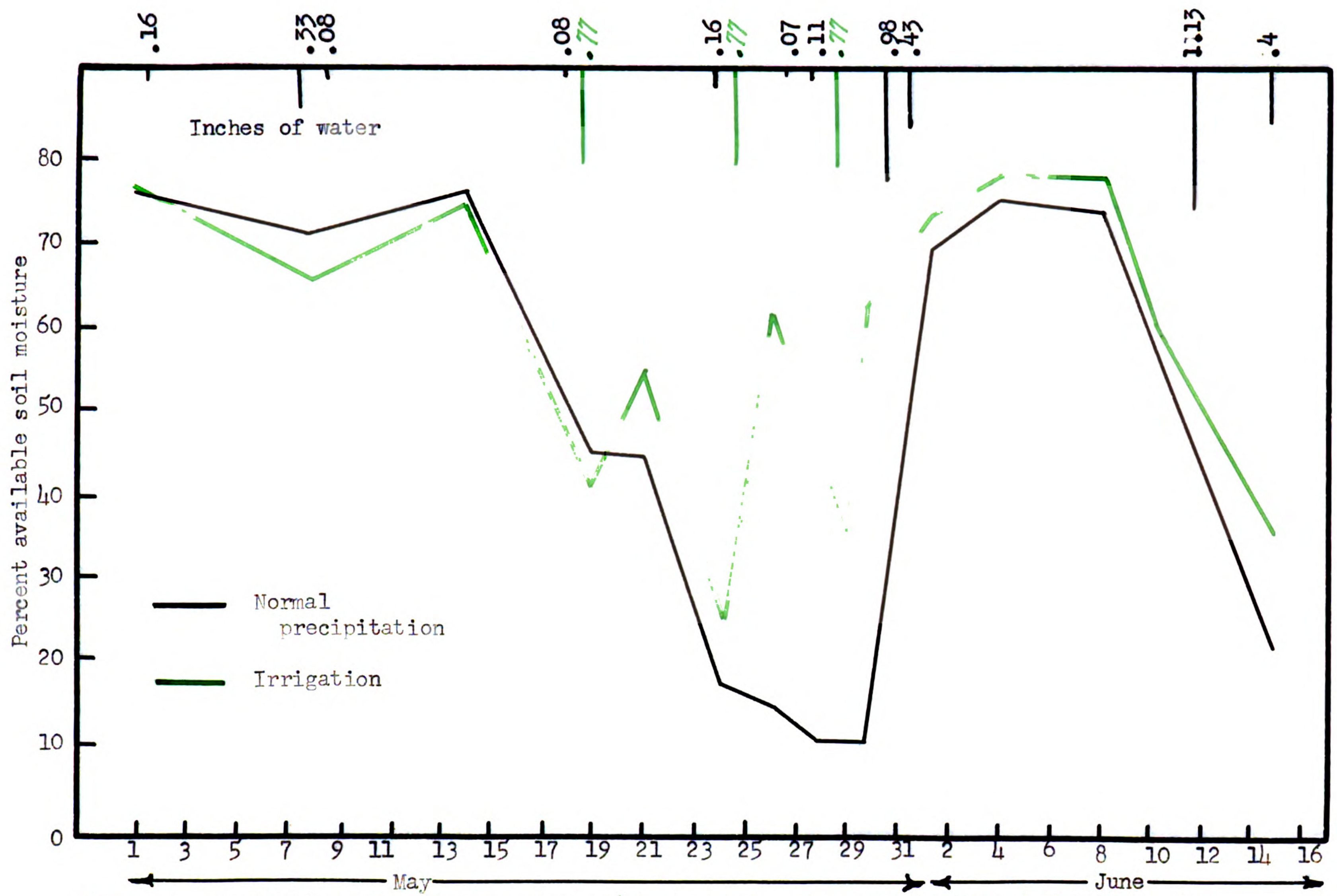


Figure 3. Available soil moisture at the 6 inch depth under an established alfalfa sod as affected by normal precipitation and irrigation. (Experiment I)

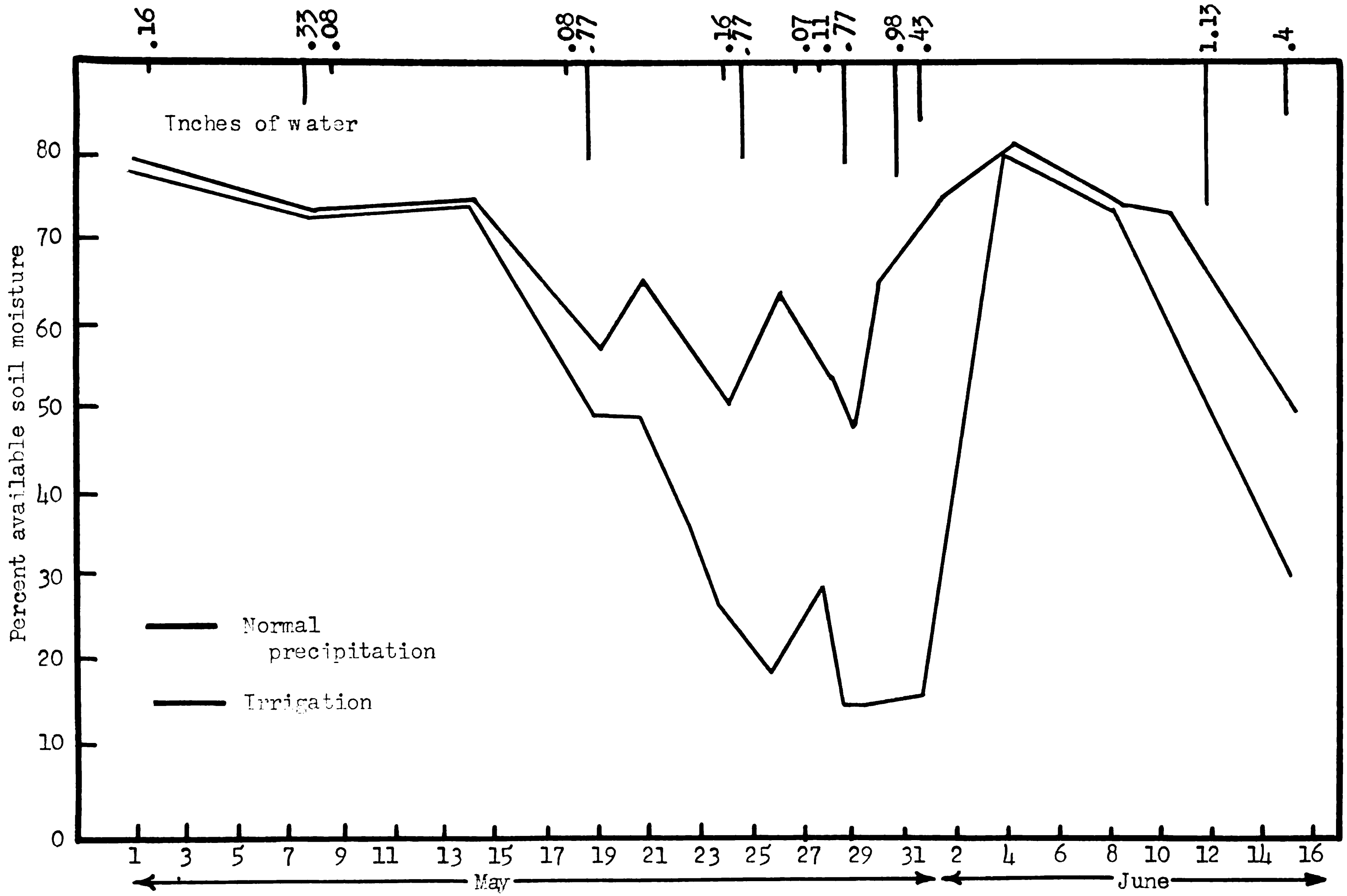


Figure 4. Available soil moisture at the 12 inch depth under an established alfalfa sod as affected by normal precipitation and irrigation. (Experiment I)

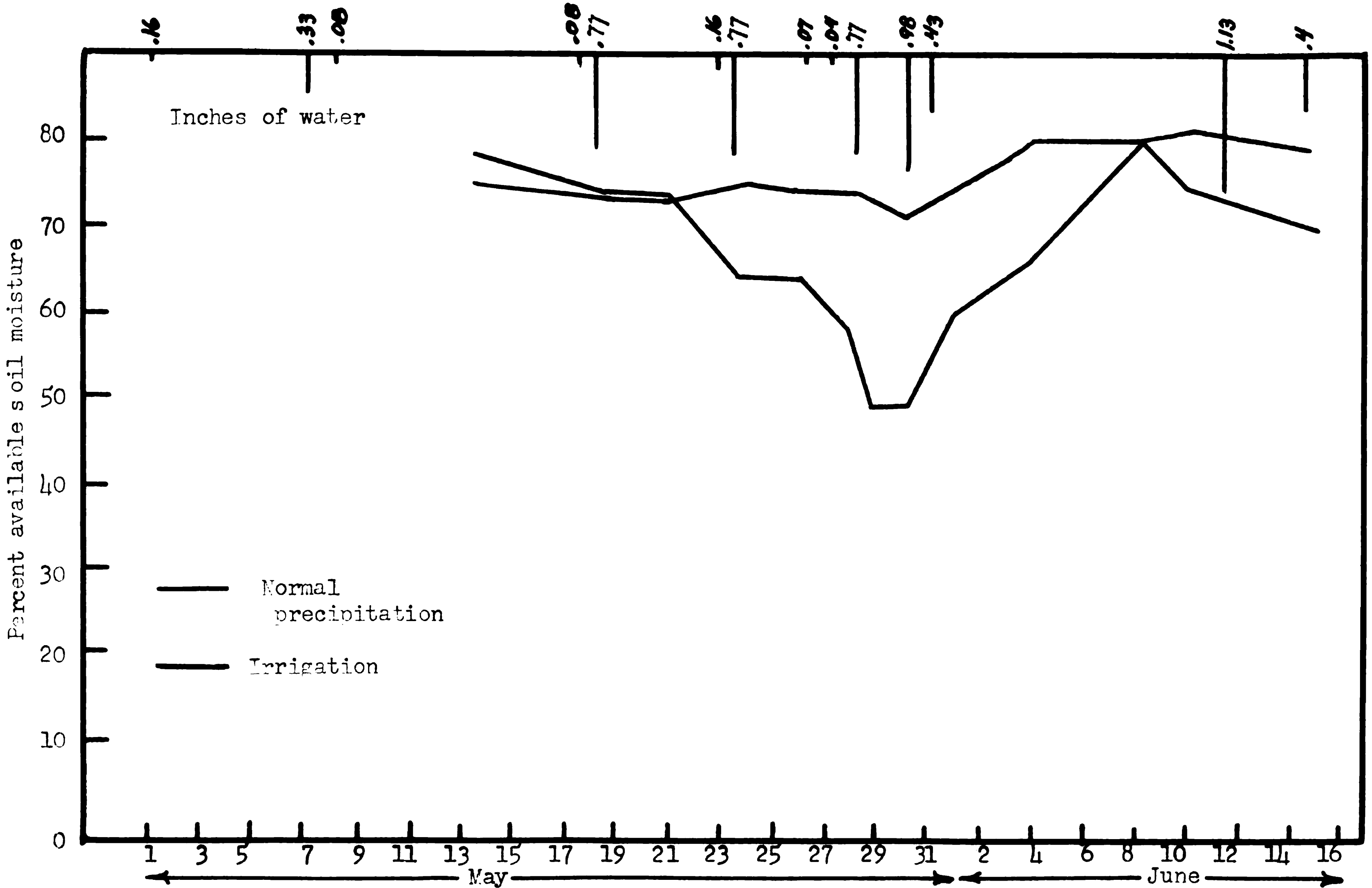


Figure 5. Available soil moisture at the 24 inch depth under an established alfalfa sod as affected by normal precipitation and irrigation. (Experiment I)

samples taken up to twelve inches. In two of these experiments the lowest soil pH was found within the 0--2 inch soil depth. Samples taken about twenty-four inches deept for Experiment I and III were considerably higher in pH and acid extractable phosphorus. How much effect this high phosphate level in an alkaline medium has in reducing fertilizer phosphorus absorption from this depth is not known. However, soil test correlation studies by Lawton et al (8) on some of the alkaline soils of Michigan show that phosphorus extracted with a strong acid does not correlate too well with response of alfalfa to phosphate fertilizer.

At final harvest on June 15 the dry weight of alfalfa listed in Table 5 did not vary appreciably between the irrigated and non-irrigated areas when plots of similar depth were compared. It should be emphasized that significant differences for yield figures based on three square feet are likely to be quite high.

Experiment II

In Table 6 data for the phosphorus content of alfalfa are given for three samplings of first growth and one sampling of second growth hay on a Brookston clay loam soil. Again as in Experiment I, these values decreased with depth of fertilizer placement, especially at the June 7 and the June 26 samplings.

The absorption of fertilizer phosphorus by alfalfa as affected by depth of fertilizer placement is listed in Table 7. The highest absorption of fertilizer phosphorus was from the labeled phosphate placed on the surface and at depths of one and three inches. It is

TABLE 5. THE EFFECT OF FERTILIZER PLACEMENT AND IRRIGATION ON THE DRY WEIGHT YIELD OF ALFALFA GROWN ON HILLSDALE SANDY LOAM. (Experiment I)

Depth of fertilizer placement in inches	Grams of air dry hay per three square feet at sampling dates		
	May 29	June 7	June 15
	No Irrigation		
Surface**	74.5*	140.1	124.4
1	59.0	121.1	134.4
3	73.0	133.6	131.9
6	68.0	128.1	171.4
12	58.5	125.1	179.4
24	60.5	119.1	139.4
Average***	65.6	127.8	146.8
Check	51.5	119.6	141.4
	Irrigated		
Surface**	70.5	185.1	142.9
1	68.0	141.1	139.9
3	70.5	116.6	157.4
6	59.0	104.6	123.4
12	70.0	136.6	135.4
24	69.5	133.1	109.4
Average***	67.9	119.0	134.7
Check	----	142.6	100.4

* Values are the averages of two replicates.
** Broadcast application; other placements localized
*** Check plots were not included.

TABLE 6. THE EFFECT OF FERTILIZER PLACEMENT ON THE PHOSPHORUS CONTENT OF ALFALFA CUTTINGS FROM A BROOKSTON CLAY LOAM. (Experiment II)

Depth of fertilizer placement in inches	Percent phosphorus in alfalfa cuttings at sampling dates			
	May 28*	June 7	June 26	July 16**
Surface****	0.24***	0.32	0.25	0.31
1	0.24	0.33	0.22	0.27
3	0.23	0.25	0.27	0.35
6	0.20	0.21	0.19	0.24
12	0.23	0.18	0.20	0.27
18	0.22	0.20	0.20	0.25
Check	----	0.16	0.19	----

* Fertilizer put in May 5th

** First area recut

*** All values are averages of two replicates.

**** Broadcast application; others localized

TABLE 7. THE EFFECT OF FERTILIZER PLACEMENT ON THE ABSORPTION OF FERTILIZER PHOSPHORUS BY AN ESTABLISHED ALFALFA STAND ON A BROOKSTON CLAY LOAM. (Experiment II)

Depth of fertilizer placement in inches	Percent plant phosphorus derived from fertilizer at sampling dates*			
	May 28	June 7	June 26	July 16**
Surface****	43.9***	47.6	42.6	14.8
1	28.0	41.2	69.8	18.8
3	17.3	59.6	48.0	15.0
6	4.9	18.2	47.0	11.6
12	3.6	19.5	20.4	14.8
18	4.2	4.3	15.7	4.0

* Fertilizer applied May 5th
** First area recut
*** All values are averages of two replicates.
**** Broadcast application; other placements localized

interesting to note that the feeder roots in the top soil are more active in the spring than those at the lower levels. However, in the June 7 and June 26 cuttings while the feeder roots in the surface three inches remained active the roots in the 6, 12 and 18 inch depths increased their activity. Possibly the latter difference was influenced by the lower moisture levels at the 1 and 3 inch depths during the last of May as indicated in Figure 6. Although no data were collected on the movement of fertilizer phosphorus in the soil, on the basis of work by Fiskel et al (4) and others it is postulated that extensive downward movement of phosphate ions from surface applications was negligible. Fiskel and co-workers concluded that very little of surface applied phosphate penetrated to a depth greater than one inch, and that more than ninety percent of the phosphate that was broadcast remained in the surface one inch of soil.

The reasons for such a high proportion of plant phosphorus derived from surface applied or 1, 3 and 6 inch depth placements of fertilizer in the May 29 cutting are not clear. Precipitation from May 5, the date of the fertilizer application, to May 30 was only 0.18 inches and available soil moisture during the last week in May in the surface six inches was less than twenty-five percent. The moisture levels at the 12 and 18 inch depths of soil were high. During the month of May the moisture blocks at these depths never read lower than fifty-three percent available moisture as indicated on Figure 6.

Evidence accumulated over the years has indicated that downward penetration of phosphorus usually is quite limited. The studies of Stanford et al (14) indicate that ninety percent or more of the

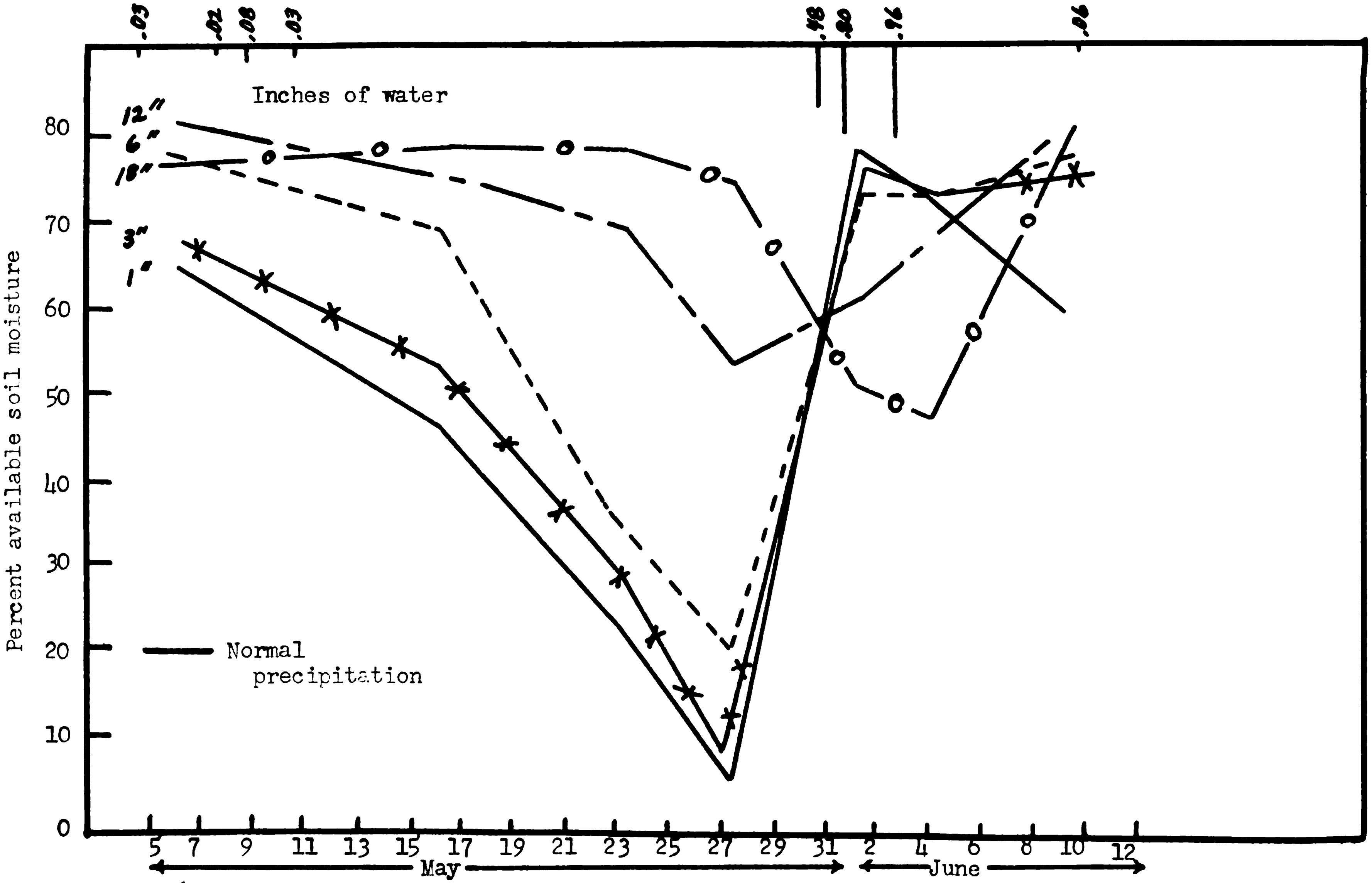


Figure 6. Available soil moisture under an established alfalfa sod as affected by normal precipitation. (Experiment II)

applied phosphorus remained within an inch of the point of application even after long periods of contact. These workers also found that a relatively high proportion of the phosphorus absorbed by alfalfa, ladino clover and orchard grass was derived from surface applications of superphosphate. Utilization of the fertilizer phosphorus was much the same for the three crops despite the fact that alfalfa is a relarively deep rooted plant while ladino clover is shallow rooted. The work of Stanford et al (14) supports the data presented here which indicates the presence of a surface pattern of active feeding roots of established alfalfa plants.

Another condition which may have resulted in a greater absorption of fertilizer phosphorus by roots within the surface foot is that a minimum of fixation of phosphorus probably occurred with the fertilizer placed in soil down to the 12 inch depth. The surface foot of soil was slightly acid in reaction and therefore, the applied phosphorus was somewhat more available to alfalfa than fertilizer phosphorus placed eighteen inches below the surface where the soil was alkaline as indicated in Table 1.

The percent of fertilizer phosphorus in alfalfa from the first area that was recut on July 16 was quite uniform for all the depth placements except that of eighteen inches. It seems quite notable that the second cutting of alfalfa absorbed approximately fifteen percent of its phosphorus from the fertilizer placed at any depth down to twelve inches two months previously. Since no moisture readings were made after June 8 no relationship between soil moisture and phosphorus uptake can be drawn.

In June the rainfall was low and the available soil moisture in the surface six inches declined rapidly (see Figure 6). During this time increased amounts of fertilizer derived phosphorus were being absorbed from the 12 and 18 inch depths as illustrated by Table 7. This might be explained by the decrease in activity of the feeder roots near the surface and an increase in the activity of the feeder roots at the 12 and 18 inch depths due to the more favorable moisture conditions.

From the data in Table 8 it can be concluded that the depth of fertilizer placement had little or no effect on dry weight yields at any of the sampling dates.

Experiment III

The values for the phosphorus content and percent of phosphorus derived from fertilizer for the dry plant material are presented in Tables 9 and 10 respectively. In general, little difference was noted between the phosphorus content of alfalfa where fertilizer was placed at different depths. Also, the use of supplemental water seemed to have little effect on the percent of phosphorus in second growth alfalfa. However, one exception should be noted. Alfalfa from the August 1 cutting on the non-irrigated plots was substantially lower than that grown under high irrigation. A higher phosphorus uptake was also recorded at this time since the dry weight yield for the high irrigation rate was higher than where no supplemental water was applied.

Marked differences in absorption of fertilizer phosphorus were noted with variation in depth of fertilizer placement but not for rates of irrigation. As in Experiments I and II, the highest amount of

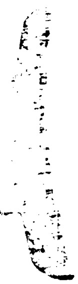


TABLE 8.. THE EFFECT OF FERTILIZER PLACEMENT ON THE DRY WEIGHT YIELD OF ALFALFA GROWN ON BROOKSTON CLAY LOAM. (Experiment III)

Depth of fertilizer placement in inches	Grams of air dry hay per three aquare feet at sampling dates			
	May 28	June 7	June 26	July 16*
Surface	73.4**	87.4	161.1	37.6
1	70.4	112.4	123.6	40.1
3	69.9	103.4	130.6	42.1
6	52.4	98.4	124.6	49.6
12	70.9	97.4	141.1	43.6
18	76.4	95.9	110.1	51.1
Check	----	84.4	114.1	----
Average***	68.9	99.1	131.8	94.0

* First area recut

** Values are averages of two replicates.

*** Does not include the check plots

TABLE 9. THE EFFECT OF FERTILIZER PLACEMENT AND IRRIGATION ON THE PHOSPHORUS CONTENT OF ALFALFA FROM A HILLSDALE SANDY LOAM. (Experiment III)

Depth of fertilizer placement in inches	Percent total phosphorus in alfalfa cuttings at sampling date*		
	July 9	July 20	August 1
	No Irrigation		
Surface***	0.35**	0.29	0.21
1	0.31	0.25	0.19
3	0.33	0.28	0.18
6	0.32	0.25	0.18
12	0.32	0.24	0.19
24	0.32	0.26	0.18
Check	0.28	0.29	0.16
	Low Irrigation		
Surface***	0.36**	0.29	0.23
1	0.36	0.30	0.20
3	0.29	0.29	0.20
6	0.33	0.28	0.21
12	0.35	0.28	0.21
24	0.34	0.32	0.24
Check	0.40	0.29	0.25
	High Irrigation		
Surface***	0.35	0.30	0.23
1	0.35	0.31	0.23
3	0.36	0.29	0.22
6	0.32	0.29	0.22
12	0.33	0.28	0.19
Check	0.26	0.28	0.28

* Fertilizers applied June 21st

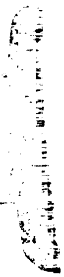
** All values are averages of two replications.

*** Broadcast application; other placements localized

TABLE 10. THE EFFECT OF FERTILIZER PLACEMENT ON THE ABSORPTION OF FERTILIZER PHOSPHORUS BY AN ESTABLISHED ALFALFA STAND ON A HILLSDALE SANDY LOAM. (Experiment III)

Depth of fertilizer placement in inches	Percent plant phosphorus derived from fertilizer at sampling dates*		
	July 9	July 20	August 1
	No Irrigation		
Surface***	27.0**	31.5	35.8
1	10.6	19.9	24.1
3	0.4	19.9	19.9
6	6.1	14.0	17.2
12	2.4	7.3	11.2
24	1.0	2.0	1.7
	Low Irrigation		
Surface***	22.0**	32.0	26.0
1	6.3	10.7	13.7
3	5.2	12.2	23.5
6	3.2	5.3	7.2
12	.9	4.7	5.1
24	.7	1.4	1.8
	High Irrigation		
Surface***	29.8**	15.5	32.2
1	9.4	17.9	23.6
3	9.8	19.3	23.8
6	7.8	16.0	23.5
12	2.6	3.6	8.8

* Fertilizer applied June 21st
** All values are averages of two replicates.
*** Broadcast application; other placements localized



of labeled phosphate was found in alfalfa from fertilizer placements at or close to the surface.

In the first and second sampling of second growth alfalfa there were no notable differences in fertilizer phosphorus uptake between the non-irrigated and high irrigated areas. This can be explained since the available soil moisture for the several depths presented in Figures 7 through 11 were quite similar at all irrigation rates due to reasonably adequate rainfall. The data presented in these figures show that up to July 8 supplemental water was applied only once. Precipitation of 1.01 inches on July 2, 3 and 4 brought the available water generally up to between sixty-five and seventy-five percent at all depths. During the period of July 15 to July 20 soil moisture values on the non-irrigated plots fell to fifteen percent or less in the surface six inches. It seems probably that a drop in absorption of fertilizer phosphorus follows a very dry period since feeder roots desiccated by lack of moisture would not be capable of absorbing nutrients immediately after soil moisture was again at an adequate level. This would account for a lag in relationship between uptake of fertilizer phosphorus and soil moisture level noted for the July 20 sampling. Available soil moisture levels continued to drop until August 1 when readings of less than ten percent available moisture at the 24 inch depth were noted.

Examination of fertilizer phosphorus absorption data determined on the second and third samplings from the non-irrigated plots indicate alfalfa continued to remove appreciable amounts of labeled phosphorus at all depths except the 24 inch placement. During the period of July 20 to August 1 when the surface six inches of soil contained less than

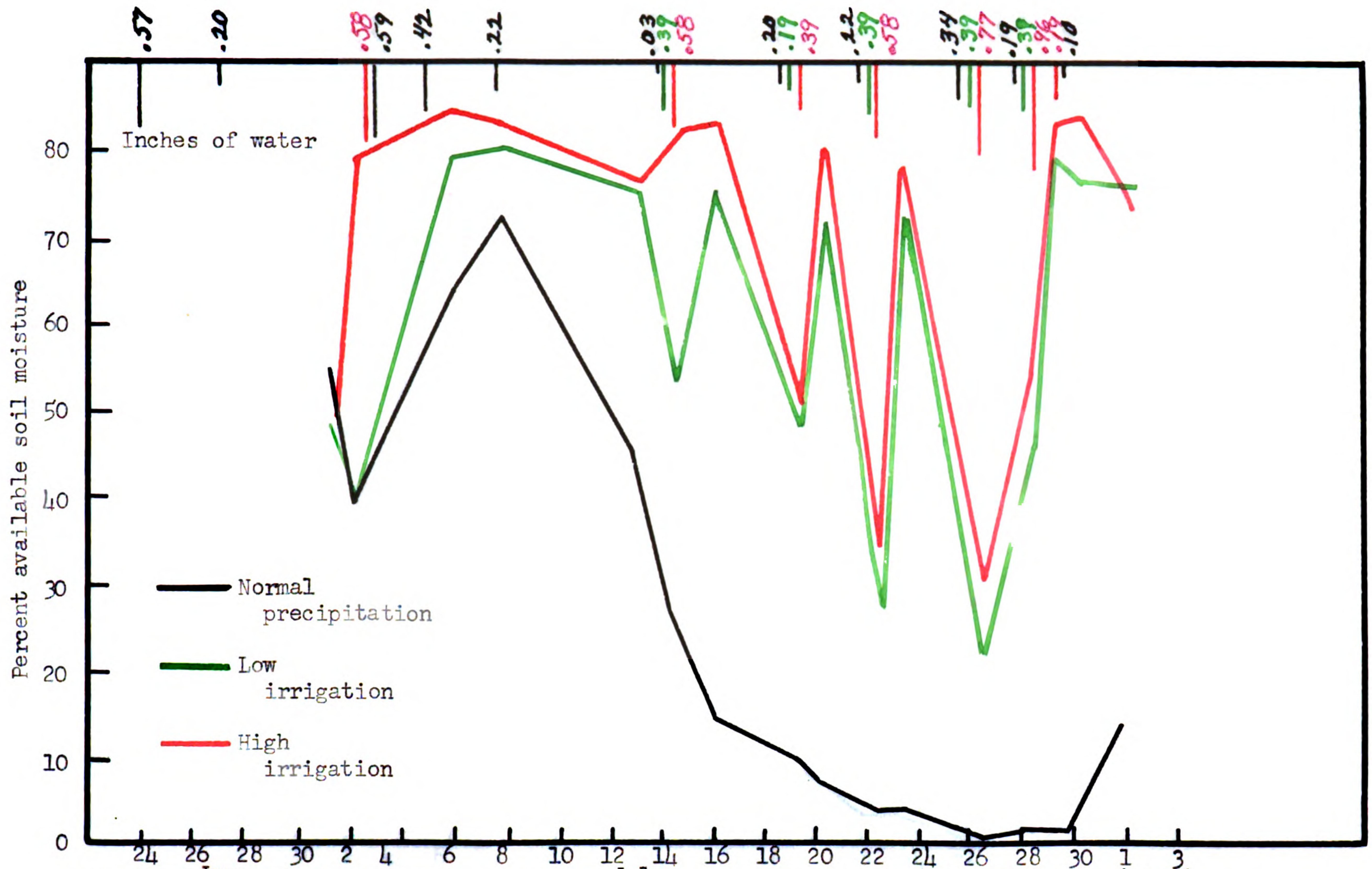


Figure 7. **Available soil moisture at the 1 inch depth under an established alfalfa sod as affected by normal precipitation and irrigation.** (Experiment III)

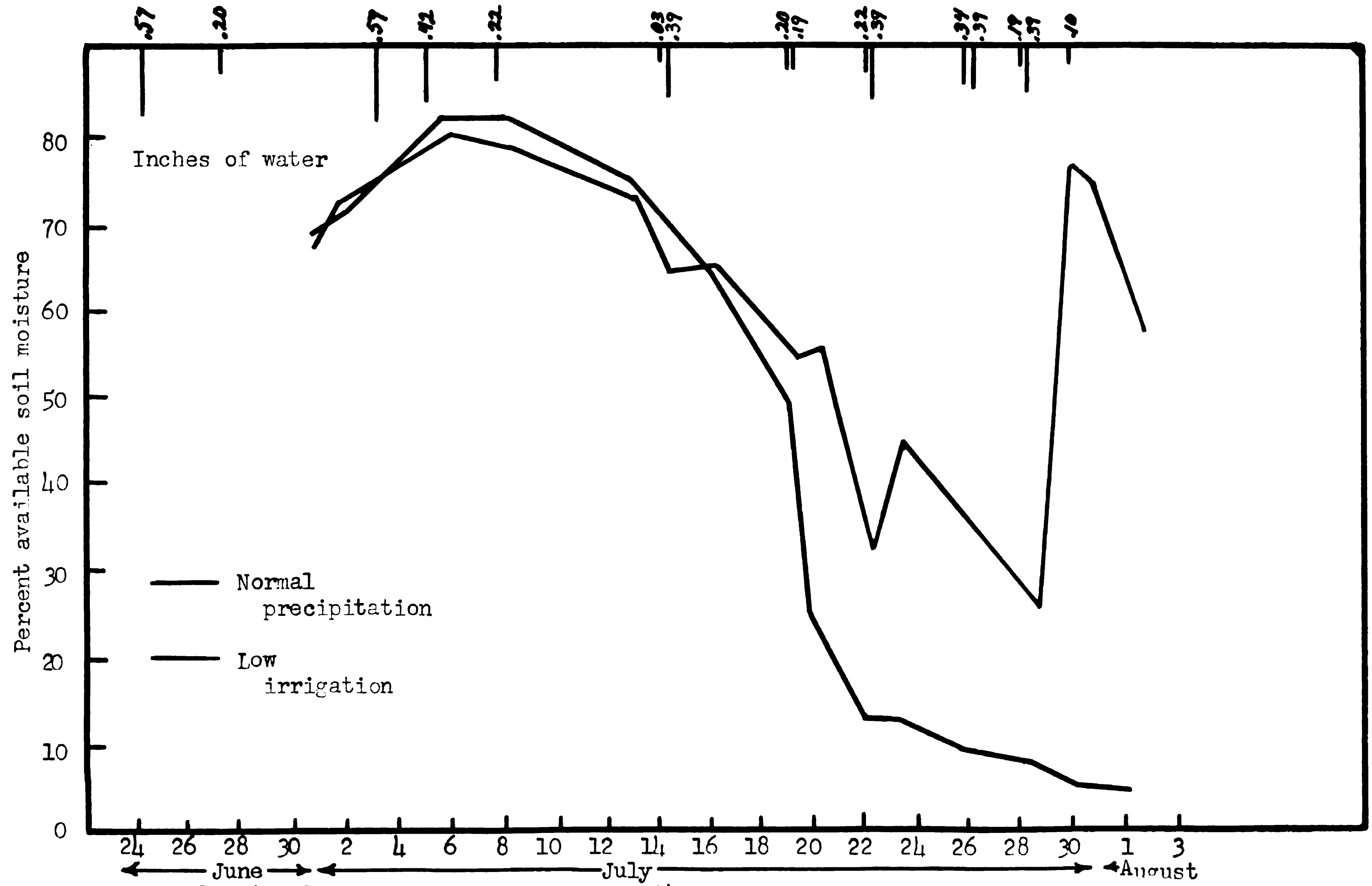


Figure 11. **Available soil moisture at the 24 inch depth under an established alfalfa sod as affected by normal precipitation and irrigation.** (Experiment III)

ten percent available water some increase in the percent of plant phosphorus derived from fertilizer was noted in alfalfa from plots receiving surface applications and 1 and 6 inch depth placements. This trend is similar to that reported by McAuliffe et al (9) who found that considerable fertilizer phosphorus was absorbed by legumes from surface or near surface placements of fertilizer under semi-drought conditions.

An increase in the fertilizer phosphorus content in alfalfa from low and high irrigated plots was also noted when the second and third samplings are compared for each level of supplemental water. A similar trend of a higher fertilizer phosphorus content in alfalfa from low and high irrigated plots was noted in the second and third samplings. The only marked decrease was found in plants from plots where fertilizer was surface applied and a low irrigation rate was used. Comparison of the fertilizer phosphorus contents of alfalfa at the different depth placements for irrigated plots in Table 10 shows that cuttings made on July 9 and July 20 were considerably higher than for non-irrigated plots on which fertilizer was applied to the surface. By August 1 this trend was less evident, especially at the high irrigation rate. Alfalfa cut on August 1 from high irrigated plots having the 3 and 6 inch depth placements were higher in percent of plant phosphorus derived from fertilizer than alfalfa from non-irrigated plots. Little or no difference was noted in fertilizer phosphorus content of plants from plots where fertilizer was surface applied or placed one inch below the surface. This latter condition is difficult to explain since on the non-irrigated plots no increase in dry weight was found between the July 20 and

August 1 samplings and a lower total amount of fertilizer phosphorus was taken up by alfalfa out on August 1. It would seem reasonable to expect the greatest effect of irrigation on absorption of phosphorus from fertilizer of any placement, since the greatest spread between the soil moisture levels due to irrigation was evident at this time as noted in Figures 7 to 11.

At the final harvest the dry weight yields as presented in Table 11 were quite variable, especially between depth of fertilizer placements within irrigation levels. However, if averages of the dry weights at each sampling date for all fertilizer placements in a given irrigation rate are compared, some interesting points can be noted. There was no important difference between the samplings made on July 9. The high rainfall several weeks prior to this date brought soil moisture contents to adequate levels for all plots. The average weights of the first and second samplings from the low irrigated plots were slightly but probably not significantly lower than those of the non-irrigated areas. Most notable is the fact that the dry weight yields of the second and third samplings from plots receiving high irrigation were considerably greater than for the other irrigation levels. This increase was most apparent for the August 1 sampling and is believed to be due to water supplied during the very dry and hot period in the last two weeks of July.

There are several possible reasons why a higher percentage of fertilizer phosphorus might be expected in alfalfa where a high level of irrigation was used than in plants receiving less water. First, the higher available soil moisture conditions may have resulted in more

TABLE 11. THE EFFECT OF FERTILIZER PLACEMENT AND IRRIGATION ON THE DRY WEIGHT YIELD OF ALFALFA GROWN ON HILLSDALE SANDY LOAM. (Experiment III)

Depth of fertilizer placement in inches	Grams of air dry hay per three square feet at sampling dates July 9	July 20	August 1
	No Irrigation		
Surface**	80.6*	113.6	107.6
1	72.1	99.1	90.6
3	64.1	111.6	131.1
6	78.6	123.6	147.5
12	53.6	86.1	124.6
24	59.6	96.6	132.1
Check	69.1	111.1	108.1
Average***	68.1	105.1	122.2
	Low Irrigation		
Surface**	76.1	99.1	146.6
1	56.1	112.1	133.6
3	62.6	106.1	139.6
6	61.1	95.1	126.6
12	50.1	94.1	104.6
24	56.1	82.6	115.6
Check	70.1	86.1	113.1
Average***	60.4	98.1	127.8
	High Irrigation		
Surface**	67.1	130.1	141.1
1	64.1	131.6	154.6
3	68.6	101.1	155.1
6	80.1	119.1	135.1
12	60.1	135.6	172.1
Check	52.1	125.1	136.0
Average***	68.0	123.5	151.6

* Values are averages of two replications.
** Broadcast application; other placements localized
*** Does not include the check plots

extensive development of small lateral roots and greater absorption of the available fertilizer phosphorus. This conclusion is substantiated in part by yield increases from high irrigation at the last sampling. However, it is of interest to note that Dean et al (3) concluded that the factors that influence growth do not necessarily effect the percentage of plant phosphorus that is derived from fertilizer applied at the time of planting.

Second, a higher irrigation rate may have caused a greater diffusion of fertilizer phosphorus from the points of application allowing more root contact with the labeled phosphate. Actually the movement of applied phosphorus in most soils has generally been shown to be very small. However, work by Heslep and Black (5) and Lawton and Vomocil (8) indicated that diffusion of fertilizer phosphorus in soils from a given point source increased with increasing soil moisture content. As previously mentioned, no data of this type taken in the field were obtained for this experiment. Consequently, this hypothesis of extensive phosphorus migration to lower soil depths is open to question. Satchell (12) also noted that the longer the phosphate was in the ground the greater was the movement and that there apparently was a direct relationship between the amount of moisture and the movement of the phosphorus.

However, even with the leaching effect of water applied as surface irrigation, it is still doubtful whether increased migration could account for a higher utilization of fertilizer phosphorus since a considerable period had elapsed for fixation of phosphate ions to take place between the time of application of fertilizer and the period

of frequent irrigation. In addition, Heslep and Black (5) noted that the diffusion rate of phosphorus in soil was reduced by the addition of nitrogen and potassium in proportions typical of those found in mixed fertilizers. Thus the muriate of potash mixed with the labeled superphosphate may have reduced phosphate ion migration.

Figure 12. Experiment I, located on Michigan State College farms near Bennett Road. When the plots were put in a white stake was placed on each corner.

Figure 13. The plots at Experiment II. The photograph was taken just after fertilizers were applied June 21.

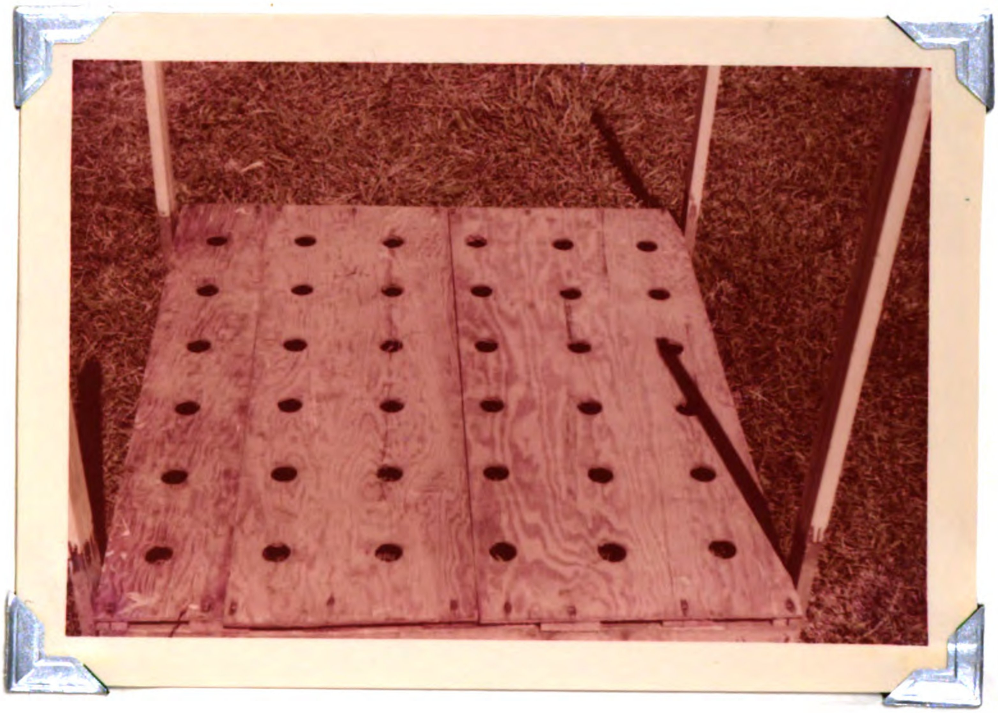


Figure 14. The board used to lay out the plots. The board was 3 feet by 3 feet which was the size of the plots. A stake was placed in each corner. The fertilizer was placed in holes in a 6 by 6 inch grid pattern. The holes in the board were in a 6 by 6 inch grid pattern so the borings were made through each hole.

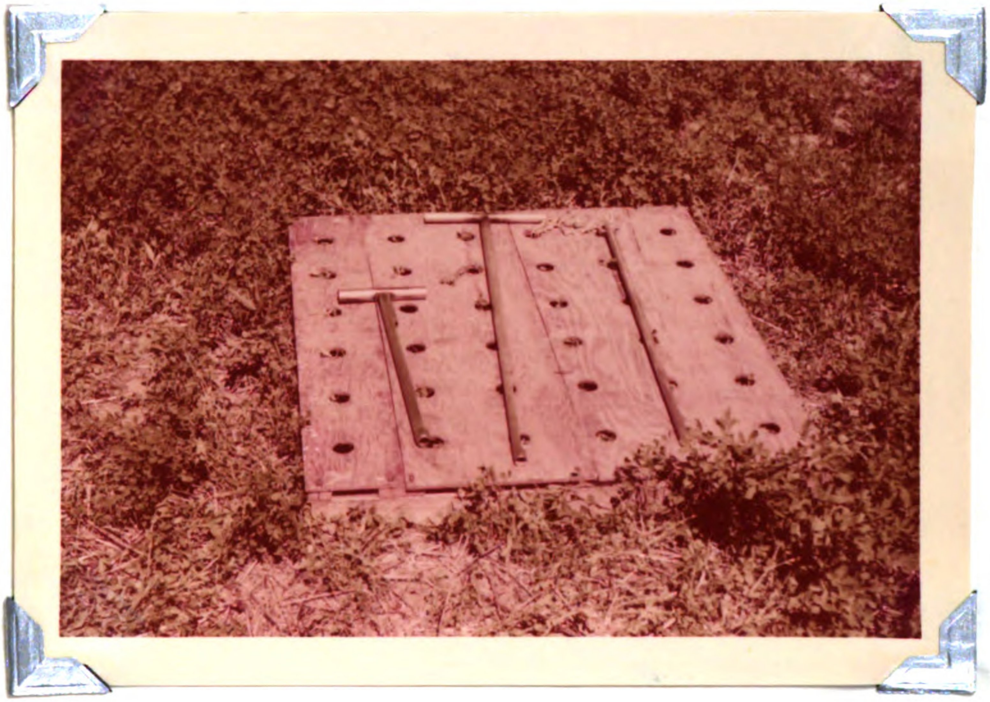


Figure 15. These are the tools used to make the borings. The soil smple tube on the left was purchased, the soil sample tube in the center was made from a 7/8 inch stainless steel tube. The rod on the right was made from a piece of 5/8 inch drill rod.

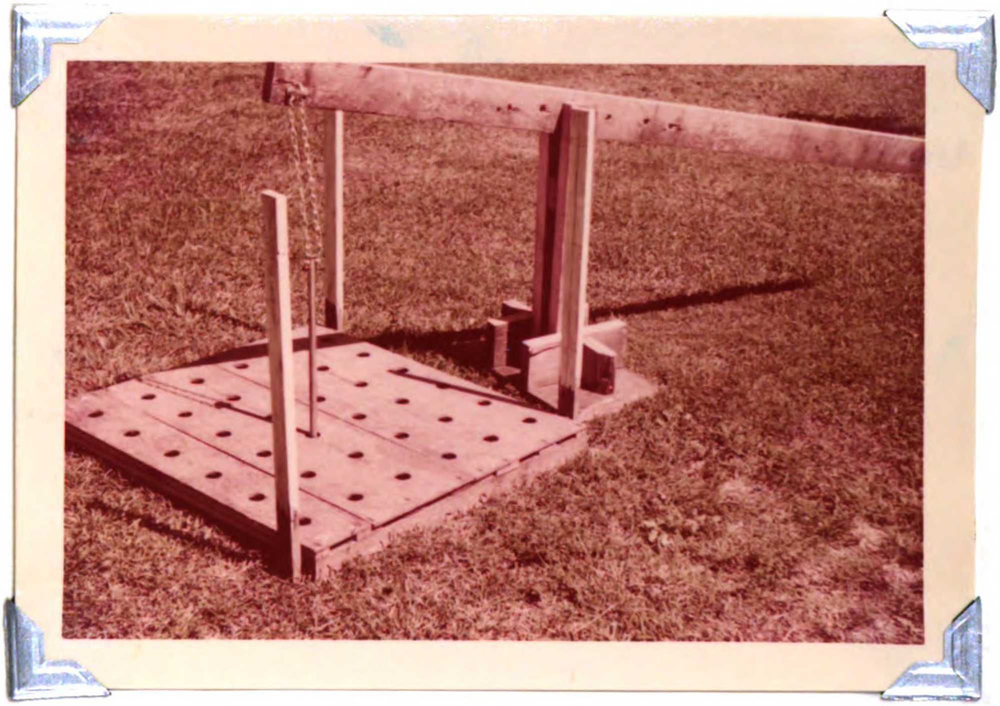


Figure 16. Because of small stones the borings around the 24 inch depth were hard to make. Also small pieces of soil fell down the holes and plugged the glass tube when the fertilizer was poured down. To make a hole through the small pieces of rocks and to eliminate the loose pieces of soil at the bottom, the 5/8 inch drill rod was used. If the rod got stuck between the rocks, the chain and the lever were used to extract it.

Figure 17. The fertilizer was measured out in small envelopes preparatory to placing it in the plots. First, the muriate of potash, then the labeled triple superphosphate were placed in the envelopes. The superphosphate was measured out with tongs behind the glass so that protection was offered against the beta rays.

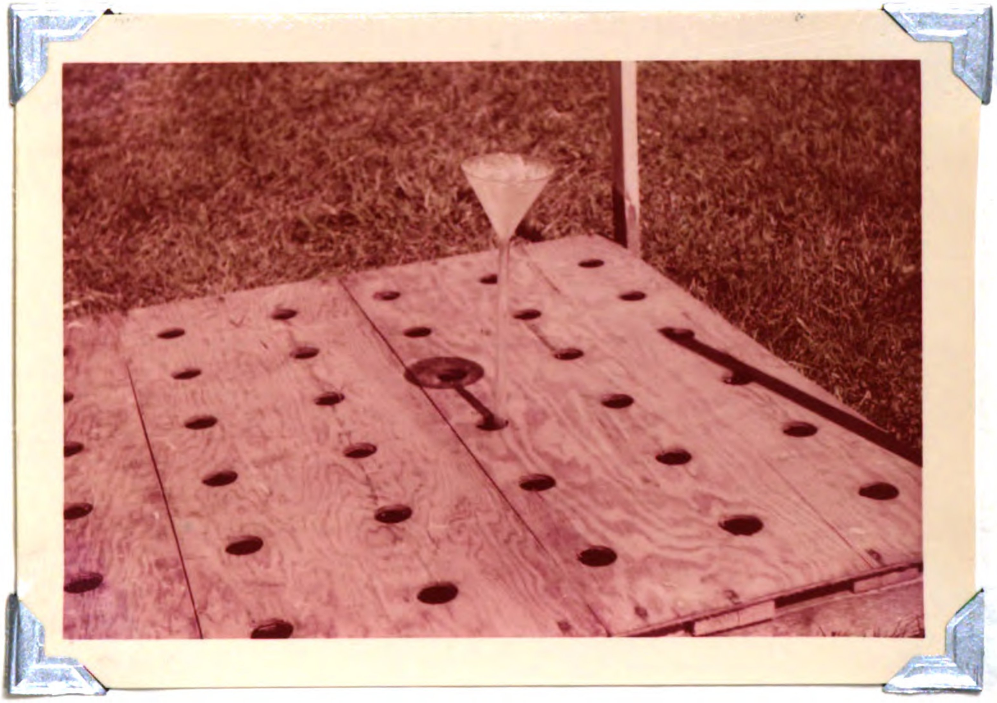


Figure 18. The fertilizer was placed at the bottom of the holes by using a glass tube and funnel to avoid contaminating the sides of the holes.

Figure 19. After the muriate of potash and labeled superphosphate were placed in the holes, they were filled with dry soil. The dry soil was placed in the holes by pouring it through a large funnel.

Figure 20. The plots were irrigated by hauling the water in the cans shown above. When the plots were irrigated, a 5 by 5 foot area was watered. One gallon of water on 25 square feet was equivalent to 0.0645 inches. The water was carried to the plots in three gallon sprinkling cans.

Figure 21. A close-up of one of the plots. The area on the right had just been cut. There were three cuttings made from each plot and 1/3 of the plot or three square feet was cut each time.

Figure 22. Views of the plots in Experiment II.

SUMMARY

The phosphorus uptake by alfalfa as affected by depth of fertilizer placement and supplemental irrigation was studied on a Brookston clay loam and a Hillsdale sandy loam. From the data obtained, the following conclusions can be made:

1. Feeder roots of alfalfa within the six inch soil depth of an established alfalfa stand were very effective in absorbing fertilizer phosphorus placed in this depth zone. These data support the concept of a surface pattern of active feeding roots of established alfalfa plants.

2. The ability of alfalfa roots to absorb fertilizer phosphorus decreased with depth of fertilizer placement from the surface to twenty four inches. Although the highest percentage of fertilizer phosphorus in alfalfa was obtained from a surface application, the absorption of some phosphorus through leaf surfaces and crowns cannot be ruled out.

3. The use of supplemental water during the dry periods increased the fertilizer phosphorus content of first cutting alfalfa from plots receiving surface applied fertilizer and the one inch depth placement. On second growth hay, a high irrigation rate increased the percentage of plant phosphorus derived from fertilizer placed at the six and twelve inch depths. In this respect a low irrigation rate had little effect. The following hypotheses have proposed to account for increased absorption of fertilizer phosphorus during dry periods, especially at depths up to twelve inches when a high rate of irrigation

was used: (a) the number of lateral roots or their capacity to absorb phosphorus were increased, (b) the root-fertilizer contact was improved by increasing the area of dissolution and the downward movement of fertilizer phosphorus by a leaching action.

4. The continued absorption of phosphorus placed on the soil surface or at a depth of one inch when the available soil moisture was very low on non-irrigated plots cannot be adequately explained.

5. In samplings of first growth alfalfa, there was a decrease in percentage of total phosphorus in the dry plant tissue with increasing depth of fertilizer placement. For second growth alfalfa this effect was not evident. The use of supplemental water had no influence on the total phosphorus content of alfalfa at any given sampling except the final harvest of the second growth, at which time the phosphorus content was substantially higher where a high irrigation rate was employed.

6. The dry weights of hay at the final sampling of both first and second growth alfalfa were quite variable with respect to depth of fertilizer placement. Only in the case of plots on Brookston soil was the yield of hay sampled midway through the second growth higher for the lower depth placements than those closer to the surface. Irrigation had no effect on the average dry weights of three samplings of first growth alfalfa and the first sampling of second growth alfalfa. An appreciable increase in average dry weight of hay due to high irrigation was noted for two samplings taken during the last two weeks of July.

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APPENDIX

TABLE 12. DATA USED FOR CALCULATIONS. (Experiment I)

Replicate	Depth	PPM of phosphorus May 29	June 7	June 15	Counts per minute* May 29	June 7	June 15
				No Irrigation			
I	Bdcst	9.1	6.8	6.7	4329	6079	2231
II	Bdcst	9.4	6.7	7.5	4343	3954	2694
I	1	8.2	6.2	6.2	2789	3014	2241
II	1	9.1	6.3	4.8	2908	2917	1716
I	3	8.4	5.8	6.0	3338	6147	3587
II	3	9.4	6.8	5.9	1818	2844	1879
I	6	9.4	6.6	5.8	1895	2154	1867
II	6	9.0	6.6	5.8	1694	2559	1644
I	12	8.1	6.0	5.3	820	979	814
II	12	8.6	6.2	5.8	307	847	568
I	24	9.4	6.3	5.2	166	529	313
II	24	8.1	5.5	5.0	179	443	220
I	Check	6.2	6.0	6.5	—	—	—
				Irrigated			
I	Bdcst	9.0	6.8	6.3	7358	5525	3955
II	Bdcst	9.4	7.5	6.7	5086	6260	2395
I	1	8.4	6.0	5.2	3102	5542	3526
II	1	9.7	6.7	6.2	4032	3317	3245
I	3	9.5	6.1	6.0	2260	6114	2784
II	3	9.0	8.5	5.8	2035	2059	2109
I	6	8.1	6.1	6.5	1369	4846	2066
II	6	7.0	6.4	5.4	1518	2172	3194
I	12	8.0	5.6	3.6	287	872	1013
II	12	8.9	6.4	5.9	741	1406	1431
I	24	8.6	5.2	4.8	141	680	980
II	24	7.9	6.3	5.8	187	322	590
I	Check	—	6.5	5.0	—	—	—

* For the first cutting the counts per minute were 67824 for standard number 1 and 65876 for standard number 2. For the second cutting standard number 1 was 58850. For the third cutting standard number 1 was 27831 and standard number 2 was 27888.

TABLE 13. DATA USED FOR CALCULATIONS. (Experiment II)

Replicate	Depth	PPM of phosphorus May 29	June 7	June 26	July 16	Counts per minute* May 29	June 7	June 26	July 16
I	Bdcst	5.2	6.9	4.8	6.2	1515	3119	2150	4209
II	Bdcst	4.2	6.2	4.8	6.0	1382	3996	3054	2031
I	1	4.6	5.0	5.0	5.3	1492	2829	3659	3564
II	1	5.2	8.3	5.0	5.7	1632	3395	4223	3588
I	3	5.0	4.4	4.4	6.6	1126	2841	2989	3462
II	3	4.6	5.6	4.7	7.6	804	3778	3841	3922
I	6	5.2	4.7	6.9	4.6	496	1330	2734	1873
II	6	4.2	3.8	3.9	5.3	122	860	2401	2039
I	12	4.5	3.9	4.1	5.2	180	440	1148	1427
II	12	3.6	3.6	3.4	5.7	151	446	1035	4181
I	18	5.3	4.2	4.2	5.1	90	539	821	739
II	18	4.3	3.7	4.0	5.0	372	372	765	678
I	Check	—	3.9	3.6	—	—	—	—	—
II	Check	—	3.3	4.1	—	—	—	—	—

* For the May 29th cutting the counts per minute on standard 1 were 28728, and for standard 2 were 27830. For the June 7th cutting the counts per minute on standard 1 were 28691, and for standard 2 were 27830. For the June 26th cutting the counts per minute for standard 2 were 24309. For the July 16th cutting the counts per minute for standard 1 were 8868, and for standard 2 were 12406.

TABLE 14. DATA USED FOR CALCULATIONS. (Experiment III)

		PPM of phosphorus			Counts per minute*		
Replicate	Depth	July 9	July 20	Aug. 1	July 9	July 20	Aug.1
			No Irrigation				
I	Bdcst	7.2	5.4	4.4	6108	4705	3704
II	Bdcst	6.9	5.2	3.8	9403	8591	8026
I	1	5.7	4.9	4.0	2124	3719	2577
II	1	6.9	5.0	3.6	3282	4251	4587
I	3	6.7	5.8	3.5	2440	3664	2701
II	3	6.6	5.3	3.9	3229	4315	3072
I	6	6.5	5.0	3.7	1753	2907	3053
II	6	6.5	5.1	3.7	1463	2846	1924
I	12	6.5	4.5	3.2	924	1907	1768
II	12	6.2	5.0	3.1	335	827	1055
I	24	5.6	5.4	3.6	257	607	250
II	24	7.3	5.3	3.6	287	269	249
I	Check	5.6	5.9	3.3	—	—	—
			Low Irrigation				
I	Bdcst	7.0	5.8	4.2	4203	6787	3365
II	Bdcst	7.3	5.9	4.9	5273	8213	4721
I	1	7.3	6.4	4.2	1454	2071	1316
II	1	7.2	5.5	4.3	2250	3008	2414
I	3	4.4	5.3	4.8	411	2785	4260
II	3	7.2	6.2	4.2	1644	6055	3098
I	6	6.7	6.0	4.2	460	1277	1479
II	6	6.9	6.5	6.9	1317	1296	2221
I	12	7.1	5.6	4.0	203	705	471
II	12	6.9	5.9	4.9	311	1451	1251
I	24	6.8	9.1	5.1	272	667	379
II	24	6.7	5.7	4.8	113	206	348
I	Check	8.0	5.9	5.2	—	—	—

* For the July 9 cutting the counts per minute were 11981 for standard 3 and 11651 for standard 4. The counts per minute for the July 20 cutting were 11891 for standard 3 and 11501 for standard 4. The counts per minute for the August 1 cutting for standard 3 were 11572 and 11372 for standard 4.

TABLE 15. DATA USED FOR CALCULATIONS. (Experiment III)

Replicate	Depth	PPM of phosphorus July 9	July 20	Aug. 1	Counts per minute* July 9	July 20	Aug. 1
			High Irrigation				
I	Bdcst	7.0	6.2	4.6	5191	3899	6003
II	Bdcst	7.1	5.9	4.4	9794	3610	5996
I	1	7.8	6.2	4.7	2361	4317	4343
II	1	6.6	6.2	4.5	2978	4673	4392
I	3	7.2	5.9	4.4	3261	4772	4612
II	3	7.2	5.8	4.3	2497	4451	4557
I	6	6.7	5.7	4.5	1948	3742	4061
II	6	5.9	5.9	4.2	2061	830	4029
I	12	6.4	5.9	3.9	667	705	——
II	12	7.0	5.3	3.9	745	875	1380
I	Check	5.2	5.5	4.8	——	——	——

* For the July 9 cutting the counts per minute were 11981 for standard 3 and 11651 for standard 4. The counts per minute for the July 20 cutting were 11891 for standard 3 and 11501 for standard 4. The counts per minute for the August 1 cutting for standard 3 were 11572 and 11372 for standard 4.

TABLE 16. CALCULATION OF STANDARDS FROM LABELED FERTILIZER RECEIVED IN THE SPRING

Standard Number 1

Used 12 ml. of solution from a flash containing 100 ml. of .13N HCl and 2.4746 gm. of 48.5% P_2O_5. Wet 5 grams of plant material.

2.4746 x 48.5% = 1.2002 grams of P_2O_5 in solution

1.2002 x 12/100 = .14402 (amount fertilizer in 5 grams of hay)

.14402 ÷ 2/5 = .05761 (grams in 2 grams)

.05761 ÷ 2.29 = .02518 (grams fertilizer phosphorus in 2 grams)

Standard Number 2

Used 11.1 ml. of solution from a flask containing 100 ml. of .13N HCl and 2.5918 grams of 48.5% P_2O_5. Wet 5 grams of plant material.

2.5918 x 48.5% = 1.2570 grams of P_2O_5 in solution

1.2570 x 11.1/100 = .13933 (amount of fertilizer in 5 grams of hay)

.13933 ÷ 2/5 = .05573 (grams in 2 grams)

.05573 ÷ 2.29 = .02434 grams fertilizer phosphorus in 2 grams

TABLE 17. CALCULATION OF STANDARDS FROM LABELED FERTILIZER RECEIVED IN THE SUMMER

Standard Number 3

Dissolved 2.5639 grams of 48% P_2O_5 in 500 ml. of .13N HCl.
Used 6.9 ml. of solution to wet 5 grams of plant material.

2.5639 x 48% = 1.2307 grams P_2O_5 in solution

1.2307 x 6.9/500 = .01698 gm. of fertilizer phosphorus in 5 grams of hay

.01698 ÷ 2/5 = .00679 (gm. fertilizer phosphorus in 2 gms. of hay)

.00679 ÷ 2.29 = .00296 (gm. of phosphorus in 2 gms. of hay)

Standard Number 4

Dissolved 2.5640 grams of 48% P_2O_5 in 500 ml. of .13N HCl.
Used 6.9 ml. of solution to wet 5 gms. of plant material.

2.5640 x 48% = 1.2307 grams of P_2O_5 in solution

1.2307 x 6.9/500 = .01698 gm. of fertilizer phosphorus in 5 grams of hay

.01698 ÷ 2/5 = .00679 (gm. of fertilizer phosphorus in 2 gms. of hay)

.00679 ÷ 2.29 = .00296 (gm. of phosphorus in 2 gms. of hay)