A study of the chemical composition of certain vegetables grown under different conditions of soil moisture
by Jack E Myers

A THESIS Submitted to the Graduate Committee in partial fulfillment of the requirements for the Degree of Master of Science in Chemistry at Montana State College
Montana State University
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Abstract:
This Investigation has been an Intensely practical one. No attempt has been made to study the principles or mechanisms Involved In the Intake of mineral nutrients by plants. Only actual field conditions have been studied.

1. Several techniques of irrigation have been studied in regard to their effects upon the calcium, iron, nitrogen, phosphorous, ash, and water content of the edible portion of a number of common vegetables. The period of irrigation, the amount of water applied, and the method of application have been shown to be three influencing factors.

2. Three different periods for single irrigations by the flooding method were found to influence the chemical composition of the seeds of peas. High nitrogen content was definitely favored by early irritation. Calcium, iron, and phosphorous contents were high for different periods. Water content was not appreciably influenced by the period of irrigation.

3. Three different amounts of water applied by the flooding method were found to influence the chemical composition of the seeds of peas. In general the total content of ash constituents was depressed by increasing amounts of water. Water content of seeds was not appreciably influenced by the amount of water applied.

4. The response of chemical composition to varying amounts and periods of irrigation was less marked than the response of the total production of edible portion.

5. Three different methods of irrigation and a lack of irrigation were found to have different effects upon the composition of the edible portions of twelve common garden vegetables. Lack of irrigation produced vegetables generally low in moisture, high in nitrogen, and high in total ash. No correlation was found for the response of different vegetables to the three methods of irrigation.

6. On the basis of this study and previous statistical studies of the composition of plants, it has been pointed out that mineral composition of vegetables varies a great deal more than is commonly supposed.

7. It has been suggested from the results of this study that irrigation offers a means of controlling the mineral and nitrogenous composition of vegetable crops.

A STUDY OF THE CHEMICAL COMPOSITION OF CERTAIN VEGETABLES GROWN UNDER DIFFERENT CONDITIONS OF SOIL MOISTURE

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30

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Approved:

Jessie E. Richardson
In Charge of Major Work

Oden E. Sheppard
Chairman Examining Committee

F. B. Cotner
Chairman Graduate Committee

Bozeman, Montana
June, 1935

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A STUDY OF THE CHEMICAL COMPOSITION OF CERTAIN VEGETABLES GROWN UNDER DIFFERENT CONDITIONS OF SOIL MOISTURE

I. INTRODUCTION

During the past few years the practice of irrigation has undergone unusually rapid development. Agriculture is seeking dependability, greater possible diversification, and the use of more efficient climatic conditions. Irrigation is a possible answer to each of these. It is therefore not surprising that the practice of irrigation, once proved practicable, should have developed so much more rapidly than its investigation by scientific methods.

One of the problems inherent to the practice of irrigation is how to apply water most efficiently. In this problem at least three important factors are involved: the method of application, the time of application, and the amount of water applied.

In 1933 the Horticulture Department of the Montana Agricultural Experiment Station, having observed several different methods of irrigation in use throughout the state, became interested in the relative merits of these methods. One of the questions raised was whether the various methods have any different effects on the nutritive value of the vegetables raised. This was taken to the Department of Home Economics, but in a search for literature on the subject no conclusive data were found. The Horticulture Department and the Home Economics

Department then initiated a joint project to determine the relative efficiency of the methods and the nutritive value of the common garden vegetables grown under these methods. One phase of this project, the study of the chemical composition of the vegetables, is the subject of this investigation.

Because of the extent of the project and the large number of samples to be investigated, it was necessary to limit the extent of the analysis. From theoretical considerations the composition of plants subjected to different conditions of soil moisture would be expected to vary the most in respect to those materials which are taken up by the roots. Several of these materials are also important from the standpoint of animal nutrition. It was therefore decided to include in the analysis determinations for nitrogen, calcium, iron, phosphorous, moisture, and total ash. To further carry out the investigation in relation to the requirements of animal and human nutrition, only the edible portions of the vegetables were analyzed.

In addition to the garden plots of the Horticulture Department it was found that there was a second series of plots available, these latter prepared by the Irrigation Department in a study of the effects of irrigation on certain pathological conditions of peas. Thus the problem assumed two distinct aspects. The plots of peas were irrigated with definite, varying amounts of water at different stages in the maturity of the peas, i.e., before bloom, early bloom, full bloom.

A study of samples taken from these plots might be expected to determine the effect of the relative amount of water applied, and also to determine the effect of the time or period of the irrigations.

The plots of garden vegetables, on the other hand, were subjected to four different methods of water application:

1. Water applied by overhead sprinkling;
2. Water applied from lath tiles set eighteen inches beneath the surface of the ground;
3. Water applied by the furrow method;
4. No water applied by irrigation (dry-land).

The vegetables investigated for these different methods were selected by the Horticulture Department as the ones most representative of the gardens of this region. A study of samples from these plots might be expected to determine the effects of the different methods of irrgation on the chemical composition of the common garden vegetables grown.

It is to be emphasized that this is essentially a preliminary investigation. There was no previous work to suggest what kind of results might be expected. Conditions of the growth of the vegetables were not always as closely controlled as they should have been. Furthermore, this is only a one-year investigation and therefore subject to the criticisms pertinent to all experiments of such short duration. However it was expected that the results obtained would give some indication of the lines along which further work should be carried on.

II. REVIEW OF THE LITERATURE

The work of previous investigators which is pertinent to the problem at hand can best be considered in regard to the three factors involved: method of irrigation, period of irrigation, amount of water applied.

Little work has been done on general methods of irrigation. Widstoe and Stewart (28) at the Utah Experiment Station have compared the flooding and furrow methods in respect to total yield and per cent protein and per cent ash in a variety of crops. Of these two methods they concluded that "differences in the methods of irrigation are so small as to be of no practical value". However Gelitzer (7), studying the furrow and flooding methods on cotton, concluded that the furrow method gave better soil aeration, greater nitrification, and greater availability of minerals. In a study of the evaporation from irrigated soils Fortier and Beckett (6) recommended deep furrow irrigation for the most efficient use of water.

Apparently no general comparative study has been made of the common methods of irrigation applicable to vegetable crops in Montana.

A number of solution-culture experiments have demonstrated quite clearly that certain nutrient materials are taken up at very definite stages in the growth of plants. Outstanding among these is the work of Gericke (9) on wheat. The results of three of his experiments may be cited:

1. After the first four weeks (which was one-seventh of the total growth) in complete nutrient solution, wheat was removed to a solution devoid of magnesium, phosphorous, and sulphur. These plants produced more grain and straw than plants continued on a full nutrient solution.

2. The elements required longest throughout the growth period were calcium and iron. Cultures deprived of calcium produced a grain low in nitrogen.

3. Maximum development was obtained from plants kept four weeks in complete nutrient solution and then transferred to a solution devoid of phosphorous.

From somewhat similar experiments on barley, Brenchley (2) concludes: "indications are that the most critical period for phosphate nutrition is during the early stages of growth, and that late provision of phosphate tends to affect the composition of the crop without having a corresponding effect on the yield."

Several other workers have reported investigations on the variance in chemical composition of grains with the period of growth. McCall and Richards (16) showed that the mineral food requirements of wheat vary at different growth stages, but did not show precisely how the different requirements varied. Burd (3) reported that barley absorbs minerals and nitrogen at different rates in its successive growth stages. Potassium and nitrogen reached a maximum (per plant) at a comparatively early stage in development. Additional experiments

led this worker to conclude that these varying rates of absorption are typical of the plant and not of the soil or of external conditions. Sekera (23), also working on barley, found that the maximum intake of nutrients occurs in the flowering period. During the formation and ripening of the grain he noted a partial transferance of minerals from the leaves and stem to the grain.

Gericke (8) followed the nitrogen intake of several grains through the growth periods. He added sodium nitrate to pot cultures at different stages in growth. For spring wheat (White Australian), oats (Texas Red), and rye (variety unknown) the earlier the application of sodium nitrate, the lower the nitrogen content of the plants. However on winter wheat (Turkey Red) the variation was much less pronounced. These results are rather contradictory to those of Singleton (26), who found that in certain varieties of rye, wheat, millet, rape, oats, and buckwheat the nitrogen is absorbed most rapidly in the early stages of growth. These latter results seem to be in better agreement with the opinions of men working in the field.

This general work has no direct bearing upon the case at hand except for its indications that soil nutrients are absorbed at different rates during the different growth periods. But if there is any relation between the water present and the intake of minerals, then some relation may be expected between the time of application and the mineral intake.

No work has been reported on the effect of the period of irrigation on either the yield or the composition of the crop. Widstoe and Stewart (27), approaching the problem from an entirely different angle, studied peas and other crops harvested at different periods in growth. They concluded: "During the early periods of growth plants need less water than during later periods." They did not indicate the times of irrigation.

Seiden (22), from a study of the external factors which may influence the chemical composition of the plant, suggested that "it is possible to vary the ash of the plant by regulating the amount of water and fertilizer added to the soil." Dunnewald (4), in comparing certain areas of land in Wyoming, noted that the greater the yearly precipitation, the less the available phosphorous. However he failed to determine whether this variance is due to rainfall, to temperature conditions, or to the total phosphorous reserves of the soils. Morse (19) showed that on soils low in potash, millet and soybeans obtained their supplies of potassium in direct proportion to the amount of water in the soil.

Actual irrigation experiments on wheat, oats, and barley were carried out by Greaves and Carter (11). They found that in the plants studied, increased amounts of irrigation water caused a decrease in the per cent of nitrogen but an increase in the per cent of total ash, phosphorous, and calcium in the grain. From this

evidence they criticized over-irrigation on two grounds: that it washes nitrogen out of the soil, and that it causes a greater uptake of phosphorous and potassium, thus depleting the soil. Subsequent studies by Greaves and Nelson (12) revealed that increased amounts of irrigation raised the iron content in wheat but had no corresponding effect on oats and barley.

These results confirmed the earlier reports of Widstoe and Stewart (27, 28) that increased amounts of irrigation gave a lower per cent protein, but increased the total production of ash per acre. They had studied the effects of the amounts of irrigation water on the protein, ether extract, ash, and water content of wheat, oats, peas, sugar beets, and potatoes. They reached three general conclusions (one of which has already been cited) in regard to the effects of the amount of water:

1. The per cent of ash in the parts of the plant above ground varies directly, while in the parts below the grown inversely, with the amount of available moisture.

2. Variations in chemical composition due to varying amounts of irrigation are more marked as maturity is approached.

3. Less water is needed in the early than in the late periods.

The data on peas reported from their investigation indicates that increased amounts of water gave decreased ash content and decreased nitrogen content in the heads.

In general it seems that for the plant as a whole, increased irrigation causes a low per cent of nitrogen and a high per cent of total ash. This correlation between mineral content and water has often in the past been attributed to the transpiration stream. However at least two workers (14,15) have recently advanced evidence that this is not the case. There are probably many factors concerned in any relation between irrigation water and the plant supply of minerals. These factors must be determined one by one and under carefully controlled conditions; they cannot be made evident from an investigation such as the present one, which is concerned only with the practical applications.

In considering the literature pertinent to the problem, it seems evident that the method of application, the period of application, and the amount of irrigation water applied have some effect on the chemical composition of irrigated crops. But there are no data which show how the nutritive value of irrigated crops is affected by these three factors.

III. CONDITIONS UNDER WHICH THE VEGETABLES WERE GROWN

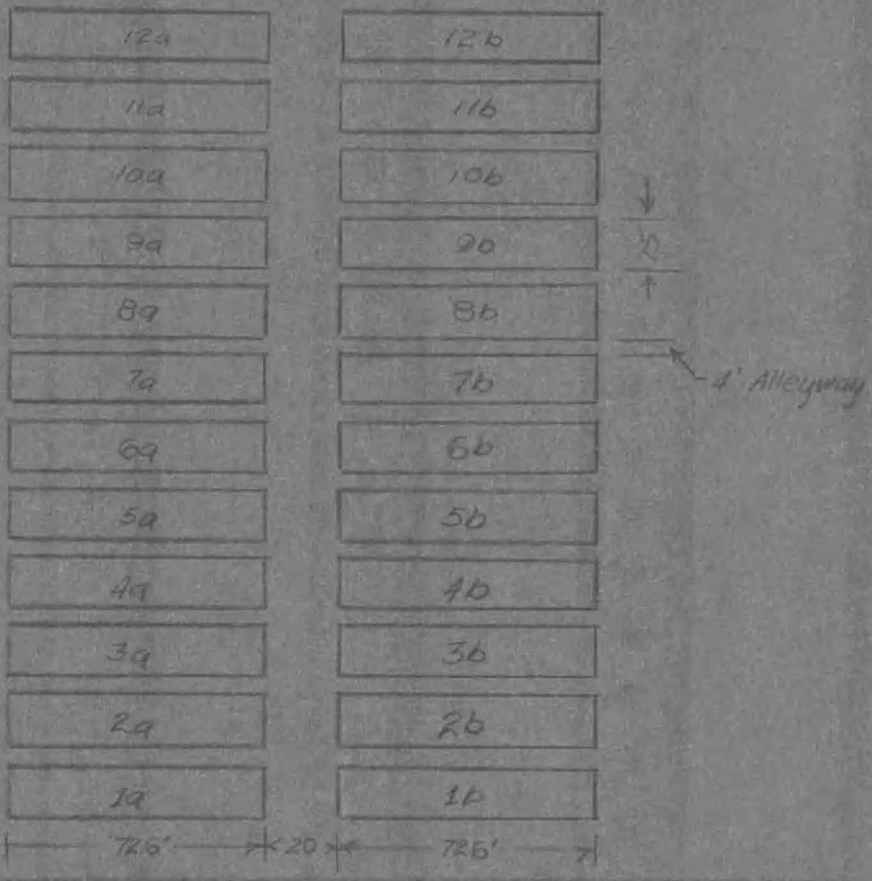
A. The Peas Plots

The plots of peas under investigation were prepared and maintained by the Irrigation Department. The quoted descriptions which follow, the photographs and diagrams of plots, and the data on irrigation, soil moistures, yields, and weather conditions are taken from the as yet unpublished report of Mr. O. W. Monson and are reproduced with his permission. Since the data on yields and weather conditions are merely supplementary to this investigation, they are given in Parts A and B of the Appendix.

"For the work of 1934 the field work was conducted on twenty-four plots, each containing one-fortieth of an acre (fig. 1). The depth of irrigation and the stage of growth at which the water was applied are given for each plot.

"The land was fall plowed and was worked down early by disking and leveled with an Eversman automatic leveler. It was necessary to scrape off from .1 to .4 foot of soil from about the middle of the field and move it to the east end in order to make it possible to irrigate all plots. After leveling, the soil was left rather dry especially along the east end of the "b" tier of plots where loose dirt had been dumped. The soil is a dark brown clay loam about 2 to 2½ feet deep where it grades into a light brown gravelly clay. It weighs about 77 pounds per cubic-foot. Its apparent specific

THE PEAS PLOTS



PLOT	AMOUNT	Period IRRIGATED	METHOD	DATE
1-a&b	4"	B.B	Flood	6-15-34
2-a&b	4"	E.B.	"	7-2-34
3-a&b	4"	F.B.	"	7-10-34
4-a&b	8"	B.B.	"	6-15-34
5-a&b	8"	E.B.	"	7-2-34
6-a&b	8"	F.B.	"	7-10-34
7-a&b	12"	B.B.	"	6-15-34
8-a&b	12"	E.B.	"	7-2-34
9-a&b	12"	F.B.	"	7-10-34
10-a&b	12"	E.B.	Corrugation	7-2-32
11-a&b	12"-6"	B.B.	"	6-15-34
	-6"	E.B	"	7-2-34
12-a&b	12"-4"	B.B.	"	6-15-34
	-4"	E.B	"	7-2-34
	-4"	Late	"	7-10-34

B.B = Before Bloom ; E.B = Early Bloom ; F.B. = Full Bloom.

Fig. 1.

gravity is 1.23, real specific gravity 2.52, and porosity about 51% in the upper foot and 46% in the second foot.

"An undesirable feature of the soil in these plots was that there were spots where, due to some condition of the soil, the peas practically stopped growing when 3 to 4 inches high. They did not die but were definitely stunted the rest of the season in spite of irrigation. The opinion of Professor Burke of the Chemistry Department is that these spots are old buffalo wallows.

"The plots were seeded May 10 with Perfection peas at the rate of 3 bushels per acre. A nice rain the following day left the soil in a fairly moist condition, and by May 22, the peas were coming up with promise of a good stand."

"It is seen from figure 1 that the plan this year provided principally for a study of the effect of time of irrigation and amount of water applied. Of the 24 plots 18 were needed for these comparisons. Three stages of growth were chosen at which to give a single irrigation: before bloom, early bloom, full bloom. A light, medium, and a heavy irrigation was applied to two plots of each of these stages. As the tests were in duplicate, three pairs of plots were irrigated at each stage, applying 4 inches, 8 inches, and 12 inches of water to them. The water was measured over a V-notch weir for each plot* (Plate I, fig. 1 and 2).

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*The measurements indicated in inches are exactly such as would be for inches of rainfall.

"The before-bloom irrigation was applied June 16, giving 4 inches to plots 1a and 1b, 8 inches to 4a and 4b, and 12 inches to 7a and 7b. The early bloom irrigation was given July 3, with 4 inches applied to 2a and 2b, 8 inches to 5a and 5b, and 12 inches to 8a and 8b. The full-bloom irrigation was given July 10, with 4 inches applied to plots 3a and 3b, 8 inches to 6a and 6b, and 12 inches to 9a and 9b.

"These 18 plots were irrigated by the flooding method,* the remaining plots by the corrugation method with 12 inches applied to each (Plate I, fig. 3). Plots 10a and 10b were irrigated at the early bloom stage with 12 inches of water at one application; 11a and 11b received 12 inches in two 6-inch irrigations, before bloom on June 15, and early bloom on July 3; 12a and 12b received three irrigations of 4 inches each, before bloom, early-bloom and full-bloom.

"A record of the moisture condition of the soil as a result of irrigation is given in Table I. Samples were taken before irrigation and at definite periods after irrigation.** In Table I the amount of water is expressed in inches per foot of soil." "Each observation represents only one sample which was taken near the middle of the plot. Lack of oven space prevented taking multiple samples." "A light rain

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*The flooding method was studied most extensively since it is the method most commonly used by local commercial growers of peas.

**The method used is described in Part B of the Appendix.

Table I

The Amount of Irrigation Water Retained on the Peas Plots

Plot	No. Days After Irr.	Inches Water Applied	Depth Soil Sample (in.)	Inches Water Per Foot of Soil		
				Before Irrigation (inches)	After Irrigation (inches)	Retained (inches)
1a	1	4	0-12	3.410	3.321	-0.089
			13-24	3.485	4.356	0.871
7			0-12		2.834	-0.576
			13-24		3.501	0.016
14			0-12		2.286	-1.124
			13-24		2.962	-0.523
27			0-12		1.875	-1.535
			13-24		1.280	-2.205
2a	2	4½	0-12	3.410	4.251	0.841
			13-24	3.485	3.897	0.412
	7		0-12		3.129	-0.281
			13-24		3.136	-0.349
	14		0-12		1.904	-1.506
			13-24		2.218	-1.267
3a	1	4	0-12	1.520	4.118	2.598
			13-24	2.107	3.992	1.885
	7		0-12		2.893	1.373
			13-24		3.295	1.188
	13		0-12		1.963	0.443
			13-24		1.806	-0.301
4a	1	8	0-12	3.262	4.162	0.900
			13-24	3.580	4.213	0.633
	7		0-12		2.878	-0.384
			13-24		3.596	0.016
	14		0-12		1.993	-1.269
			13-24		2.281	-1.299
	27		0-12		1.830	-1.432
			13-24		0.936	-2.644
5a	2	8½	0-12	3.262	4.118	0.856
			13-24	3.580	3.612	0.032
	7		0-12		3.218	-0.044
			13-24		3.412	-0.159
	14		0-12		2.480	-0.782
			13-24		2.344	-1.236

Table I (continued)

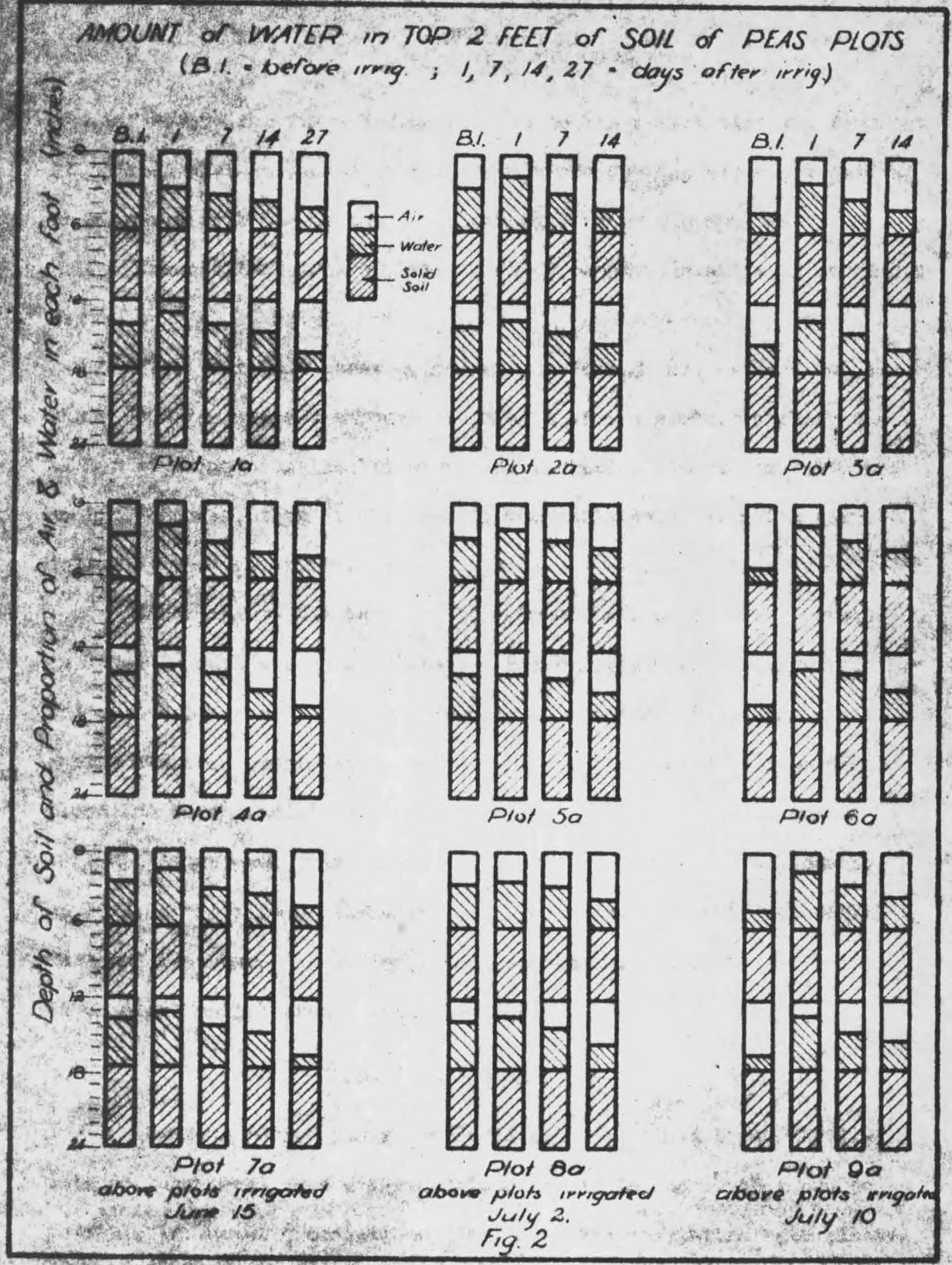
The Amount of Irrigation Water Retained on the Peas Plots

Plot	No. Days After Irr.	Inches Water Applied	Depth Soil Sample (in.)	Inches Water Per Foot of Soil: Before Irrigation (inches)	After Irrigation (inches)	Retained (inches)
6a	1	8 1/3	0-12	0.970	4.433	3.463
			13-24	1.267	4.213	2.946
			0-12		3.306	2.336
			13-24		3.817	2.550
			0-12		2.568	1.598
			13-24		2.598	1.331
7a	1	12	0-12	3.498	4.458	0.960
			13-24	3.928	4.404	0.476
	7		0-12		3.129	-0.369
			13-24		3.453	-0.475
	14		0-12		2.568	-0.930
			13-24		2.804	-1.124
	26		0-12		1.653	-1.845
			13-24		1.004	-2.924
8a	2	11½	0-12	3.498	3.779	-0.281
			13-24	3.928	4.182	0.254
	7		0-12		3.365	-0.133
			13-24		3.374	-0.554
	14		0-12		2.347	-1.151
			13-24		2.059	-1.869
9a	1	12	0-12	1.281	4.561	3.280
			13-24	1.264	4.467	3.203
	7		0-12		3.557	2.276
			13-22		3.073	1.809
	13		0-12		2.480	1.199
			13-22		2.550	1.286
10a	2	12	0-12	2.996	4.000	1.004
			13-24	3.374	4.213	0.839
	7		0-12		3.424	0.428
			13-24		3.659	0.285
	14		0-12		2.258	-0.738
			13-22		2.487	-0.887

Table I (continued)

The Amount of Irrigation Water Retained on the Peas Plots

Plot	No. Days After Irr.	Inches Water Applied	Depth Soil Sample (in.)	Inches Water Per Foot of Soil: Before Irrigation (inches)	After Irrigation (inches)	Retained (inches)
11a	1	6 (1st)	0-12	2.996	4.177	1.181
			13-24	3.374	4.087	0.713
	7		0-12		3.262	0.266
			13-24		3.881	0.507
	14		0-12		2.170	-0.826
			13-24		2.598	0.776
	2	6 (2nd)	0-12	2.170	3.838	1.668
			13-24	2.598	3.770	1.172
	7		0-12		3.218	1.049
			13-24		3.642	1.044
	14		0-12		2.583	0.413
			13-23		2.534	-0.064
12a	1	4 (1st)	0-12	2.996	4.369	1.373
			13-24	3.374	4.150	0.776
	7		0-12		3.247	0.251
			13-24		4.404	1.030
	14		0-12		2.184	-0.812
			13-24		3.057	-0.317
	2	4 (2nd)	0-12	2.184	3.528	1.344
			13-24	3.057	3.358	0.301
	7		0-12		2.583	0.399
			13-24		2.661	-0.396
	1	4 (3rd)	0-12	2.583	4.517	1.934
			13-24	2.661	4.150	1.489
	7		0-12		2.937	0.354
			13-24		3.010	0.349
	13		0-12		2.199	-0.384
			13-24		1.885	-0.776


AMOUNT of WATER in TOP 2 FEET of SOIL of PEAS PLOTS
(B.I. - before irrig. ; 1, 7, 14, 27 - days after irrig.)
Depth of Soil and Proportion of Air & Water in each Foot (inches)
B.I. 1 7 14 27
Air
Water
Solid Soil
Plot 1a
Plot 2a
Plot 3a
Plot 4a
Plot 5a
Plot 6a
Plot 7a
above plots irrigated June 15
Plot 8a
above plots irrigated July 2.
Plot 9a
above plots irrigated July 10
Fig. 2

the day before the first irrigation may be the reason that the top foot of soil on plot 1a showed a loss in moisture one day after irrigation, as compared with the amount present before water was applied."

The critical data of Table I are presented graphically in figure 2.

"Two four-foot observation wells were dug, one at each end of the wide alley running through the middle of the plots, to check the effect of irrigation locally on the water table. The water table was so low, however, that it appeared in the wells only for a few hours following the irrigation."

According to the Agronomy Department, all parts of the area included in each series of plots had had exactly the same treatment for the past ten years. A cropping system of alternate fallow and small grains had been consistently used. Thus in the season of 1933 the plots had been planted to winter wheat; and in 1932 left to summer fallow. After each cutting of grain, stable manure had been evenly applied at the rate of about ten tons per acre. No artifical fertilizer had been used for at least ten years back. There are no data of chemical soil analyses available for these plots.

B. The Garden Plots

The four garden plots, prepared and maintained by the Horticulture Department, are diagramed in relation to one another and to possible influencing conditions (fig. 3). The vegetables were planted

in rows running straight through the four plots. It will be noted that the areas of the plots are not all the same. Comparative yield data were secured by harvesting equal lengths of rows on each plot.

According to the Horticulture Department, for at least four years previous to 1934 all four plots had been cropped as a single unit and had thus received identical treatment. In 1933 they had been in head lettuce; 1932, celery; 1931, tomatoes; 1930, cabbage. Each fall (including the fall of 1933) the area had received a uniform application of stable manure at the rate of about 10 tons per acre. No commercial fertilizers had been used. There are no data of chemical soil analyses available for these plots.

Plot A was irrigated by overhead sprinkling; plot B by a series of 12 lath tiles placed 18 inches below the surface and running parallel to the rows; plot C by furrows running between each row of plants. Plot D received no artificial irrigation. It will be noted that Plot D (presumably dry-land) was at the lower end of the series. This can hardly be considered a true dry-land plot. The methods of irrigation used were selected by the Horticulture Department as the ones best adapted to the growing of vegetables in Montana.

Plots A, B, C were irrigated at intervals of from 7 to 12 days. No measurement was made of the amount of water applied to each plot.

Soil moisture determinations were made by the writer at weekly intervals throughout July and daily between the first two irrigations

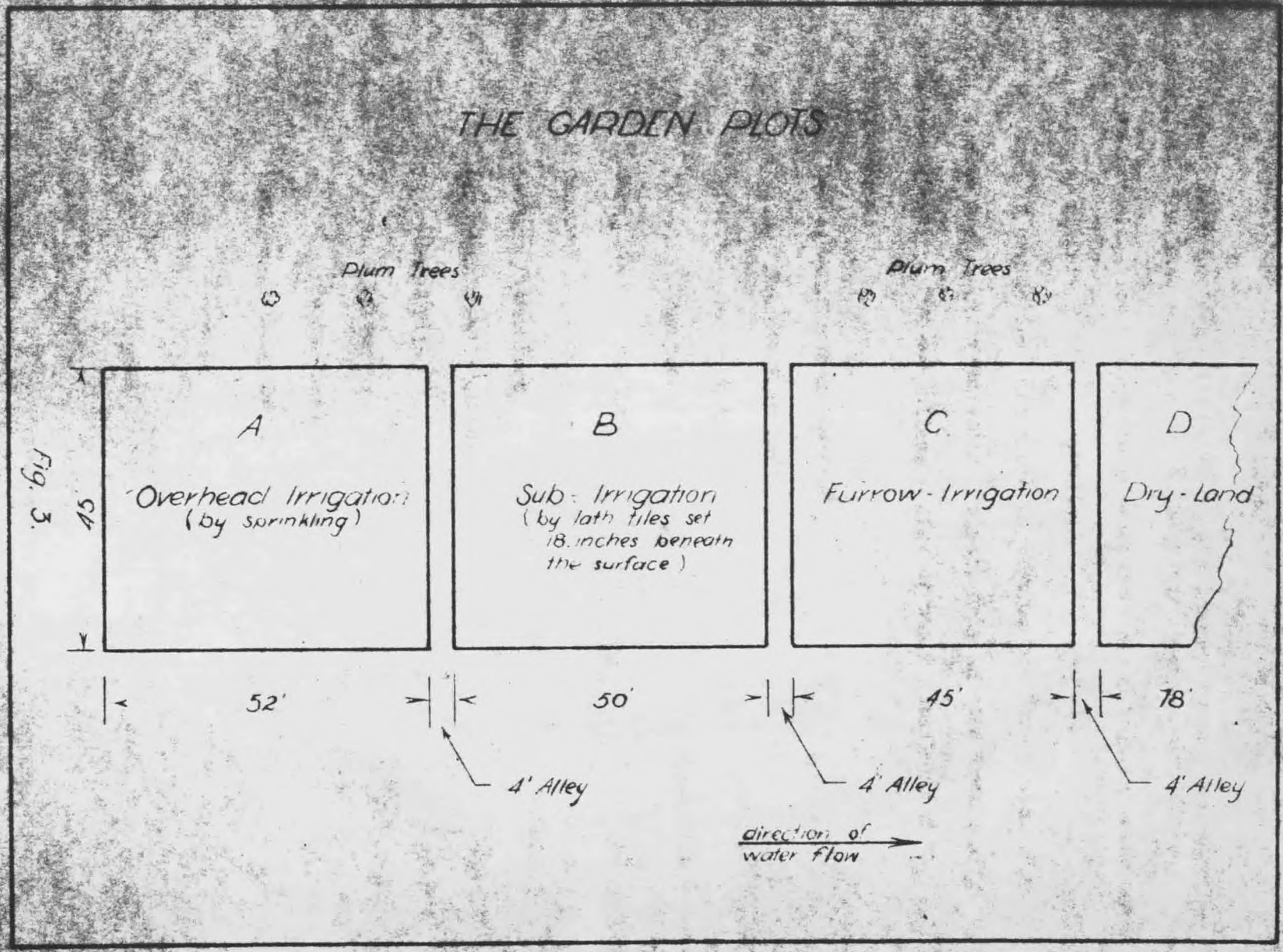

THE GARDEN PLOTS
Plum Trees
Plum Trees
A
Overhead Irrigation
(by sprinkling)
B
Sub-Irrigation
(by lath tiles set 18 inches beneath the surface)
C
Furrow-Irrigation
D
Dry-Land
45'
52'
50'
45'
78'
4' Alley
4' Alley
4' Alley
direction of water flow

Fig. 3.

in August. The data obtained are without any apparent significance for this investigation. They are presented in part, together with the method used, in Part B of the Appendix.

Some 15 vegetables were grown on each of the four plots. However, due to a poor stand in several cases, only 12 were included in this investigation. There follows a list of the vegetables and varieties used:

Beans, Stringless Greenpod

Beets, Detroit Dark Red

Cabbage, Danish Ballhead

Carrots, Chantenay

Corn, Golden Bantam

Cucumbers, Chicago Pickling

Lettuce, New York

Parsnips, Hollow Crown

Potatoes, Bliss

Squash, Buttercup

Table Queen

Tomatoes, Bonny Best

IV. PREPARATION OF SAMPLES

The procedures involved in the preparation of samples naturally fall into three groups and will be considered in this manner. Early in the investigation it was hoped to include iodine in the problem. Although this later became impossible due to limitations in time, the original samples taken were for this reason much larger than would otherwise have been the case.

A. Harvesting and Preparation of the Edible Portion

The peas were harvested by cutting the vines in the field and shelling in the laboratory. All samples were taken from the western end of tier "a" (at the left ends of the plots of the "a" tier as they appear in figure 1). There are several reasons why this method of sampling was used in preference to the general practice of taking multiple samples:

1. Irrigation water was applied from a ditch on the west side of tier "a". It is therefore on tier "a", and particularly on the west portion, that the irrigation could be most carefully controlled.

2. On some of the plots of tier "b" the ground sloped so much that control of irrigation was less precise. It was also on this tier that the topsoil had been leveled off in places, thus tending toward unevenness of soil composition.

3. None of the "dead spots" (supposedly old buffalo wallows) occurred in the western portion of the plots of tier "a".

4. The method used was the most convenient one by which a record could be kept of the area harvested.

Starting from the west end of each plot, the first eight feet were left untouched. From the eight foot mark a sufficient number of running feet were harvested to give the desired sample. During the harvesting, all vines in the area forming a two foot border inside the ditch were kept separate, shelled separately, weighed, and discarded. These precautions were taken to eliminate as far as possible the effect of the irrigating waters of the ditches and adjacent plots. In computing the total yield of the area harvested, the weight of peas from the "border" area were added to the weight of the actual sample. The data on yields and area harvested are given in Part A of the Appendix.

Due to the large amounts of material to be handled, the harvesting had to be spread out over a three day period.* The peas were weighed immediately after shelling, and stored in a refrigerator until they could be dried.

All the vegetables from the garden plots were harvested by the Horticulture Department and delivered to the Home Economics Department for further preparation. The "edible portion" was obtained in the manner commonly used in the preparation of each vegetable. Except for

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*Dates for each plot are given in Appendix A.

the beets, carrots, cucumbers, and lettuce this was done by the Home Economics Department. There are two cases in which there might be a question as to method of preparation. In the case of cucumbers the entire fruit was used since this constitutes the most common edible portion. In the case of beets the skins were removed by the common practice of placing in boiling water. Whenever the material was in pieces too large for efficient drying, it was cut into smaller pieces with a stainless steel knife.

B. Drying and Grinding

The drying was done in either a steam heated or electrically heated drier, both of which were provided with fans for circulating the air. The vegetables were placed in wooden trays, the bottoms of which were covered with light muslin. The temperature of the driers ranged from 55° to 65° C. This method of drying did not eliminate dust, which may have had a contaminating and significant effect on the iron content. However, no other method was available.

After from 48 to 96 hours in the drier, depending upon the nature of the vegetable, the sample was removed and the larger pieces broken up by hand. It was then "tabled" by placing on a piece of oilcloth about 2½ ft. square and pulling each corner of the cloth in succession over the diagonal corner, thus causing the pieces to roll over one another. This was continued until each corner had been pulled across for 10 times.

A special sample for the iron determination of from 10 to 80 grams was withdrawn by picking out pieces at random. This iron sample was ground by hand in a porcelain mortar. The main sample was ground in a feed grinder. Experience on the lettuce sample showed that if only this treatment were given, the sample might be hard to handle due to gain in weight while weighing. Consequently each sample was spread out between newspapers on tables in the laboratory for a period of 10 days, so that it might become "air-conditioned" to the moisture conditions of the laboratory.

C. Sampling and Preserving

After ten days "air-conditioning" to the laboratory, the iron samples were tranferred to pint canning jars provided with rubber seals. Because of their size, the main samples were again "tabled" and then likewise bottled up.

V. METHODS OF ANALYSIS

As closely as possible the methods of analysis of the Association of Official Agricultural Chemists (1) were followed. These will be referred to as the "Official Methods." However, in several cases, due to lack of proper equipment, the method had to be modified. Each determination was done at least in duplicate.

A. Moisture in the Fresh Sample

In the case of the peas the water in the fresh sample was determined by weighing the whole sample before and after drying, and then determining the residual moisture as to be explained for the estimation of moisture in the dry sample. The sum of these two determinations was taken as a representation of the moisture in the fresh sample. This method proved impractical due to unavoidable losses in handling. A different method was used for the samples from the garden plots.

Immediately after the preparation of the edible portion a sample, as representative as possible, was weighed out in an aluminum weighing can and dried to constant weight at 55° to 60° C. The weight of sample taken varied with the nature of the vegetable but averaged about 10 to 15 grams. Most of this work was done in the laboratories of the Home Economics Department.

B. Moisture in the Dry Sample

After the "air-conditioning" of the sample (see above), a five to seven gram portion was weighed out in an aluminum weighing can,

dried for 15 hours at 95° C., cooled in a dessicator, and weighed. No vacuum oven or vacuum dessicators of suitable capacity were available for either moisture determination.

It is obvious that neither of the moisture analyses are complete expressions of the actual amount of water present. Their dependability is limited to comparative results for any one vegetable. However, since the arbitrarily set conditions were rigidly maintained, the moisture determinations are sufficiently accurate on a relative basis. And it is on this basis only that they are to be interpreted.

C. Total Ash

Ash was determined according to the Official Methods (XXVII,8).*

D. Calcium

Calcium was determined according to the Official Methods (XII, 9, first procedure).

Because of the comparatively low calcium content of most of the vegetables, rather large initial samples had to be used. Since there was no muffle available which would handle the quantities necessary, a preliminary removal of most of the organic material had to be accomplished in an evaporating dish over an open flame. When the volume was sufficiently reduced, the residue was transferred to a 100 ml. porcelain crucible and further ignited in an electric muffle. This

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*Numbers refer to procedures in the Official Methods (1).

was a cumbersome and time-consuming operation. To reduce the time required, wherever possible the material for duplicates was obtained in one ashing. The ash was then dissolved to a definite volume of solution and aliquots taken for duplicates. For several vegetables the sample required was too large for this operation. There was no significant difference in the agreement between the duplicates taken by aliquot and the duplicates obtained by separate ashing.

E. Iron

Iron was determined according to the micro-colorimetric procedure of the Official Methods (XII, 7). The preliminary ashing and sampling was done by the same procedure described for Calcium.

F. Nitrogen

Nitrogen was determined according to the procedure of the Official Methods for "Organic and Ammoniacal Nitrogen Only" (II, 19).

G. Phosphorous

The determination of phosphorous by the volumetric procedure of the Official Methods (II, 7), was first attempted. For some undetermined reason this method failed time and again to give consistent results. Finally the gravimetric method was substituted, and proved completely satisfactory. Since the procedure used was a modification of several methods (5, 24), it is given in detail.

The ashing was done, using a two gram sample in a 100 ml. pyrex beaker, by the magnesium nitrate procedure of the Official Methods (XII, 26). The stock solutions used in the analysis are given.

Molybdate Solution. This was prepared by mixing together just before using, two volumes of a solution of 400 ml. nitric acid in 600 ml. water and one volume of a solution of 100 gm. ammonium molybdate and 80 ml. ammonia in 400 ml. water.

Acid Ammonium Nitrate Solution. Fifty ml. of nitric acid and 70 gm. of ammonium nitrate were dissolved in water and diluted to one liter.

Magnesia Mixture. Fifty-five gm. magnesium chloride hexahydrate, 105 gm. ammonium chloride, and 5 ml. concentrated hydrochloric acid were dissolved in water and diluted to one liter.

The ash was dissolved in water and nitric acid and aliquots taken when necessary to obtain a smaller sample. The volume was made up to 100 ml. and 12 gm. of solid ammonium nitrate added. The pH was adjusted by the addition of ammonium hydroxide until the solution was just barely acid to methyl orange. The solution was heated to 60°, 30 ml. of Molybdate Solution added, and the mixture stirred and let stand over night.

The supernatant liquid was filtered off, keeping as much of the precipitate as possible in the beaker. The precipitate was washed five times by decantation with Acid Ammonium Nitrate Solution. The

beaker, containing most of the yellow precipitate, was placed under the funnel and the filter was washed down with several 10 ml. portions of 2.5 M ammonium hydroxide, with several 5 ml. portions of hot water, and finally with a 5 ml. portion of 6 N hydrochloric acid.

6 N hydrochloric acid was added until the solution was just acid to methyl red, and then 5 ml. of concentrated hydrochloric acid in excess. The solution was diluted to 150 ml. and 20 ml. of Magnesia Mixture added. Concentrated ammonia was then added slowly with stirring to neutralization. After three to four minutes stirring, a 10 ml. excess of concentrated ammonia was added. After 10 minutes of frequent stirring, the mixture was allowed to stand over night. The precipitate was filtered through a #40 Whatman paper and washed with 1.5 M ammonium hydroxide solution.

The precipitate was ignited at low heat in an electric muffle until the ash was white, and then at full heat for two hours. Experience showed that this time was sufficient to reduce the residue to constant weight.

VI. TABULATION AND DISCUSSION OF DATA

The results of the analyses are best presented in tabular form. Since the study of the peas plots and the study of the garden plots are two distinct aspects of the problem, the two groups of data will be presented and discussed separately before any general conclusions are attempted.

A. The Peas Plots

The results of the analyses of the peas are presented in Table II. The plots were grown under conditions controlled in such a manner that four different problems were involved:

1. The effect of the amount of water applied;
2. The effect of the period of irrigation;
3. The relative efficiency of the flooding and corrugation methods;
4. The relative efficiency of water applied at one or several irrigations.

Nine of the twelve duplicate plots were concerned only with the effects of the amount and period of irrigation (for the flooding method). The first two problems listed above are, therefore, the only ones upon which sufficient data can be secured to draw any valid conclusions. In regard to the last two of the problems suggested above, data are so meager that any conclusions drawn can be valid only as indications for further work.

Although this problem is essentially concerned with composition, i.e., percentages of constituents, still the relative yields cannot be neglected. For instance the dry-land plot (of the garden plots) produced vegetables frequently higher in percentages of minerals than those of the irrigated plots; but the quality and yields from this plot were so low that the higher percentage of minerals loses its practical significance. The data for the peas plots will therefore be presented in two ways: in terms of percentage composition, and in terms of total yields.

All the data given for peas are on the dry basis. The moisture content varied so little that an average of 80.4% water was taken as the best expression for the peas of each plot. This means that the results for both the fresh and dry basis are relatively the same. Because of this constant relation, only one set of data, that for the dry basis, will be given.

In Tables III and IV the data of Table II on percentage composition are averaged in respect to the period and the amount of irrigation. In order to compare the variations caused by these two factors, the average deviations from the mean or the "mean deviations" have been calculated. This affords only a very arbitrary comparison. It depends upon the assumption that "light", "medium", and "heavy" irrigations were applied at "early", "medium", and "late" periods; and these terms are obviously matters of opinion. There is no comparative yardstick available.

Table II

Percentage Composition of Peas

Plot	Calcium	Iron	Phosphorous	Nitrogen	Ash
1a	.0988	.0104	.680	5.45	3.75
2a	.0933	.0121	.614	5.35	3.70
3a	.1051	.0099	.542	4.57	3.56
4a	.0886	.0109	.599	5.42	3.58
5a	.0914	.0116	.572	4.91	3.53
6a	.1030	.0094	.507	4.44	3.40
7a	.0973	.0086	.605	5.60	3.47
8a	.0998	.0099	.508	4.88	3.44
9a	.1071	.0092	.524	4.61	3.45
10a	.1021	.0095	.600	4.90	3.47
11a	.0933	.0099	.662	5.28	3.76
12a	.0982	.0111	.696	5.69	4.38

All figures in %, air dry basis

Table III

Averages for Percentage Composition of Peas of All Plots Irrigated at the Same Time

(air-dry basis)

	Calcium	Iron	Phosp.	Nitrogen	Ash
Before Bloom 1a, 4a, 7a	.0949	.0100	.628	5.49	3.60
Early Bloom 2a, 5a, 8a	.0948	.0112	.565	5.05	3.56
Full Bloom 3a, 6a, 9a	.1051	.0095	.524	4.54	3.47
Average	.0983	.0102	.573	5.03	3.54
Mean Deviation	.0046	.0007	.034	.32	.05

Table IV

Averages for Percentage Composition of Peas of All Plots Irrigated with the Same Amounts of Water

(air-dry basis)

	Calcium	Iron	Phosp.	Nitrogen	Ash
4 inches 1a, 2a, 3a	.0991	.0108	.612	5.12	3.67
8 inches 4a, 5a, 6a	.0943	.0106	.559	4.92	3.50
12 inches 7a, 8a, 9a	.1014	.0092	.546	5.03	3.45
Average	.0983	.0102	.573	5.03	3.54
Mean Deviation	.0026	.0007	.027	.06	.09

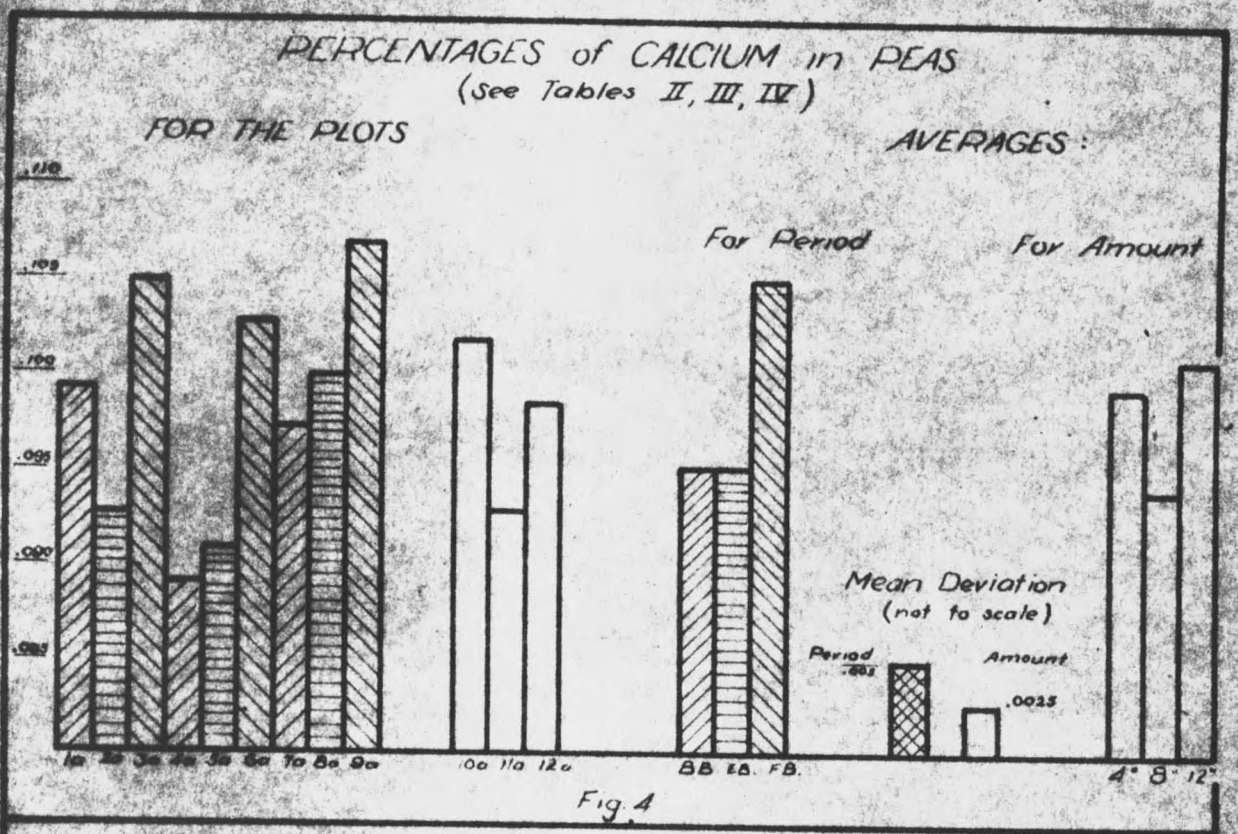

PERCENTAGES of CALCIUM in PEAS
(see Tables II, III, IV)
FOR THE PLOTS
AVERAGES :
For Period
For Amount
Mean Deviation
(not to scale)
Period
Amount
.0025
1a 2a 3a 4a 5a 6a 7a 8a 9a
10a 11a 12a
BB EB. FB.
4" 8" 12"

Fig. 4

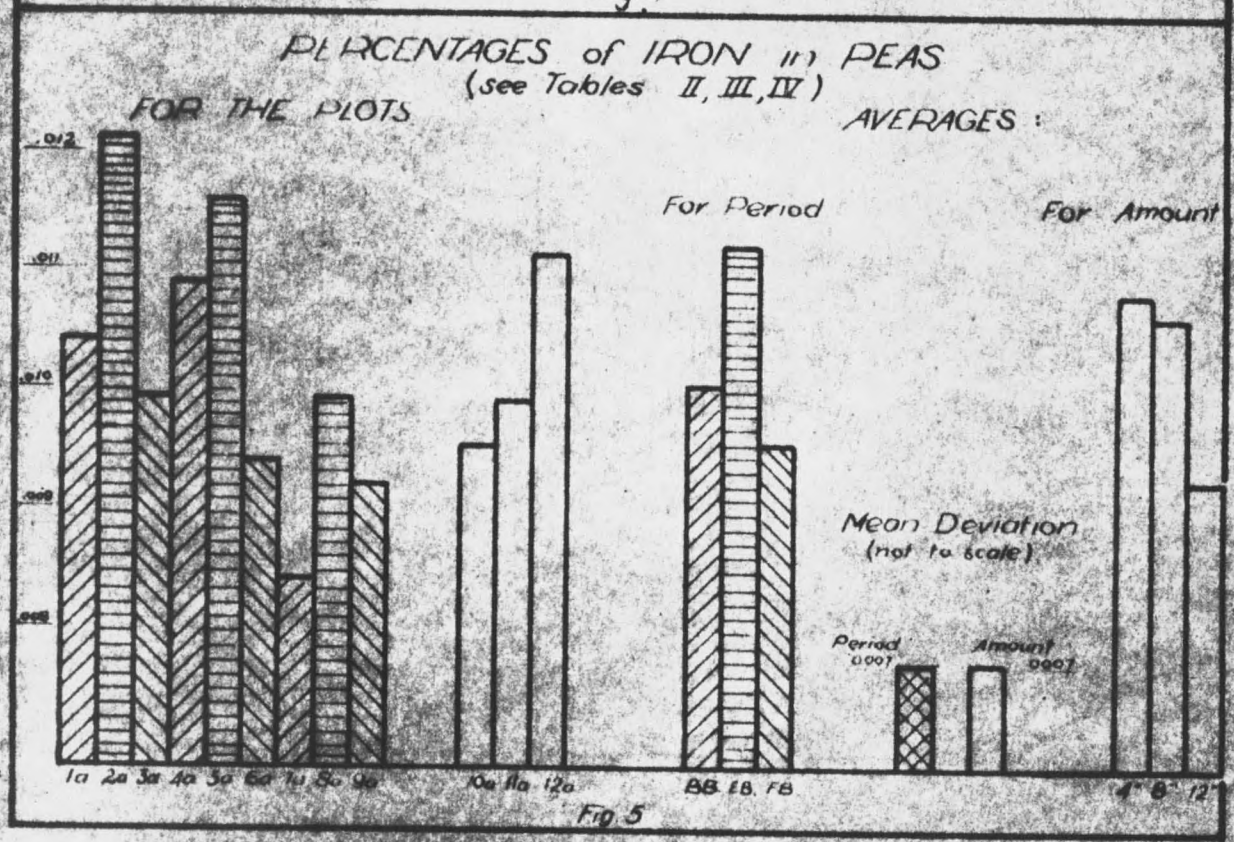

PERCENTAGES of IRON in PEAS
(see Tables II, III, IV)
FOR THE PLOTS
AVERAGES :
For Period
For Amount
Mean Deviation
(not to scale)
Period
Amount
1a 2a 3a 4a 5a 6a 7a 8a 9a
10a 11a 12a
BB EB. FB
4" 8" 12"

Fig. 5

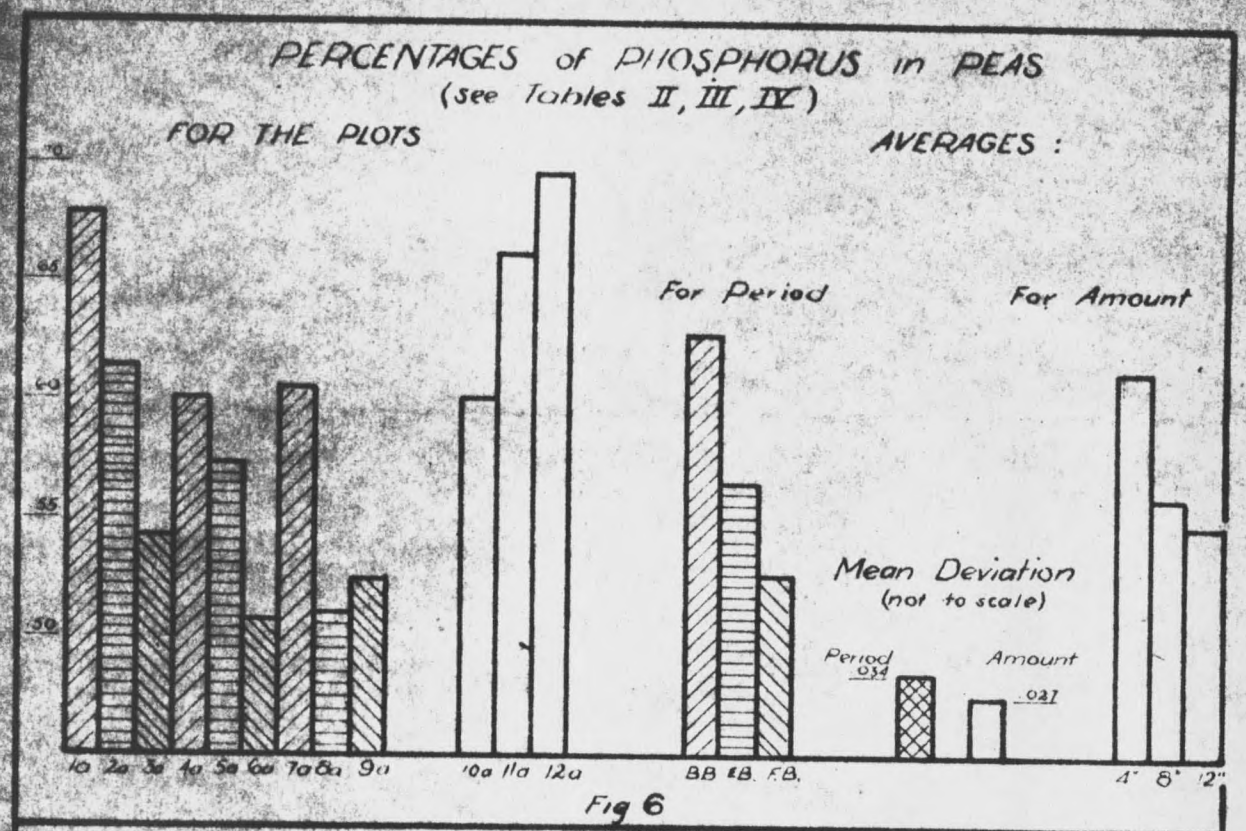

PERCENTAGES of PHOSPHORUS in PEAS
(see Tables II, III, IV)
FOR THE PLOTS
AVERAGES :
For Period
For Amount
Mean Deviation
(not to scale)
Period .034
Amount .021
1a 2a 3a 4a 5a 6a 7a 8a 9a
10a 11a 12a
BB EB. FB.
4" 8" 12"

Fig 6

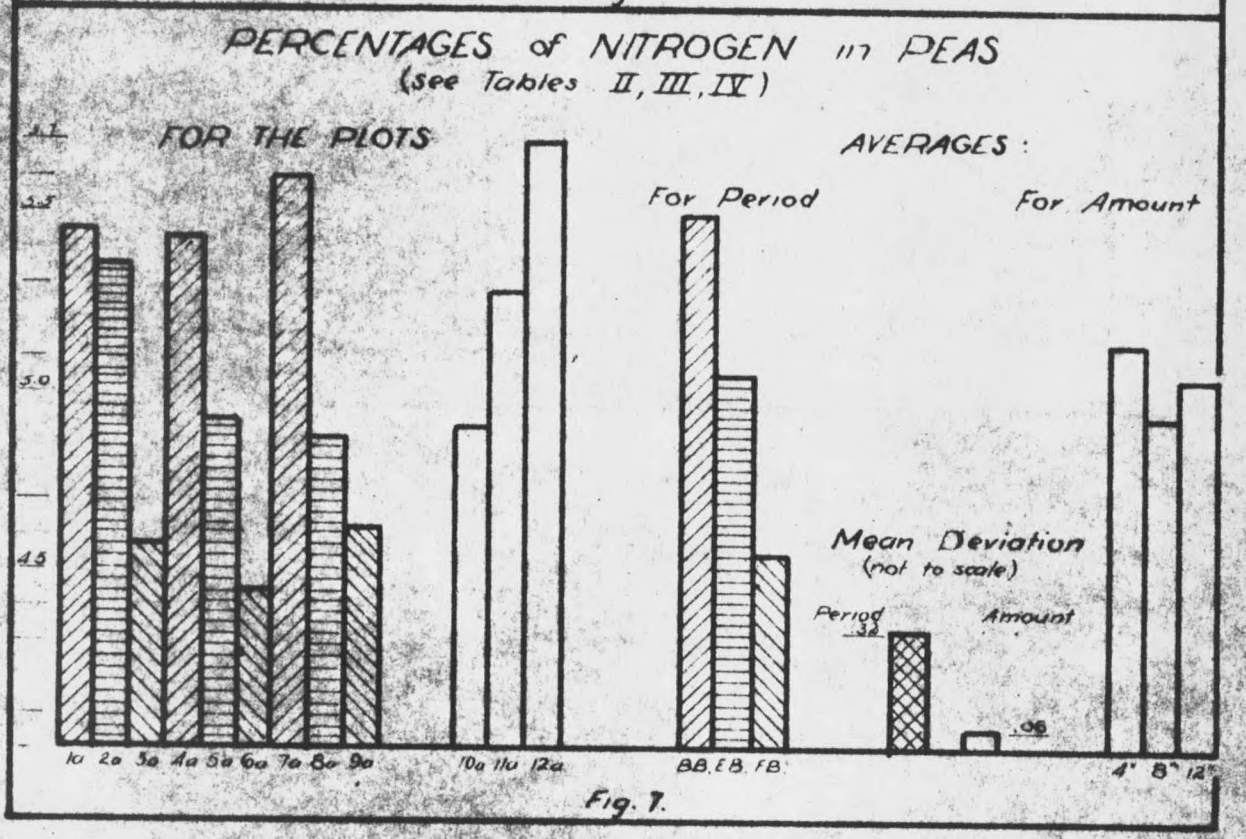

PERCENTAGES of NITROGEN in PEAS
(see Tables II, III, IV)
FOR THE PLOTS
AVERAGES :
For Period
For Amount
Mean Deviation
(not to scale)
Period .32
Amount .06
1a 2a 3a 4a 5a 6a 7a 8a 9a
10a 11a 12a
BB. EB. FB.
4" 8" 12"

Fig. 7.

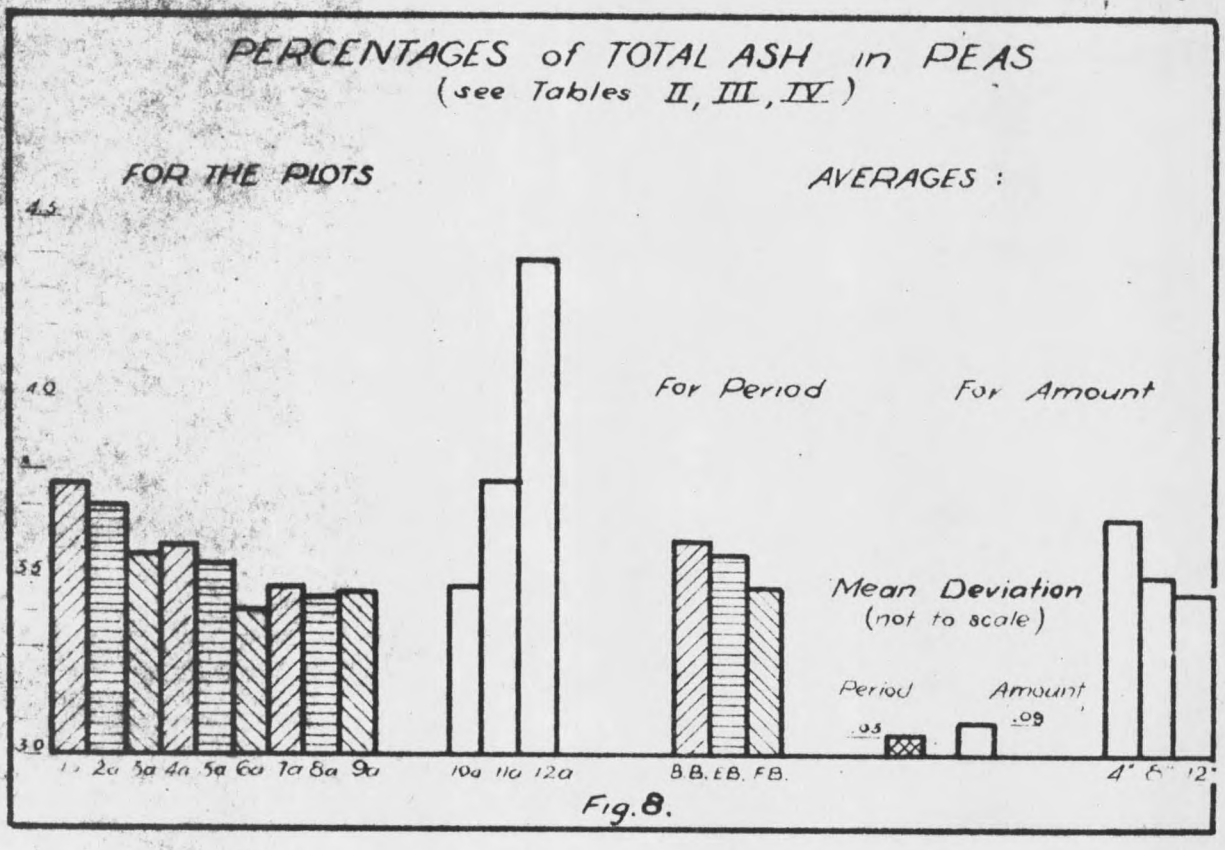

PERCENTAGES of TOTAL ASH in PEAS
(see Tables II, III, IV)
FOR THE PLOTS
AVERAGES :
4.5
4.0
3.5
3.0
For Period
For Amount
Mean Deviation
(not to scale)
Period
Amount
.05
.09
1a 2a 3a 4a 5a 6a 7a 8a 9a
10a 11a 12a
B.B. E.B. F.B.
4" 8" 12"

Fig. 8.

Table V

Total Yield of Constituents per Plot
on Peas

Plot	Calcium	Iron	Phosphorous	Nitrogen	Ash
1a	6.9	.73	48	385	265
2a	12.0	1.56	79	690	465
3a	15.7	1.48	81	683	532
4a	6.4	.79	43	393	259
5a	9.8	1.24	61	525	378
6a	16.0	1.46	79	688	527
7a	6.4	.56	40	367	228
8a	11.1	1.10	57	544	384
9a	13.0	1.11	63	558	417
10a	12.8	1.20	75	616	436
11a	9.1	.97	65	515	367
12a	8.0	.90	56	461	355

All figures in grams, expressing total yield per plot in the seeds. Calculated by use of Table and data listed in Appendix A.

Table VI

Averages for Total Yields of Constituents of Peas of All Plots Irrigated at the Same Period

	Calcium	Iron	Phosp.	Nitrogen	Ash
Before Bloom 1a, 4a, 7a	6.6	.69	44	382	251
Early Bloom 2a, 5a, 8a	11.0	1.30	66	586	409
Full Bloom 3a, 6a, 9a	14.9	1.35	74	643	492
Average	10.8	1.11	61	537	384
Mean Deviation	2.8	.28	12	103	89

Table VII

Averages for Total Yields of Constituents of Peas of All Plots Irrigated with the Same Amounts of Water

	Calcium	Iron	Phosp.	Nitrogen	Ash
4 inches 1a, 2a, 3a	11.5	1.26	69	586	421
8 inches 4a, 5a, 6a	10.7	1.16	61	535	388
12 inches 7a, 8a, 9a	10.2	.92	53	490	343
Average	10.8	1.11	61	537	384
Mean Deviation	.5	.10	5	33	24

All figures in grams, for seeds only

TOTAL YIELDS of CALCIUM per PLOT of PEAS
(see Tables V, VI, VII)

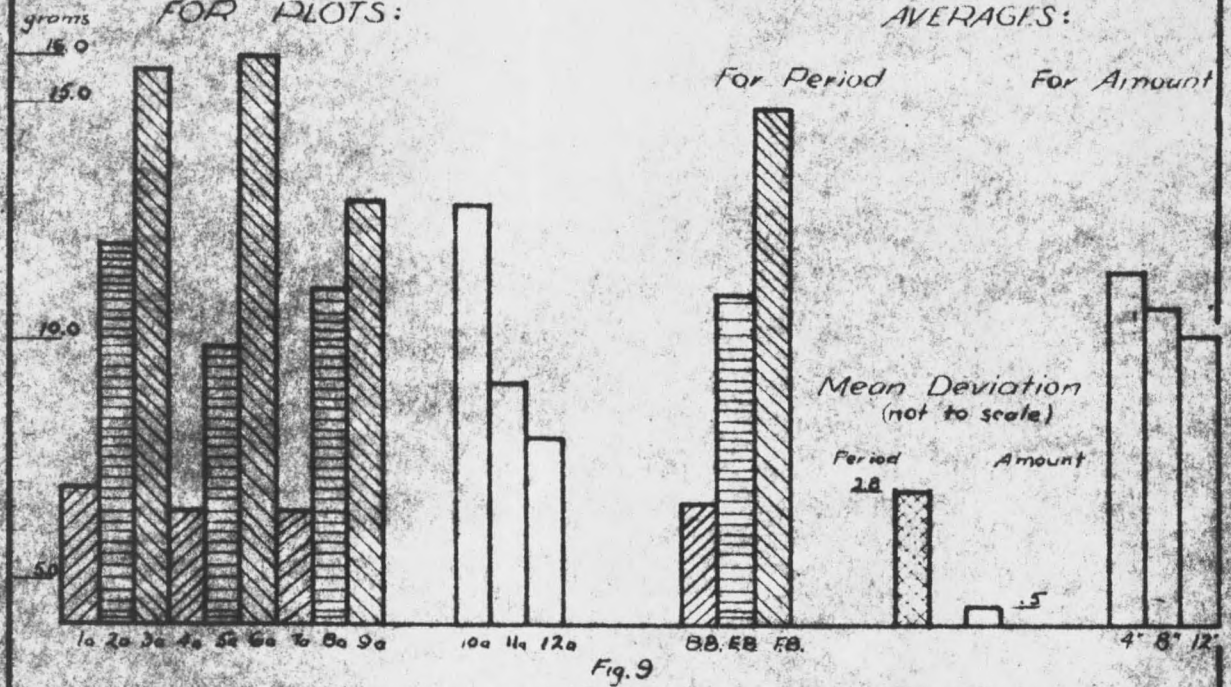


Fig. 9

TOTAL YIELDS of IRON per PLOT of PEAS
(see Tables V, VI, VII)

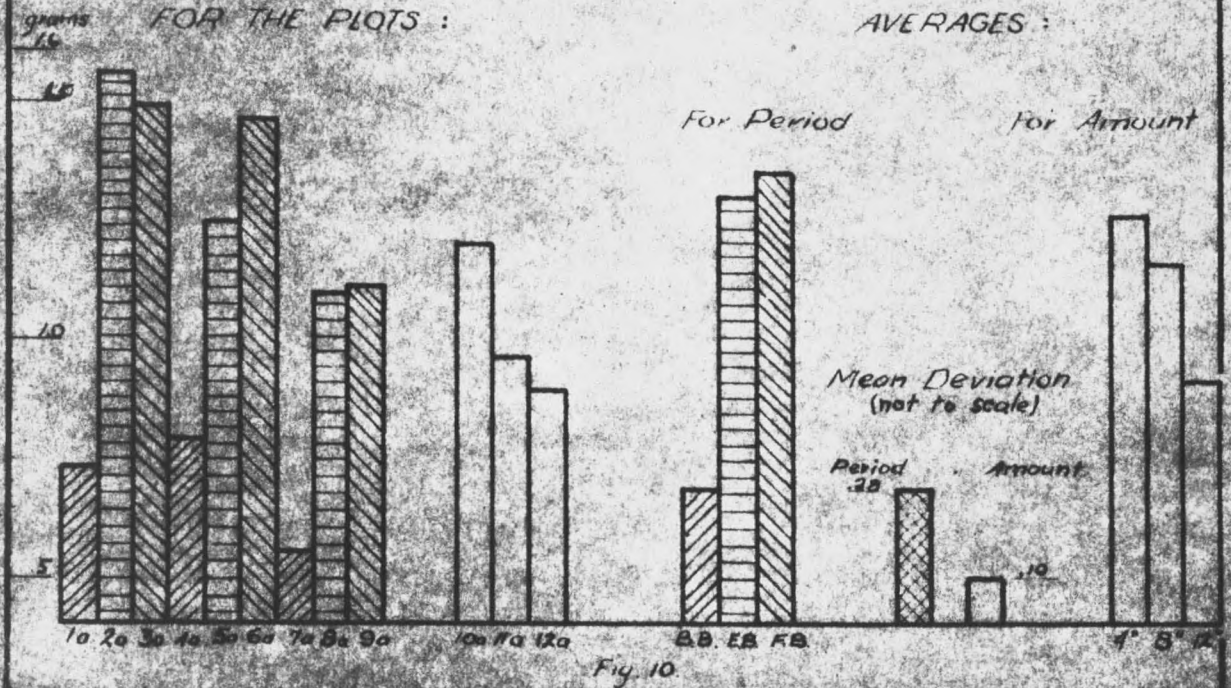


Fig. 10

TOTAL YIELDS of PHOSPHORUS per PLOT of PEAS
(see Tables V, VI, VII)

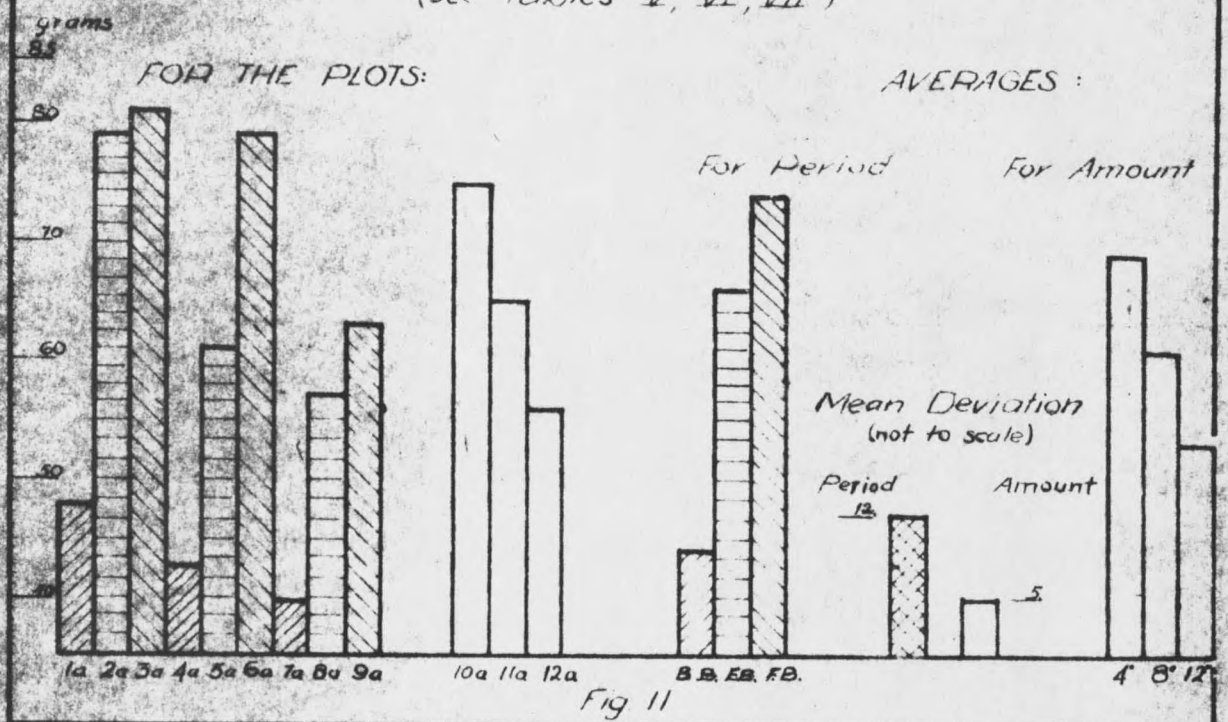


Fig 11

TOTAL YIELDS of NITROGEN per PLOT of PEAS
(see Tables V, VI, VII)

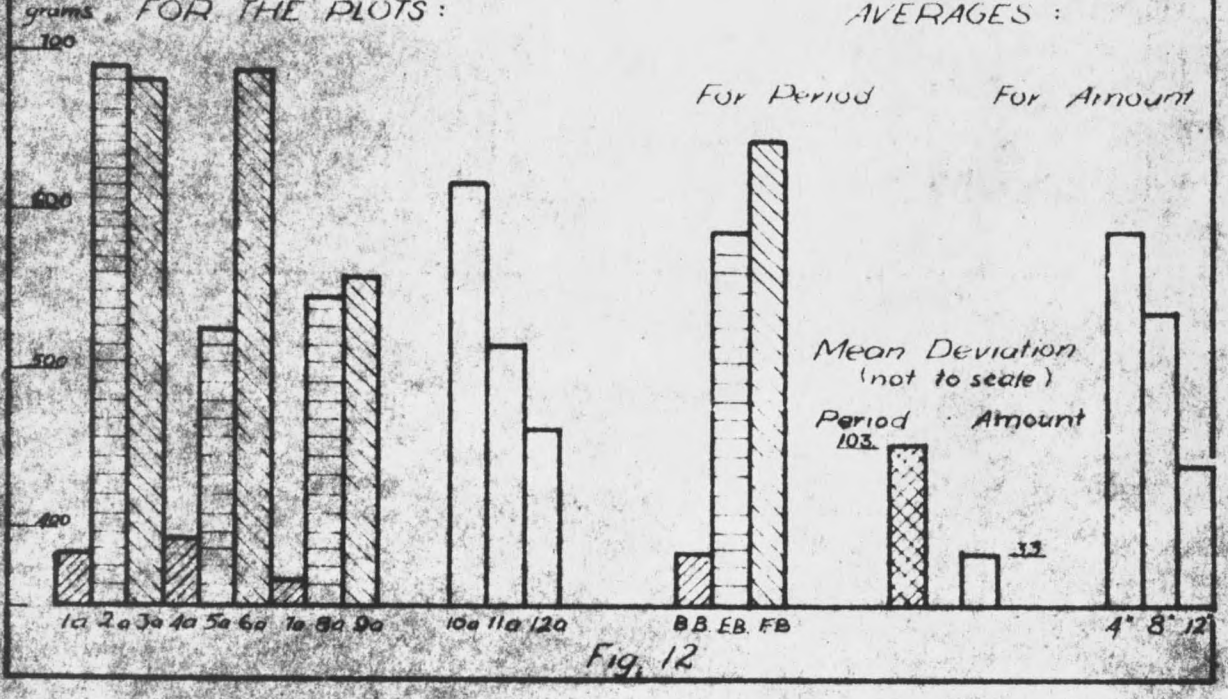


Fig. 12

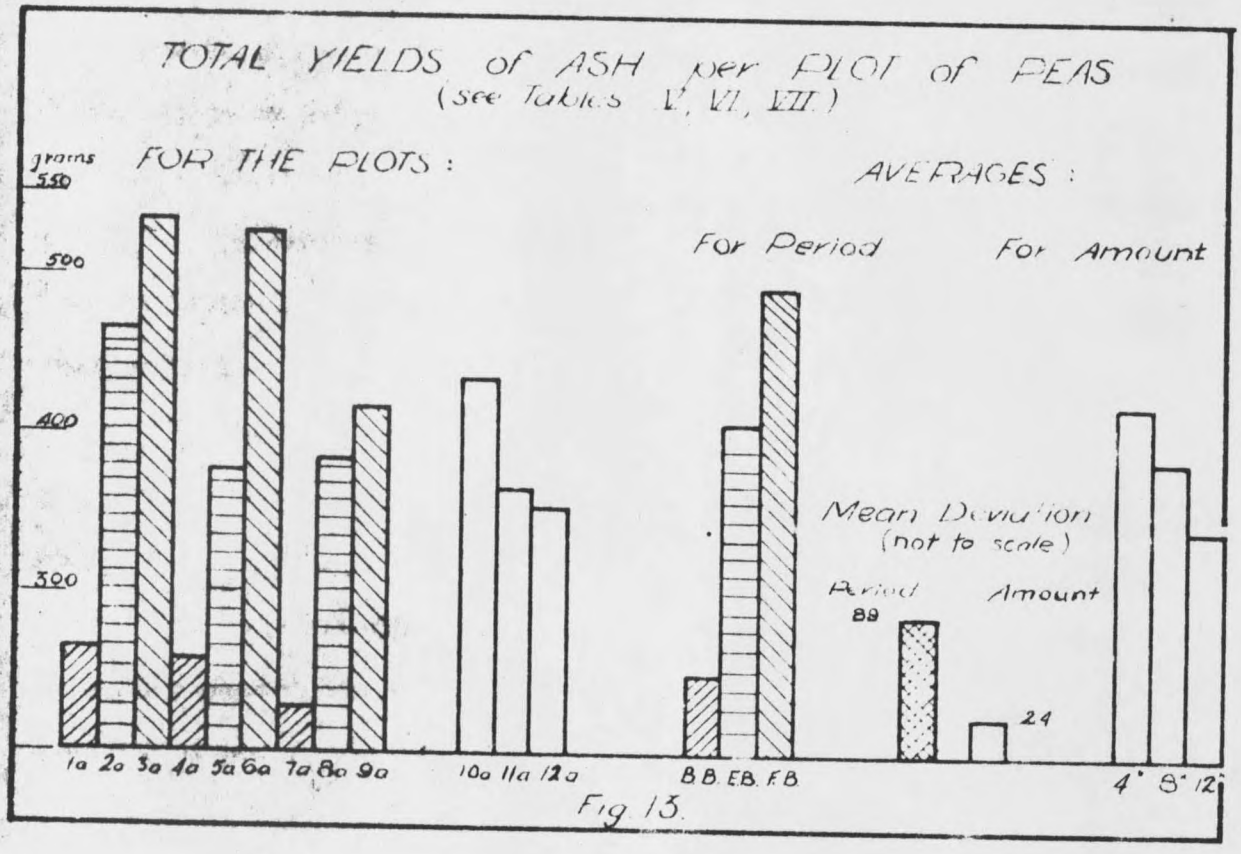

TOTAL YIELDS of ASH per PLOT of PEAS
(see Tables V, VI, VII.)
grains
550
500
400
300
FOR THE PLOTS :
AVERAGES :
For Period
For Amount
Mean Deviation
(not to scale)
Period
Amount
89
24
1a 2a 3a 4a 5a 6a 7a 8a 9a
10a 11a 12a
B.B. E.B. F.B
4° 8° 12°

Fig. 13.

The material of Tables II, III, IV is treated graphically in Figures 4 to 8. The mean deviations are termed "not to scale". This means that their values are not to be read off from the included scale. The actual ratio of unit value to unit measurement is the same as that used throughout the figure.

From the data of Table II and the yield data (Appendix A) the total yields of Table V were calculated. The averages for yields in respect to the period and amount of irrigation are given in Tables VI and VII. The variations in these averages are also compared by the mean deviations. (It is to be emphasized that these are yields for the seeds only.)

The data of Tables V, VI, and VII on total yields are treated graphically in Figures 9 to 13 by the same method used for percentage composition.

The significance of the data is shown so clearly in the graphs that any extended discussion would be superfluous. However, there are a number of points which deserve special consideration.

1. Variations in the total ash were much less pronounced than variations in calcium, iron, or phosphorous. This indicates that period and amount of irrigation were important in their "balancing" effects upon mineral composition of the seeds.

2. The period of irrigation was relatively more important than the amount of irrigation upon the nitrogen content of peas. Earlier irrigation gave markedly higher nitrogen content.

3. The variance between methods was generally less than the variance for period and amount. However, the methods (flooding and corrugation) were compared for only one amount and one period of irrigation. To some extent this substantiates the conclusion of Widstoe and Stewart (28), who found that the difference between the two methods were not significant.

4. Calcium, iron, and phosphorous showed different optimum periods of irrigation for percentage composition. The calcium content was greatest for full-bloom irrigation, but the difference in effect between before-bloom and early-bloom irrigation was negligible. The iron content was highest for early-bloom irrigation and lowest for full-bloom. The phosphorous content was highest for before-bloom and lowest for full-bloom irrigation.

5. In comparing the corrugated plots irrigated by twelve inches of water, it is interesting to note that plot 12a which received three 4-inch irrigations is high for percentages of iron, nitrogen, phosphorous, and total ash. But the yield on plot 10a (one 12-inch irrigation) was so much larger that the total yields are consistently higher for this plot.

6. The water content of the peas was not appreciably affected by any of the observed conditions.

7. The response of yield of edible portion was much more pronounced than the response of chemical composition. This is evident

from a comparison of the graphs for percentage composition and those for total yields. Four-inch irrigations at full-bloom were optimum for all total yields; 12-inch irrigations before bloom were poorest.

8. The highest content of iron, phosphorous, and total ash was produced by the smallest amounts of irrigation.

B. The Garden Plots

The results of the analyses of the vegetables of the garden plots are presented in Tables VIII to XIII. Data are given for both the dry and fresh basis since there was considerable variation in moisture content. No data are available for comparative yields since all of the yields of vegetables were not always prepared for the edible portion.

Table VIII

Percentages of Calcium in the Vegetables of the Garden Plots

	Dry Basis, Plots				Fresh Basis, Plots			
	A	B	C	D	A	B	C	D
Beans	.458	.598	.582	.517	.0412	.0448	.0524	.0698
Beets	.190	.244	.134	.249	.0236	.0400	.0196	.0421
Cabbage	.395	.441	.452	.832	.0356	.0366	.0416	.109
Carrots	.329	.318	.325	.325	.0359	.0366	.0354	.0507
Cucumbers	.344	.344	.315	---	.0172	.0200	.0170	----
Lettuce	.890	.974	.789	2.19	.0570	.0682	.0505	.221
Parsnips	.235	.215	.174	---	.0670	.0710	.0463	---
Potatoes	.0543	.0354	.0293	.0547	.00988	.00644	.00554	.0123
Squash, B'cup	.0514	.0437	.0345	----	.00900	.00725	-----	-----
T. Queen	.115	.0835	.116	.240	.0102	.00952	.0150	.0211
Sweet Corn	.0128	.0096	.0105	---	.00277	.00272	.00255	-----
Tomatoes	.126	.115	.103	.0510	.00895	.00736	.00752	.00587

Table IX

Percentages of Iron in the Vegetables of the Garden Plots

	Dry Basis, Plots				Fresh Basis, Plots			
	A	B	C	D	A	B	C	D
Beans	.0136	.0145	.0133	.0135	.00122	.00131	.00120	.00182
Beets *	.0045	.0043	.0037	.0049	.00056	.00071	.00054	.00083
Cabbage	.00429	.00539	.00473	.00825	.000386	.000447	.000435	.00108
Carrots	.00606	.00828	.00647	.00607	.000661	.000953	.000705	.000947
Cucumbers	.0160	.00987	.0125	.00769	.000800	.000572	.000675	.000532
Lettuce	.0185	.0213	.0198	.0345	.00108	.00149	.00127	.00348
Parsnips	.00348	.00307	.00321	.00461	.000992	.00101	.000854	-------
Potatoes	.00682	.00514	.00458	.00540	.00124	.000935	.000866	.00121
Squash	.00292	.00322	.00269	.00544	.000511	.000535	-------	.000554
Squash	.00335	.00318	.00303	.00457	.000298	.000363	.000391	.000402
Sweet Corn	.00895	.00458	.00344	----	.00194	.00130	.00836	------
Tomatoes	.00792	.00720	.00751	.0752	.000562	.000461	.000548	.00865

*Expressed only to second significant figure. Iron content so much lower than expected from accepted figures that a good colorimetric comparison could not be made. Not sufficient sample for repetition.

Table X

Percentages of Phosphorous in the Vegetables of the Garden Plots

	Dry Basis, Plots				Fresh Basis, Plots			
	A	B	C	D	A	B	C	D
Beans	.644	.601	.654	.593	.0580	.0541	.05890	.0801
Beets	.445	.377	.416	.354	.0552	.0618	.0607	.0598
Cabbage	.451	.478	.445	.589	.0406	.0397	.0409	.0772
Carrots	.451	.430	.467	.498	.0491	.0495	.0509	.0777
Cucumbers	1.10	1.00	1.06	.537	.0550	.0580	.0572	.0376
Lettuce	.949	.820	.876	.480	.0607	.0574	.0561	.0484
Parsnips	.505	.456	.445	.514	.144	.150	.118	---
Potatoes	.508	.464	.437	.504	.0924	.0844	.0826	.1128
Squash B'cup T. Queen	The existing data on the phosphorous content of squash indicated such low percentages that analyses for this element seemed impractical with the apparatus at hand.							
Sweet Corn	.509	.485	.502	---	.110	.137	.122	---
Tomatoes	.591	.505	.573	.472	.0420	.0323	.0418	.0543

Table XI

Percentages of Nitrogen in the Vegetables of the Garden Plots

	Dry Basis, Plots				Fresh Basis, Plots			
	A	B	C,	D	A	B	C	D
Beans	3.00	2.83	2.69	3.80	.270	.255	.242	.513
Beets	1.90	2.10	1.62	2.76	.235	.344	.237	.466
Cabbage	.906	1.36	1.29	3.22	.0815	.117	.119	.422
Carrots	.979	.880	.940	1.45	.107	.101	.102	.226
Cucumbers	3.70	3.23	1.58	----	.185	.187	.0853	---
Lettuce	3.39	3.25	2.30	3.44	.217	.228	.147	.347
Parsnips	.975	.887	.796	1.56	.277	.293	.212	---
Potatoes	1.95	1.78	1.74	2.69	.355	.324	.329	.603
Squash B'cup	1.07	1.24	..955	2.99	.187	.206	---	.305
T. Queen	1.31	.847	.640	2.42	.117	.0966	.0826	.213
Sweet Corn	2.68	2.33	2.23	----	.582	.659	.542	---
Tomatoes	2.31	1.76	2.02	3.32	.164	.113	.147	.382

Table XII

Percentages of Ash in the Vegetables of the Garden Plots

	Dry Basis, Plots				Fresh Basis, Plots			
	A	B	C	D	A	B	C	D
Beans	7.79	8.42	8.39	8.58	.701	.758	.755	1.16
Beets	5.92	5.11	5.27	7.01	.734	.838	.769	1.18
Cabbage	7.23	7.54	7.57	9.35	.651	.626	.696	1.22
Carrots	7.59	7.22	7.59	7.79	.827	.830	.827	1.21
Cucumbers	13.7	12.7	13.5	----	.685	.737	.729	----
Lettuce	13.1	12.6	12.5	17.3	.838	.882	.800	1.75
Parsnips	5.52	5.19	5.00	4.42	1.57	1.71	1.33	----
Potatoes	5.71	5.28	5.21	6.46	1.04	.961	.985	1.45
Squash B'cup	4.58	4.89	4.55	9.05	.802	.812	---	.923
T. Queen	8.33	8.30	8.45	10.4	.742	.946	1.09	.915
Sweet Corn	2.96	2.70	2.78	----	.642	.764	.676	---
Tomatoes	9.50	8.33	8.81	8.53	.675	.533	.643	.981

Table XIII

Percentages of Moisture in the Vegetables of the Garden Plots

	To Air-dry Condtion *, Plots			
	A	B	C	D
Beans	91.0	91.0	91.0	86.5
Beets	87.6	83.6	85.4	83.1
Cabbage	91.0	91.7	90.8	86.9
Carrots	89.1	88.5	89.1	84.4
Cucumbers	95.0	94.2	94.6	93.0
Lettuce	93.6	93.0	93.6	89.9
Parsnips	71.5	67.0	73.4	----
Potatoes	81.8	81.8	81.1	77.6
Squash B'cup	82.5	83.4	----	89.8
T. Queen	91.1	88.6	87.1	91.2
Sweet Corn	78.3	71.7	75.7	60.3
Tomatoes	92.9	93.6	92.7	88.5

*See description of Method used.

From an inspection of the data of these tables it is possible to draw several general conclusions. Under the condtions of the experiment:

1. The vegetables of the dry-land plot were invariably high in nitrogen and generally higher in the ash constituents. (However total yields and quality of crops were very poor for this plot.)

2. Except for squash, the vegetables of the dry-land plot were low in water content.

3. Except for the cases above mentioned, the response of the different vegetables to the various methods of irrigation is entirely unpredictable. This might be expected since different types of root systems were present and since different parts of the plant represent the "edible portions" of the different vegetables. But even on consideration of these two factors it is impossible to find any correlation of data. Thus if lettuce and cabbage be compared for each element, it is noticed that only on iron do they show like responses for each plot. But few of the vegetables show as good agreement as this. Even the two varieties of squash show different responses.

4. Variations as great at 1800% (iron in tomatoes, fresh basis) were produced by varying the conditions of soil moisture. Variations of 100-200% were not uncommon.

C. General Discussion

It is questionable to what extent the results obtained are subject to generalization. They indicate possibilities rather than general responses. There are at least three principle factors which may influence the response of a plant to a given condition of irrigation:

1. The species and variety of plant;
2. The chemical composition of the soil;
3. The mechanical composition of the soil.

The investigations of Burd (3), Gericke (8), and Widstoe and Stewart (27), already mentioned, are only a few of those which have led to the generally accepted conclusion that different plants respond differently to the factors influencing mineral intake. In addition there are indications that there may be different varietal responses. Gericke (8) showed differences in mineral intake between spring and winter wheats, and also different responses to influencing conditions. McHargue (18) quotes widely varying iron contents for different varieties of peas, although it is not certain that all other conditions were constant. Gregory and Crowther (13) showed that varieties of barley respond differently to fertilizing conditions.

That the chemical composition of the soil may be a determining factor has been indicated by McCool and Weldon (17). They found that if the limiting element of a soil is supplied by a fertilizer, then the percentages of other elements taken up by the plant is cut down.

It seems unlikely that irrigation water affects all of the inorganic soil constituents in the same way. Thus if irrigation water should give relatively greater mobilization of calcium, then the effects of this irrigation on peas grown on a soil high in calcium and those grown on a soil deficient in calcium would hardly be the same.

The mechanical composition of the soil has a great deal to do with the techniques of irrigation. Soils vary a great deal in their water-holding capacities. In this respect the type of soil used was a fortunate selection. As shown by the moisture blocks of Figure 2, the water of any one irrigation was not long retained. The soils of this immediate region are exceptionally fast draining, probably because of the gravelly subsoil. For any soil which is more slowly draining the variations found in this experiment would hardly be expected to be so pronounced. The mechanical composition of the soil bears another relation to irrigation in regard to the action of the soil bacteria. Greaves and Carter (10) showed that different types of soil have different optimum points of moisture content for the action of the soil nitrifying bacteria. And Otryganiev (20) found different relations between soil moisture and the nitrogen content of tobacco grown on sand and clay soils.

There are no known data which will make possible a prediction of the effects of a specified procedure of irrigation on the composition of a given plant grown on any given soil. No generalizations can be made. But the data obtained for the peas plots do indicate

that for a given set of conditions it will most likely be possible to determine optimum periods and amounts of irrigation for a desired constituent.

Likewise, the method of irrigation used apparently does have an appreciable effect on the chemical composition of ordinary garden vegetables. But which method is best adapted to any particular crop can hardly be predicted from the data at hand.

No generalizations from the data found have been attempted. It is felt that there are far too many factors which, under field conditions, vary from place to place and from season to season. One conclusion, however, may be drawn. And this alone justifies the work of this investigation. The study shows more definitely than any previous one that in irrigation lies a dependable means of controlling the mineral and nitrogenous composition of vegetable products.

The opinion seems to be rather general that any given vegetable has a constant mineral composition. At least two (21, 25) of the standard texts on foods and nutrition have included tables which quote to the third significant figure percentages of minerals in vegetables. The student is given to understand that these values were obtained as statistical averages of published data from various sources. Yet a search through the literature will reveal variations sometimes as great as several hundred per cent between the results of different sets of analyses. This practice of expressing averages without indicating the range of variation has given a misleading conception of the

constancy of vegetable composition.

From the results of this study it is felt that for the productive land of any given locality of low rainfall it would be possible to develop techniques of irrigation which would produce (within limits) vegetables of any given proportion of mineral constituents. With our increasing knowledge of the requirements of animal nutrition, the ability to exert such control of the mineral content of foods is likely to become more and more valuable. Irrigation is the only known form of large scale agriculture which offers the possibility of such control.

VII. SUMMARY

This investigation has been an intensely practical one. No attempt has been made to study the principles or mechanisms involved in the intake of mineral nutrients by plants. Only actual field conditions have been studied.

1. Several techniques of irrigation have been studied in regard to their effects upon the calcium, iron, nitrogen, phosphorous, ash, and water content of the edible portion of a number of common vegetables. The period of irrigation, the amount of water applied, and the method of application have been shown to be three influencing factors.

2. Three different periods for single irrigations by the flooding method were found to influence the chemical composition of the seeds of peas. High nitrogen content was definitely favored by early irritation. Calcium, iron, and phosphorous contents were high for different periods. Water content was not appreciably influenced by the period of irrigation.

3. Three different amounts of water applied by the flooding method were found to influence the chemical composition of the seeds of peas. In general the total content of ash constituents was depressed by increasing amounts of water. Water content of seeds was not appreciably influenced by the amount of water applied.

4. The response of chemical composition to varying amounts and periods of irrigation was less marked than the response of the total

production of edible portion.

5. Three different methods of irrigation and a lack of irrigation were found to have different effects upon the composition of the edible portions of twelve common garden vegetables. Lack of irrigation produced vegetables generally low in moisture, high in nitrogen, and high in total ash. No correlation was found for the response of different vegetables to the three methods of irrigation.

6. On the basis of this study and previous statistical studies of the composition of plants, it has been pointed out that mineral composition of vegetables varies a great deal more than is commonly supposed.

7. It has been suggested from the results of this study that irrigation offers a means of controlling the mineral and nitrogenous composition of vegetable crops.

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FOUR STAR
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DESCRIPTION OF PLATES

Plate I

Fig. 1. Dry irrigation ditch showing weir in position. (Peas Plots)

Fig. 2. Irrigation ditch showing weir in operation. (Peas Plots)

Plate II

Fig. 1. A plot immediately after irrigation by the corrugation method. (Peas Plots)

Fig. 2. A plot immediately before irrigation by the flooding method. (Peas Plots)

Plate I



Fig. 1

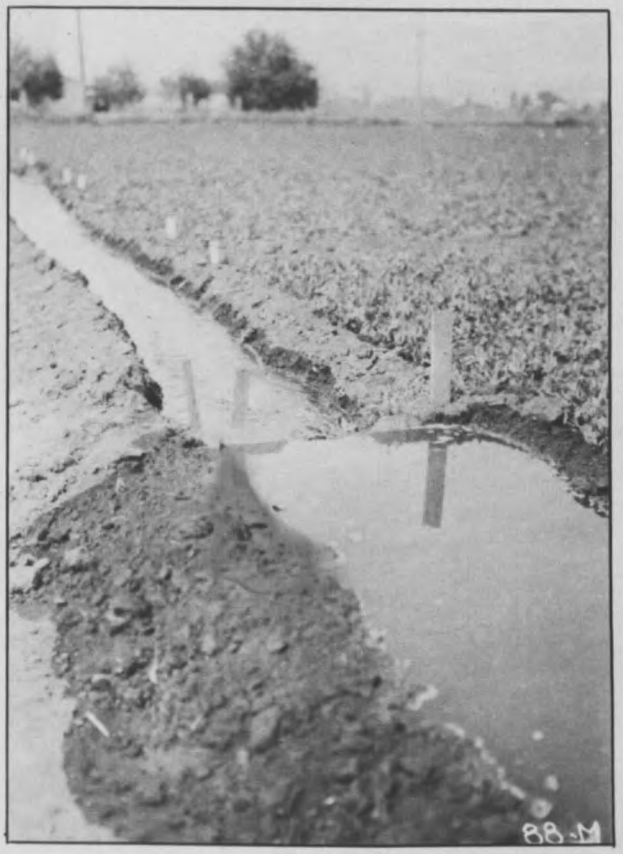


Fig. 2

Plate II



Fig. 1



Fig. 2

Appendix A

Data on the Harvesting of Peas

Plot	Date Harvested 1934	Space Harbested running ft.	Yield Canning Peas Measured grams	Yield Canning Peas Per Plot grams
1a	7/23	8 to 37.5	14,652	36,040
2a	7/25	8 to 16	7,250	65,830
3a	7/24	8 to 16	8,402	76,290
4a	7/23	8 to 23	7,635	36,950
5a	7/25	8 to 16	6,010	54,570
6a	7/25	8 to 16	8,710	79,090
7a	7/24	8 to 23	6,915	33,470
8a	7/24	8 to 20	9,405	56,900
9a	7/24	8 to 20	10,200	61,710
10a	7/25	8 to 16	7,062	64,120
11a	7/25	8 to 20	8,221	49,740
12a	7/25	8 to 20	6,844	41,400

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Appendix B

Percentages of Water in the Soil of the Garden Plots on Successive Days

Between the first two irrigations in August

Days After Irrig.	Plot A		Plot B			
			Over the Tile		Between the Tiles	
	0"-9"	19"-18"	0"-9"	10"-18"	0"-9"	10"-18"
1	26.5	22.7	32.4	20.4	24.8	23.0
2	25.7	23.3	28.0	25.6	21.8	23.2
3	25.4	22.3	23.6		22.0	20.9
4	21.5	20.0	24.6	23.8	22.8	22.6
5	20.2	19.0	21.0	20.1	21.2	22.3
6						
7	22.1	20.3	20.6	20.0	20.7	21.7
8	20.4	18.5	20.5	20.7	21.3	21.0
9	19.8	23.5	18.2	17.6	20.9	19.4
10	20.6	19.2	18.4	17.3	19.9	19.6

Appendix B (continued)

Percentages of Water in the Soil of the Garden Plots on Successive Days

Between the first two irrigations in August

Days After Irrig.	Plot C			
	Over the Furrow		Between Furrows	
	0"-9"	10"-18"	0"-9"	10"-18"
1	27.0	25.0	18.0	18.5
2	20.0	25.6	16.7	18.4
3	24.9	23.9	18.0	21.1
4	23.9	22.5	15.7	18.0
5	23.2	21.8	16.7	16.9
6				
7	23.1	21.5	17.9	19.1
8	22.7	22.8	19.7	20.1
9	19.7	20.6	19.5	19.0
10	18.7	19.2	18.5	18.2

Method for Soil Moisture Determination

The method for the determination of soil moisture was adapted to the apparatus available. Sampling was done with a soil auger. Successive samples from any plot were taken from approximately the same location and usually near the center of the plot. It is realized that this gives only a very rough indication of the general condition of the plot. Lack of time and equipment prevented more complete sampling.

For the peas plots the portions of soil obtained for the first twelve inches and the portions for the second twelve inches were kept separate and run through as individual samples. For the garden plots, because of the shallower depth of the soil, the two portions taken were for the first nine inches and the second nine inches. On garden plots B and C, where the distribution of water was uneven, samples were taken "over the tile" and "between the tile", and "over the furrow" and "between the furrows". Garden plot D (dry-land) got so dry that samples could not be obtained with an auger.

The sample (usually of 300-400 grams) was transferred directly from the auger to a can fitted with a friction lid and numbered for the purpose. The can and its contents were dried at 85° C. for 24 hours. Experience showed that this was sufficient to obtain constant weight. The loss in weight by drying and the weight of dry soil were determined. Moisture is expressed "as percentage of the moisture-

free weight of the sample taken" according to the practice advocated by the Official Methods (I, 3).

For the peas plots all moisture data have been recalculated to inches of water per foot of soil. For this purpose the dry weight of a cubic foot of soil was determined from the dry weight of a measured volume of moist soil obtained by driving a soil tube into the ground. The soil was found to weigh approximately 77 pounds per cubic foot. A corresponding volume of water weighs 62.5 pounds. A vertical inch of water in a cube one foot on edge therefore weighs one-twelfth of 62.5 or about 5.2 pounds. Now since the per cent of moisture is expressed on the basis of the dry soil (pounds water per 100 pounds of dry soil), it is possible to formulate the relation

$$\frac{77 \text{ lb.} \times \frac{\% \text{ Water}}{100}}{5.2 \text{ lb. per inch}} = \text{inches of water per foot of soil.}$$

By use of this relation the data of Table I were calculated.

Appendix C

Weather Report of Bozeman, Montana for the Growing Season of 1934

Date 1934	Temperature Max. (degrees Fahr.)	Temperature Min. (degrees Fahr.)	Temperature Ave. (degrees Fahr.)	Precipitation inches
5 - 1	57	32	44.5	
2	62	43	52.5	
3	66	44	55	
4	76	34	55	
5	83	55	69	
6	80	43	61.5	.01
7	84	43	63.5	.01
8	74	47	60.5	.13
9	58	37	47.5	.01
10	72	34	53	
11	74	41	57.5	
12	62	34	48	.62
13	58	28	43	
14	73	36	54.5	
15	80	47	63.5	
16	80	53	66.5	
17	78	43	60.5	
18	74	46	60	
19	75	41	58	
20	69	41	55	
21	64	30	47	
22	73	39	56	
23	68	43	55.5	
24	81	49	65	
25	83	52	67.5	
26	82	56	69	.01
27	84	48	66	
28	85	52	68.5	
29	84	51	67.5	
30	78	55	66.5	
31	66	51.5	51.5	Trace
6- 1	68	41	54.5	.46
2	62	37	49.5	.05
3	62	44	53	.02
4	69	44	56.5	.04
5	70	42	56	Trace
6	62	49	55.5	.31
7	59	40	49.5	.66
6-8	49	35	42	.20
9	68	34	51	
10	76	45	60.5	
11	79	52	65.5	
12	78	49	63.5	.07
13	76	46	61	.04
14	73	51	62	
15	74	48	61	.01
16	74	49	61.5	.04
18	79	54	66.5	.04
19	63	48	55.5	.21
20	70	40	55	.05
21	74	47	60.5	.02
22	75	51	63	
23	73	36	54.5	
24	76	50	63	
25	80	46	63	Trace
26	75	51	63	.13
27	72	47	59.5	
28	73	43	58	
29	76	46	61	
30	82	49	65.5	
7-1	83	46	64.5	
2	82	52	67	
3	76	49	62.5	
4	77	45	61	.02
5	69	48	58.5	.07
6	82	49	65.5	
7	82	60	71	
8	77	42	59.5	
9	84	44	64	
10	86	49	67.5	
11	81	46	63.5	
12	82	47	64.5	
13	85	45	65	
14	82	50	66	
15	87	50	68.5	
16	89	48	68.5	

Appendix C

Weather Report of Bozeman, Montana for the Growing Season of 1934

Date 1934	Temperature Max.	Min.	Ave.	Precipitation inches	Date 1934	Temperature Max.	Min.	Ave.	Precipitation inches
	degrees Fahr.					Degrees Fahr.			
7-17	92	53	72.5		8-17	89	60	74.5	
18	92	54	73		18	85	52	68.5	
19	95	54	74.5		19	79	51	65	
20	91	59	75		20	78	47	62.5	
21	87	55	71		21	77	49	63	
22	80	51	65.5		22	76	43	59.5	
23	83	49	66		23	75	40	57.5	
24	81	56	68.5	.20	24	68	38	53	
25	74	56	65	Trace	25	78	43	60.5	
26	87	51	69		26	84	48	66	
27	90	54	72		27	84	57	70.5	
28	94	58	76		28	89	50	69.5	
29	95	60	77.5		29	84	59	71.5	.05
30	92	55	73.5		30	76	54	65	.02
31	83	50	66.5	.11	31	77	41	59	
8- 1	81	47	64		9- 1	75	53	64	
2	91	58	74.5		2	67	39	53	.10
3	96	68	82		3	80	41	60.5	
4	93	52	72.5		4	81	49	65	
5	87	55	71		5	77	50	63.5	
6	90	53	71.5		6	82	50	66	
7	88	54	71		7	79	51	65	Trace
8	86	49	67.5		8	61	41	51	.08
9	86	53	70		9	66	35	50.5	.04
10	85	56	70.5		10	80	45	63.5	
11	83	52	67.5	Trace	11	82	39	60.5	
12	80	52	66		12	79	44	61.5	
13	84	48	66		13	79	37	58	
14	85	51	68		14	53	37	50	.14
15	88	53	70.5		15	73	31	52	
16	89	59	74						

Appendix C

Weather Report of Bozeman, Montana for the Growing Season of 1934

Date 1934	Temperature degrees Fahr. Max.	Min.	Ave.	Precipitation inches	Date 1934	Temperature degrees Fahr. Max.	Min.	Ave.	Precipitation inches
7-17	92	53	72.5		8-17	89	60	74.5	
18	92	54	73		18	85	52	68.5	
19	95	54	74.5		19	79	51	65	
20	91	59	75		20	78	47	62.5	
21	87	55	71		21	77	49	63	
22	80	51	65.5		22	76	43	59.5	
23	83	49	66		23	75	40	57.5	
24	81	56	68.5	.20	24	68	38	53	
25	74	56	65	Trace	25	78	43	60.5	
26	87	51	69		26	84	48	66	
27	90	54	72		27	84	57	70.5	
28	94	58	76		28	89	50	69.5	
29	95	60	77.5		29	84	59	71.5	.05
30	92	55	73.5		30	76	54	65	.02
31	83	50	66.5	.11	31	77	41	59	
8- 1	81	47	64		9 -1	75	53	64	
2	91	58	74.5		2	67	39	53	.10
3	96	68	82		3	80	41	60.5	
4	93	52	72.5		4	81	49	65	
5	87	55	71		5	77	50	63.5	
6	90	53	71.5		6	82	50	66	
7	88	54	71		7	79	51	65	Trace
8	86	49	67.5		8	61	41	51	.08
9	86	53	70		9	66	35	50.5	.04
10	85	56	70.5		10	80	45	63.5	
11	83	52	67.5	Trace	11	82	39	60.5	
12	80	52	66		12	79	44	61.5	
13	84	48	66		13	79	37	58	
14	85	51	68		14	53	37	50	.14
15	88	53	70.5		15	73	31	52	
16	89	59	74						

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