The Effect of the Weight of the Seed on the Growth of the Plant.

A Thesis

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Introduction.

The great volume of investigations with seeds during the course of a century have been with respect to germination. Numerous and various studies have been carried on in an endeavor to determine the effect of a great range of conditions and materials upon germination. Until recently little has been done to follow up these forces and stimuli through the complete period of growth of the resulting plants.

Through a complete study of physiological pre-determination questions of general and specific environmental conditions, ripening, harvesting, storage, physiological influence of parent, various artificial treatments, and amount and condition of initial food supply, are being determined and observed with respect to their individual and relative effects upon growth and production.

In the case of annuals, the effects of the amount of reserve food material available for use by the developing embryo last throughout the physiological growth period of the plant and are readily visible in the several stages of development.

The object of this paper is to present the subject of the initial plant food in the seed, and its effect upon plant growth and crop production, and to impress the fact of resulting differences as conveyed by the data. Other conditions, other influences upon the growth of the plant, are neither overlooked nor disregarded, although only the question of initial reserve of available plant food is dealt with here.

It is hoped that the importance of this one factor, its power to create appreciable misleading differences in culture work aside from influences of environment or treatment, its value in studying plant growth, and its possible value economically will be duly considered.

It is a pleasure here to acknowledge grateful thanks to Dr. J. W. Shive for valuable suggestions, criticism, and aid in planning and executing the work, and to the various members of the departmental staff for helpful and timely aid during the progress of the investigation.

History of the study.

Plant growth may by divided, as suggested by Brenchley, into two definite periods: (a) the first period, the period during which the plant is regaining that part of its initial weight lost through respiration, and in this period growth is apparently very slow. (b) the second period, succeeding the first period, during which growth is relatively rapid, continuing throughout the growth period till desiccation sets in.

"The food consumed by seed-producing crops in their initial growth (56) during germination and prior to their independent existence originates in the reserve food stored in the endosperm of the seed or in the cotyledons of the embryo plant within the seed. This reserve food is liberated by enzymatic reaction in the process of germination. When the roots have become established in the soil and the chlorophyll-bearing foliage has commenced development above the ground, the seedling is enabled to obtain necessary plant food material independent of reserve food within the seed. Under any conditions, the seedlings may continue to draw upon the store of reserve food until the supply has become exhausted and merely the non-available seed residue remains."

During a period of approximately 300 years there has been in practise, according to Yokoi (126), seed separation by the specific gravity method. Within the past 100 years many investigations have been carried on attempting to prove or disprove this method as a general agricultural practise. Although several investigators of considerable note have produced data which tend to disprove the theory of the method, the practise in agriculture still continues and more recent research displays favorable results.

According to Clark (12) a quite definite correlation exists between the specific gravity of a seed and its germination. Seeds of low specific gravity do not germinate at all, while those in a range higher germinate scantily and in many cases produce comparatively weak plants. Seeds of highest specific gravity, and those of intermediate specific gravity in the case of oil-bearing seeds, show the highest percentage of germination. Observations appear to indicate that there is a correlation between the specific gravity of the seed and its viability; that seeds of a specific gravity representing the greatest storage of reserve material are longest lived, and that seeds of low reserve storage material soonest lose their vitality. To some extent a correlation appears to exist between the specific gravity, or the storage of reserve material, of the seed and the vigor of the resulting plant. However, specific gravity is by no means of unfailing reliability in determining the quality of seeds.

Wollny, (122), states that previous investigators reporting favorably upon seed selection by the specific gravity method have entirely disregarded the absolute weight of the seed and have thereby been led into error.

During the past thirty years there has been a great volume of investigational work done with small grains with respect to yields due to difference in weight of seed. A very concise and conclusive summary of this work has been compiled by Kiesselbach and Helme (56), in which they give assembled tables and general conclusions.

"In general the results indicate: (a) When space-planted to permit maximum development, a higher individual plant yield is obtained from large than from small seeds. As an average for all investigations, this difference amounts to 17 per cent. This is not to be regarded as an inheritable quality, but rather as an immediate advantage due to a more vigorous initial growth resulting from a greater reserve food supply in the seed."

"(b) When planted in equal numbers at a rate optimum for large seed, a lower yield is obtained from the small than from the large seed. As an average for all investigations this difference amounts to 12 per cent. This comparison resolves itself in a measure into a rate-of-planting test. The optimum number of plants, per unit area, from large seeds is too thin for maximum results from small seeds."

"(c) When planted in equal weights, at a rate optimum for the large seed, all three grades--large, small, and unselected--yield equally. As an average for all investigations, large and small seed yielded alike, and the unselected seed yielded 1 per cent more than the large. This also seems to be a matter of rate planting. The shortage in yield of plants from small seeds is overcome by planting a greater number of seeds."

"(d) When light and heavy seeds (or large and small) obtained from a fanning mill are planted in equal volumes as with a drill set at a uniform rate, slightly smaller yields are apt to result from the small seed. As an average for all investigations, this difference amounts to 4 per cent. The difference in favor of large or heavy seed as compared with the original unselected seed is very slight, and probably so small as to have little practical significance,----."

"(e) When large and small seeds are alternated in the row at the normal planting rate and grown thus in competition, plants from the small seeds are reduced in relative yield as a result of the competition. As an average for the two tests bearing on this point, the competition in favor of the large seeds amounts to

13 per cent. This suggests a natural elimination (within a mass variety) of poorly adapted types, which produce unduly small or light-weight seeds."

Cummings (14) found notable differences in numbers and size of marketable radishes produced from seeds selected and screened into different grades.

In short, definite and distinct differences have been found with respect to the effect of seed weight upon crop production, yet no conclusive decision can be made with respect to the use of this phenomenon in general agriculture.

In order to secure further data on the effect of seed weight upon plant growth a series of experiments were planned and the following report presents the work thus far carried out.

Determinative methods.

Description of these determinative methods are consistent with respect to the use of these methods in the series of experiments as described in this paper.

<u>Seed weights and seed weight grades.</u> Seeds of a population sample were weighed accurately to the tenth of a milligram. Seed weight grades were mapped on the population curve, the sections chosen being at definite intervals on the curve, although in some cases the entire sample was used. The heaviest and lightest grades of seeds were selected from the respective limits of the population curve.

<u>Germination.</u> Germination of seeds planted in soil was recorded at the time the seedling protruded through the soil surface. Germination for the solution cultures was done as follows: Seeds in their seed weight grade groups were soaked several hours in water, and then placed in a moist chamber to sprout. After sprouting they were placed in their grade groups on a germinating net as described by Shive (98), and when the primary leaves were in evidence were transferred to the culture containers.

Cultures. The greenhouse flats used contained a well mixed, rich, sandy loam soil five inches deep. The greenhouse ground beds were six feet square, with a well mixed, rich, sandy loam soil ten inches deep and underlaid with sandy gravel. Field plantings were made in a gravely loam soil on the regular experimental plot area. Solution cultures consisted of weighed and measured bottles placed on a rotating table. The solutions used with respect to the buckwheat plants were Shive's (99) solution R_4C_2 during the growth period up to the blooming stage, and solution R_3C_5 (99) from the blooming stage to maturity. Solutions were changed at three and one half day intervals throughout the growth period.

Labeling plants. Each plant was labeled with respect to its weight of seed, and similar notes made on a planting location chart.

Air-dry weights. Plants of which air-dry weights were determined were placed in paper bags and allowed to dry under glass in air of ordinary humidity, during a period of not less than 30 days. The plants were then weighed to the tenth of a gram on a torsion balance.

Dry weights. Plants were dried in an oven during 48 hours at a temperature of 101 degrees Centigrade, and after cooling in a moisture-free atmosphere were weighed to the tenth of a milligram.

Green weights. The containers were weighed, their necks file-marked, and they were then weighed when filled to the file mark with the solution used at a temperature of 21 degrees C. The plant having been placed in growth position in the culture, the complete culture was weighed. At the end of each growth interval of three and one half days, each plant was removed from its container, the old solution removed, and the new solution, at a temperature of 21 degrees C., added, the containers being carefully filled to the mark by means of a burette. Then the plants, their roots having quite thoroughly drained off the old solution, were replaced, and each entire culture carefully weighed on a torsion balance. By deducting the weight of the apparatus from the total weight, the green weight of the plant was derived. There are several factors detracting from the accuracy of this method.

Leaf areas. Leaf area of each plant was determined by taking impressions of the leaves upon blue print paper and then measuring the area of the impressions by means of a planimeter. The impressions taken at the time of harvest were in accordance with the usual blue print method. Impressions taken of leaves of plants still in culture were performed as follows: A small square of blue print paper, notched to allow for the petiole, and large enough to cover the entire leaf surface, was clamped by means of light wire clips on the under side of each leaf, with a sheet of celluloid as reinforcement and protection for the leaf. After sufficient exposure the papers were treated according to the usual blue print method. Ordinary care in this operation leaves the plant alive and free of any apparent injury to continue its growth during the usual period.

Relation of seed weight to the rate of growth and size of crimson clover plants.

Seeds of a commercial strain of crimson clover were selected and weighed accurately to the tenth of a milligram and were then planted in well mixed, screened compost soil 5 inches deep in flats 15 inches wide and 18 inches long. Three grades of seed with respect to weight were planted, five seeds of each grade in each of three flats. The weights of the individual seeds in each grade were 2.0 mgm., 3.5 mgm., and 5.0 mgm.

The seeds were planted February 1, 1921, and germination counts were made February 4. These counts were continued daily until February 7. Of the 15 seeds of each grade planted, 8 of the 2.0-mgm. grade, 14 of the 3.0-mgm. grade, and 13 of the 5.0-mgm. grade germinated. Observations made twice daily showed that the heavier seeds germinated earlier than did those of lighter weight. Similar observations were made from February 9 to February 12 on the formation of the first foliage leaves, which in crimson clover consist of single leaflets. The observations showed that the first appearance of the leaflets followed the same order as did the germination of the seeds, the plants from the heavier seeds producing the leaflets earlier than those from the lighter-weight seeds. This is clearly shown by the data in table 1.

From table 1 it will be observed that the first foliage leaves of the plants from the heaviest seed had nearly all been formed before any appeared on the plants from the lightest seed. The plants from the medium-weight seed developed the first foliage leaves earlier than did those from the lightest seed and somewhat later than those from the heaviest seed. It is thus apparent that during the germination of the seeds and during the early development of the plants, all the advantage was in favor of the heavier seeds.

The relative growth rates of the plants under observation were determined by means of three sets of measurements: (a) the length of the petioles, (b) the length and width of the terminal leaflets (the products of these two values giving rise to the so-called "leaf product" of McLean (70) who showed that the daily rate of increase, through growth, of the total leaf product is very nearly proportional to the corresponding rate of increase in actual leaf area) and (c) the average dry weights of the plants harvested at regular intervals during the growth period. The growth rates of these plants were very slow during the first 4 weeks after planting, and during this time no actual measurements were made. The fifth week, however, marked a very rapid increase in the growth rates.

Table 1

Number of first foliage leaflets formed by crimson clover plants grown from seeds of different weights

Dates of observation	Number of plants with first leaflets formed		
	2.0-mgm. seeds	3.5 mgm. seeds	5.0 mgm. seeds
February 9.........	0	1	9
February 10........	1	8	10
February 11........	4	11	11
February 12........	8	13	11

Leaf measurements were begun when the plants were 4 weeks old, and were repeated at 14-day intervals, at the same time several plants from each grade of seed being harvested and their dry weights obtained. The dates of harvesting and the average dry weights per plant corresponding to the different seed weight grades are given in table 2.

The data in table 2 show that the average dry weight of the plants from the heavier seeds is superior to that of the plants from seeds of lighter weight until past the tenth week of growth. At about this period in the growth of these plants, the small and medium seed weight plants increase in size much more rapidly than do those from the heavy weight seeds. Those from the light seed weight nearly equal in size those from the heavy seed weight, while those from medium seed weight surpass all others.

According to the data in table 3, the leaf products of the plants from the seeds of different weights show a similar relation to each other as do the average dry weights (shown in table 2) of the plants with respect to the rates of development. Although showing a much greater leaf product at the end of the fourth week of growth, the plants from heavy weight seeds do not show the same rate of increase as do those from medium and light weight seeds, and after the tenth week of growth are surpassed by those from medium weight seeds and almost equalled by those from light weight

Table 2

Average dry weights of crimson clover plants grown from seeds of different weights and harvested at various intervals during the growth period.

Dates of harvesting	Average dry weights per plant		
	2.0-mgm. seeds	3.5-mgm. seeds	5.0-mgm. seeds
	gm.	gm.	gm.
March 15............	0.2112	0.2569	0.4063
March 29............	1.0198	1.2822	1.9702
April 12............	2.6673	4.6500	5.6494
April 26............	5.9606	8.7917	7.2279

Table 3

Average leaf products of crimson clover plants grown from seeds of different weights

	Average leaf products		
Days after planting	Seed weight 2.0 mgm.	Seed weight 3.5 mgm.	seed weight 5.0 mgm.
28	260	403	584
42	2,550	3,680	4,713
56	10,718	16,865	19,104
70	34,634	49,567	47,704
84	49,516	72,711	60,003

seeds.

Because of the necessity of harvesting the remaining plants at the end of the twelfth week of their growth, it is not now possible to state whether the relations between the plants as now conveyed by the data obtained will be maintained throughout the later stages of growth to maturity.

Relation of weights of seed to growth of radish plants.

The seeds were divided into three weight grades as follows: small, 5.2 to 8.5 mgm.; medium, 8.5 to 12.5 mgm.; large, 12.5 to 20.5 mgm. Planting was made September 20, 1921, in a ground bed of well mixed sandy loam soil. To secure total dry weights of definite growth intervals, six harvests were made of ten plants each from seeds of each weight grade, beginning November 15, and following at six-day intervals. The results are recorded in table 4, each of the data given representing an average for ten plants.

From the data of table 4, it will be observed that, for each harvest, the average dry weight yields obtained from the seeds of the medium weight grade are much higher throughout than are those obtained from the light seeds, while the average dry weight yields obtained from the seeds of the heavy weight grade are nearly double the corresponding yields from the light seeds, and much superior to those from the seeds of medium weight.

Table 4

Average total dry weights of radish plants grown from seeds of different weights

Time from planting to harvest in days	Total dry weights Small seeds 5.2 to 8.5 mgm.	Medium seeds 8.5 to 12.5 mgm.	Large seeds 12.5 to 20.5 mgm.
	gms.	gms.	gms.
25	0.0416	0.0577	0.0681
31	0.0766	0.1101	0.1369
37	0.1010*	0.1168	0.1678
43	0.1658	0.2013	0.3316
49	0.2325	0.3564	0.4562
55	0.3634	0.3960	0.5576

*Average of nine plants

A study of plant growth in relation to the weight of seed.

This experiment includes studies with soybean and buckwheat. Seeds were accurately weighed to the tenth of a milligram and were then divided into grades the more easily to compare the measurements obtained from the plants grown from the seeds of different weights. The results here briefly indicated are based entirely upon quantitative plant measurements consisting of germination counts, dry weights of tops, and leaf areas which were obtained by taking impressions of the leaves upon blue print paper at regular intervals during the growth period and measuring the areas of these imprints by means of the planimeter. The main outstanding results of this study may be briefly indicated as follows:

<u>Soybeans in soil culture.</u> The seeds were divided into grades as follows: small, 63.0 to 100.0 mgm.; small medium, 100.0 to 110.0 mgm.; large medium, 110.0 to 160.0 mgm.; large, 200.0 to 270.0 mgm. These seeds were planted in the greenhouse in a ground bed of well-mixed sandy loam soil, the plan of planting

being so arranged as to afford practically equal exposure to all the plants. The seeds were planted May 18, 1921, and observations and measurements were continued during the summer. All harvests were made according to a definite prearranged plan to avoid possible selection tendency.

Germination as recorded in table 5 was best with the medium grade seeds, the heavier and lighter seeds germinating equally well but much poorer than the medium grade seeds. The earliest germination occurred with the lightest weight seeds, followed in order by the medium and heaviest seeds, the cotyledons and primary leaves ranging in size (see plate 1.) in the direct order of the weight of the seeds.

Following the germination of the seeds all the advantage in the early development of the plants was in favor of those grown from the heavier seeds.

During the early growth period, while the growth rate is slow, no plants were harvested. Commencing June 8, harvests were made at regular intervals of 12 days each until July 26. Dry weights of tops and leaf areas were obtained for the plants harvested. Twenty plants were allowed to grow to maturity, and of these, the leaf areas were determined at each regular harvest period. These twenty plants were harvested September 1. The data obtained from all the soybean plants has been recorded in table 6.

Plate 1. Showing relative size of primary leaves of soy bean seedlings grown in soil culture from seeds of different weights.

Seed weights:-

1.-	0.1040 gms.	8.-	0.2240 gms.	15.-	0.1031 gms.
2.-	0.0906	9.-	0.1039	16.-	0.1020
3.-	0.1040	10.-	0.2280	17.-	0.2325
4.-	0.0907	11.-	0.0933	18.-	0.1020
5.-	0.1040	12.-	0.1026	19.-	0.2330
6.-	0.1034	13.-	0.1031	20.-	0,1022
7.-	0.2240	14.-	0.0935	21.-	0.2350

Table 5

Germination of soybean seeds of different weights. Total number of seeds planted in each grade, 81.

Days after planting	Germination counts		
	Small seeds 83.0 to 99.0 mgm.	Medium seeds 99.0 to 128.0 mgm.	Large seeds 128.0 to 270.0 mgm.
6	8	2	1
7	33	13	6
8	58	40	20
9	69	64	41
10	74	76	72
11	74	79	74

Table 6

Average dry weights of tops and average leaf areas of soybean plants grown from seeds of different weights and harvested at intervals during the growth period.

Dry weights in gms., leaf areas in sq. cm.

Days from planting to harvest.	Seed weight 200-270 mgm.		Seed weight 110-160 mgm.		Seed weight 100-110 mgm.		Seed weight 83-100 mgm.	
	gms.	sq.cm.	gms.	sq.cm.	gms.	sq.cm.	gms.	sq.cm.
20	0.3022	54.1	0.2094	40.7	0.1619	31.3	0.1516	29.1
	*-----	45.7	*-----	44.9	*-----	32.4	*-----	30.0
32	0.6268	121.0	0.5378	111.2	0.4713	97.9	0.4277	90.1
	------	124.9	------	106.5	------	96.3	------	84.8
44	1.3791	324.8	1.0081	285.0	0.8275	235.5	0.7728	213.3
	------	285.0	------	281.4	------	262.9	------	224.4
56	3.6591	898.8	2.5276	673.0	2.6809	806.0	2.1353	637.4
	------	740.0	------	688.2	------	708.1	------	590.4
68	12.0343	2344.3	6.2494	1280.4	5.1056	1112.3	7.1960	1592.0
	-------	1365.6	------	1380.2	------	1539.0	------	1042.4
104	27.2	2968.5	43.4	4156.5	45.2	4050.4	30.1	2849.6

*--- Average periodic leaf areas and average final dry weight of tops as determined for plants allowed to grow to maturity.

According to the data as recorded in table 6, there are several points suggested which are worthy of note. During the early growth period the advantage lies with the plants grown from the heaviest seeds and appears to follow in direct correlation with the weight of seed planted. This relative advantage continues up to and slightly beyond the 44th day after planting, as shown by the average dry weights of tops and average leaf areas of plants harvested at regular intervals during the growth period. Beginning with the harvest at the 56th day after planting, there is considerable variation in the growth rate relation, which may possibly be due in part to changeable conditions of environment. The average dry weights of tops and average leaf areas of the plants which were allowed to grow to maturity and were harvested on the 104th day after planting would indicate that the plants from the lightest seeds had practically overtaken in growth the plants from the heaviest seeds, and that the two medium grades had far surpassed both the lightest and heaviest. This condition should be expected, since by observation the plants grown from the heaviest seeds tend to cease rapid growth much earlier and to mature somewhat earlier than plants grown from lighter seeds.

<u>Buckwheat in soil culture.</u> The plan of this series was similar to

that of the soybean and the plants were grown under similar conditions with respect to soil and surroundings. The seeds were separated into four weight grades as follows: small, 20 to 23 mgm.; small medium, 26 to 27 mgm.; large medium, 31 to 32 mgm.; large 36 to 38 mgm.

Germination was best with the medium grades, the heaviest and lightest seeds germinating about equally well but poorer than the seeds of the medium grades. The earliest germination occurred with the lightest seeds followed in order by the medium and heaviest seeds, the seeds of the two medium grades holding well together throughout the process. The germination data for this series is recorded in table 7. The germination data for both soybean and buckwheat show that the order of germination with respect to the seeds of the different weight grades is the exact reverse of that for crimson clover as recorded in a previous study, wherein it was shown that the heaviest seeds germinated first, followed in order by the medium and the light seeds in direct correlation with the weight of the seeds.

Seeds were planted May 20, 1921, and observations and measurements made throughout the plant growth period. Harvests on a similar plan to those made with soybean were made in this series beginning June 8, and at following intervals of 10 days each until July 18. The twenty plants were allowed to grow to maturity, were measured for leaf area at each harvest period, and were harvested

Table 7

Germination of buckwheat seeds of different weights. Total number of seeds planted in each grade, 49.

Days after planting	Germination counts			
	Small seeds 20.1-22.6 mgm.	Small medium seeds 26.3-27.3 mgm.	Large medium seeds 31.0-32.1 mgm.	Large seeds 36.0-38.5 mgm.
4	22	16	16	8
5	34	36	34	29
6	42	46	46*	43
7	44**	47	48	43

* One defective
** Two defective

July 30. Data showing average dry weight of tops and average leaf area of plants harvested is recorded in table 8.

The data as recorded in table 8 seem to indicate merely that the plants from the heaviest seeds, as shown by the results obtained at the periodic harvests, maintain a slight advantage in growth over plants grown from lighter seed weights throughout that portion of the growth period. This advantage appears to be greatly increased toward maturity, as is shown by the results obtained from the plants which were allowed to continue their period of growth. These results are not in exact conformity with the expected results, which would coincide more closely with results obtained in the soybean series of this experiment.

Table 8

Average dry weights of tops and average leaf areas of buckwheat plants grown from seeds of different weights and harvested at intervals during the growth period.

Dry weights in gms., leaf areas in sq. cm.								
Days from planting to harvest.	Seed weight 36-38 mgm.		Seed weight 31-32 mgm.		Seed weight 26-28 mgm.		Seed weight 20-23 mgm.	
	gms.	sq.cm.	gms.	sq.cm.	gms.	sq.cm.	gms.	sq.cm.
18	0.1741	43.9	0.1666	43.4	0.1179	29.8	0.0960	23.9
	*-----	46.5	*-----	34.1	*-----	28.6	*-----	28.2
28	1.0541	218.5	0.8932	194.4	0.8859	179.3	0.8702	188.2
	------	231.1	------	139.2	------	143.9	------	128.1
38	2.5091	517.1	2.8937	551.3	2.0720	409.0	2.2319	469.0
	------	697.9	------	401.8	------	467.9	------	424.2
48	8.5548	1381.5	4.3861	746.1	4.2561	710.2	5.6767	921.3
	------	1208.0	------	732.9	------	830.4	------	870.6
58	16.1747	2224.4	15.7965	2087.1	13.2250	2162.0	8.3318	1028.9
	-------	------	--------	------	-------	------	------	------
70								
	31.0714	2899.9	14.3111	1449.3	19.6920	1583.7	18.7042	1823.5

*---Average periodic leaf areas and average final dry weight of tops as determined for plants allowed to grow to maturity.

A study of plant growth in the field
and its relation to the weight
of the seed.

This experiment includes studies of the soybean and the lima bean. Seeds were weighed accurately to the tenth of a milligram and divided into weight grades. The weight of each seed, at planting, was charted to avoid later confusion of data. Plantings were made in hills 4 feet apart each way, 2 seeds of varying weights about 10 inches apart in each hill. Germination counts were made at the breaking of the cotyledons through the soil surface. Cultivation was performed by ordinary field methods. Plants were harvested when closely approaching maturity, allowed to air dry, and weights obtained by use of a torsion balance. Data used only from hills having two living plants at the time of harvest.

Lima bean in the field. Seeds of the so-called Burpee's Fordhook Bush lima were weighed and divided into the following weight-grades: 0.7 to 0.8 gms.; 0.8 gms.; 0.8 to 1.0 gms.; 1.1 to 1.2 gms.; 1.2 to 1.3 gms.; 1.3 to 1.4 gms.

Although the data for rate of germination has not been here recorded, in a general way the light weight seeds germinated more quickly than the medium and the heavy weight seeds.

The data showing air-dry weights of tops, of beans, and the totals, are recorded as averages in table 9.

From the data given in table 9, it is evident that plant production conforms directly to weight of seed planted, with the one exception of the plants from the lightest seeds here used. The number of plants for this average was much smaller than for the others, being only 7, but aside from this there is no apparent cause or explanation for so great a variation.

The data also convey the idea that the ratio of the average air-dry weight of tops to the average total air-dry weight closely approximates 56.5 per cent. This suggests an existing constant between size of plant and beans produced.

Soybean in the field. The seeds were divided into the following weight-grades: small, 108 to 150 mgm.; small medium, 152 to 200 mgm.; large medium, 206 to 249 mgm.; large, 250 to 300 mgm. Variety here used was the so-called Manchu.

In this series also, the lightest seeds tended to germinate slightly quicker than the heavy seeds. Notes taken on rate of maturity suggest that possibly the plants from the medium weight seeds will mature slightly earlier than either those from the heavy or the light seeds. The data recorded in table 10 show the average air-dry weight of tops in grams, and the ratio of these averages based on the average for the plants

Table 9

Averages of air-dry weights of tops, of beans, and of total air-dry weights of lima bean plants grown from seeds of different weights under field conditions.

Seed weight grades	Average air-dry weights in grams.		
	Tops	Beans	Total*
	gms.	gms.	gms.
1.3 to 1.4 gms.	86	76	154*
1.2 to 1.3 gms.	81	61	143*
1.1 to 1.2 gms.	78	58	137*
0.8 to 1.0 gms.	77	67	137*
0.7 to 0.8 gms.	96	76	172*

* These are averages of total air-dry weights, not averages of the sum of the averages of the partial weights.

Table 10

Average air-dry weights, with comparative ratios, of tops of soybean plants grown from seeds of different weights under field conditions.

Seed weight grades	Average air-dry weights	Ratios
	gms.	per cent
250 to 300 mgm.	81	108
206 to 249 mgm.	117	156
152 to 200 mgm.	103	138
108 to 150 mgm.	75	100

from the lightest seed weight grade as 100 per cent.

The data in table 10 indicate that the plants grown from the heaviest seeds made only slightly greater growth than those from the lightest seeds, while the greatest growth was made by the plants from the large medium seeds, followed closely by those from the small medium seeds. The greatest percentage advantage of the highest producing plants, those grown from the large medium seeds, is 56 per cent, while the smallest advantage is 13.5 per cent.

A study of plant growth in the field and its relation to the weight of the seed.

Golden bantam corn.

Seeds were weighed accurately to the tenth of a milligram and divided into seed weight grades as follows: small, 150 to 200 mgm.; small medium, 200 to 250 mgm.; large medium, 250 to 300 mgm.; large, 300 to 350 mgm. These seeds, of the so-called Golden Bantam variety of corn, were planted in the field May 16, 1922, in hills of 4 feet apart, 3 seeds in each hill, seeds 8 inches apart in triangle formation. The seeds were selected to vary the seed weight in each hill. Cultivation was performed in the usual way of field culture.

Germination counts, as made, are recorded in table 11, showing the total number of plants germinated at definite periods after planting.

The data in table 11 show a higher proportion of the seeds of medium weight germinated early in the germination period, as compared to the seeds of light and heavy weight.

On August 3, all marketable ears were harvested and husks removed. Measurements were made on each ear to determine length, greatest diameter, and green weight. The husks were allowed to air dry.

Table 11

Total number of seeds of Golden Bantam corn grown from seeds of different weights, germinated at definite periods after planting.

Germination counts								
Seed weight 150 to 200 mgm.	2	5	10	10	12	12	12	14
Seed weight 200 to 250 mgm.	6	8	13	15	16	17	17	17
Seed weight 250 to 300 mgm.	19	24	29	31	32	32	33	33
Seed weight 200 to 350 mgm.	2	4	7	7	7	7	7	8
Days after planting	9	10	11	12	13	14	15	16

Complete harvest was made August 10, and the plants were placed in large manila bags and allowed to air-dry for a period of 5 weeks. Air-dry weight determinations were then made on a torsion balance, and the averages with their comparative ratios for each seed weight grade, as well as the corresponding data for green weights of ears are recorded in table 12. Data is included only for those hills having at least two plants at the time of harvest.

According to the data in table 12, the average air-dry weight of stalk and husk increases with the increase in weight of seed from which the plant was grown. The average green weight of ears bears a similar respective relation. The advantage of stalk and husk grown from the heaviest seeds over those grown from the lightest seeds amounts to 20 per cent. The similar advantage with respect to green weight of marketable ears amounts to 28 per cent.

The data in table 13 show the average length of ears, the average greatest diameter of ears, and the percentage of plants bearing ears with respect to the corn plants grown. According to this data the ear measurements vary slightly, but in no definite direction. The percentage of plants bearing ears varies from 53 per cent with respect to the plants grown from the lightest seeds to 100 per cent with respect to the seeds grown

Table 12

Averages and relative ratios of air-dry weights of stalk and husk and of green weights of marketable ears of Golden Bantam corn grown from seeds of different weights.

Seed weight grade	Average air-dry weight of stalk and husk.	Ratio	Average weight of ears	Ratio
	grams.	per cent.	grams.	per cent.
300 to 350 mgm.	115.3	120	133.8	128
250 to 300 mgm.	110.8	115	130.9	125.5
200 to 250 mgm.	109.7	114	128.5	123
150 to 200 mgm.	96.2	100	104.3	100

Table 13

Average length of ears, average greatest diameter of ears, and the percentage of plants bearing ears with respect to Golden Bantam corn plants grown from seeds of different weights.

Seed weight grade	Average length of ears	Average greatest diameter of ears	Per cent of plants bearing ears
	cm.	cm.	per cent.
300 to 350 mgm.	16.80	3.72	100
250 to 300 mgm.	16.38	3.67	80
200 to 250 mgm.	17.10	3.73	65
150 to 200 mgm.	17.02	3.68	53

from the heaviest seeds, the percentages for the plants from the medium seed weight grades falling between, in the direct order with respect to the seed weight relation.

The relation of seed weight to the growth of buckwheat in culture solution.[1]

This experiment deals with the relation of seed weight to germination, subsequent growth of the plants, and crop production. It is the purpose here to report briefly the results of the growth of buckwheat plants, (Fagopyrum esculentum Moensch.) in culture solutions under experimental conditions, with respect to the environmental complex, which were approximately the same for all the plants.

It has long been recognized, of course, that the early growth and the subsequent development of plants may be greatly influenced by the amount and quality of the food materials stored in the seed. However, the general principles underlying and governing this relation are not at all well understood.

It is not the purpose here to consider uniformity in the weight of seeds in relation to the degree of variability of the

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plants grown from them but merely to study, from the standpoint of several quantitative plant measurements, the growth rates of the plants as these are influenced by the weight of the seeds from which they are grown. It is interesting to note, however, that the results obtained do indicate very definitely that plants grown from seeds selected for uniformity in weight show markedly less variability than do similar plants grown from seeds not so carefully selected.

Methods of procedure.

Seeds of a commercial strain of Japanese buckwheat were weighed accurately to the tenth of a milligram. Of these, five weight grades of seeds were selected as follows: (1) 40.5 mgm., (2) 35.5 mgm., (3) 32.5 mgm., (4) 29.5 mgm., and (5) 23.5 mgm. No seed was used which varied more than 0.4 mgm. from the weight grade value. The seeds selected for each particular grade were germinated in grade groups on a germinating net as described by Shive (98) and from the relatively large number of seeds germinated in each group, five seedlings selected for uniformity of size and vigor were chosen for the experiment.

When the cotyledons had fully opened, the seedlings were transferred to the culture vessels which consisted of bottles having a capacity of approximately 1050 cc. The neck of each bottle, which was about 4 cm. in diameter, inside measurement, was file-marked. Each bottle was fitted with a paraffined cork stopper and marked with the number of the plant assigned to it and with the seed-weight grade from which the seedling was selected. Each bottle with the cork stopper was carefully weighed empty and again when filled to the file-mark with solution at a temperature of 21 degrees C; all such weights being taken carefully to the tenth of a gram on a torsion balance.

For the early physiological growth period, extending from germination to the flowering stage, Shive's three-salt solution R_4C_2 was used. This solution was found well adapted for the growth of buckwheat (99) and contained the three salts KH_2PO_4, $Ca(NO_3)_2$, and $MgSO_4$ in concentrations of 0.0144 m., 0,0052 m., and 0.0200 m., respectively. To each liter of solution used was added 0.5 mgm. of iron in the form of a freshly prepared solution of ferrous sulphate.

After the seedlings were transferred to the culture solutions, the cultures were placed on a rotating table in order to insure to all the plants similar environmental conditions. At the end of each 3 1/2 day interval throughout the growth period, the cultures were removed from the rotating tables, the old solution discarded, and the bottles again filled to the file-mark with new solution at 21 degrees C. The cultures were then weighed and returned to the rotating table. This process was repeated at the end of each 3 1/2 day interval.

At the end of the seventh growth interval, when the plants were in full bloom, Shive's three-salt solution R_3C_5 was substituted for that used during the early growth stage. This change is necessary, according to Shive and Martin (100), in order to produce optimum growth of buckwheat plants in these three-salt solutions during the period from the flowering stage to maturity.

The plants were harvested after they had been in culture forty-two days and the dry weight of tops and roots and the leaf area of each plant were obtained separately. The leaf areas were secured by blue-printing the fresh leaves and subsequently determining the areas of these leaf-prints for each plant by means of the planimeter.

An attempt was here made to obtain the total green weight (tops and roots) of each plant at the end of the various growth intervals throughout the entire growth period. At the end of the growth intervals, each plant was removed from its culture bottle together with the cork stopper in which it was mounted, placed in an empty container, and allowed to drain thoroughly. The old solution was then discarded and the culture bottle filled to the file-mark with new solution at 21 degrees C.; the last few cubic centimeters of solution being added from a burette for the sake of greater accuracy. The plants were then replaced and each culture accurately weighed to the nearest tenth of a gram on a torsion balance. By deducting the weight of the filled bottle and cork stopper from the total weight, the approximate green weight of the plant as well as the increase in weight from interval to interval was derived. The method is faulty in some respects, in that it does not take into account the weight of the solution adhering to the roots after draining; but since the error thus introduced is approximately the same for all the plants, the relations indicated by the green weight data thus obtained should not be appreciable different from the true relations.

Experimental data

Green weights. In table 14 are given the total green weights of the plants as these were here derived. The first green weights were taken on the tenth day after the plants were placed in the culture solution and at the end of each succeeding 3 1/2 day growth interval thereafter. The weights of the five plants and the averages of these are shown for each seed-weight grade.

From the data of table 14 it will be observed that the green weight averages for the plants grown from the smallest seeds (23.5 mgm. grade) are the lowest throughout, while those from the next to the largest seeds (35.5 mgm. grade) are the

Table 14

Green weight of plants obtained at intervals throughout the growth period

Days in culture	10.0 gms	13.5 gms	17.0 gms	20.5 gms	24.0 gms	27.5 gms	21.0 gms	24.5 gms	28.0 gms	41.5 gms
	Green weights in grams									
	4.0	6.0	8.0	8.6	13.0	15.5	15.0	16.5	20.0	18.2
Seed	5.0	6.7	9.7	10.6	16.6	19.8	20.9	24.4	24.9	25.4
weight	5.0	5.8	7.5	7.5	12.5	14.3	15.2	16.5	17.5	16.5
40.5	3.7	6.2	6.1	8.1	9.8	12.1	12.6	14.5	14.6	15.1
mgm.	3.0	5.5	6.8	8.6	10.6	11.6	13.4	13.6	15.6	16.0
Average	4.14	6.04	7.6	8.7	12.5	14.5	15.4	17.1	18.5	18.2
	4.0	6.2	8.0	8.0	12.0	16.0	17.0	17.4	19.6	20.8
Seed	4.6	9.1	8.2	10.6	13.1	15.6	15.8	16.6	16.8	18.3
weight	4.4	7.3	8.4	9.6	11.6	15.1	16.4	17.6	18.1	20.4
35.5	4.2	7.0	8.5	10.5	14.5	17.0	17.5	20.7	21.7	23.0
mgm.	3.8	6.3	8.3	10.1	13.1	15.3	14.9	16.6	17.6	18.6
Average	4.2	7.18	8.3	9.76	12.86	15.8	16.3	17.8	18.76	20.26
	4.2	7.0	8.0	8.7	12.7	14.2	14.7	15.9	16.4	17.2
Seed	5.0	6.2	6.6	7.8	12.1	14.6	16.6	18.6	19.3	20.1
weight	3.0	5.4	7.0	6.2	10.7	14.4	14.2	15.7	17.2	17.6
32.5	3.2	5.0	6.7	6.9	10.4	11.9	13.7	14.7	15.9	15.4
mgm.	4.6	6.9	8.1	10.5	14.9	16.9	16.9	18.4	19.7	18.9
Average	4.0	6.1	7.3	8.02	12.16	14.4	15.2	16.66	17.7	17.84
	5.3	6.8	9.3	10.3	13.4	16.1	18.1	18.8	20.3	19.8
Seed	3.1	5.6	6.8	6.8	11.8	13.8	15.0	17.8	18.2	17.8
weight	3.0	5.5	7.2	7.7	11.3	11.9	13.7	14.7	15.3	14.7
29.5	4.3	5.8	7.3	8.8	12.5	14.3	15.8	17.8	18.3	17.8
mgm.	3.5	6.5	8.3	8,8	12.3	14.8	15.8	16.8	16.3	17.8
Average	3.94	6.04	7.8	8.7	12.26	14.2	15.7	17.2	17.7	17.58
	3.5	5.2	6.5	6.8	10.3	12.3	14.3	15.4	16.8	17.3
Seed	2.7	5.5	6.3	6.3	10.2	12.8	13.3	14.88	15.6	16.8
weight	3.0	5.4	6.8	8.4	12.9	14.1	16.3	17.1	17.1	17.7
23.5	3.0	3.5	6.8	6.9	10.1	11.4	13.4	14.0	14.9	13.4
mgm.	4.2	6.8	8.2	9.5	13.3	15.5	16.5	18.8	21.5	21.3
Average	3.7	5.3	6.9	7.6	11.36	13.3	14.76	16.04	17.2	17.3

highest throughout; the order of superiority of the plants grown from seeds of different weight corresponds to the order of seed weight, from the lowest to the next to the highest here used. The plants grown from the abnormally large seeds (40.5 mgm. grade) were slightly inferior in average green weight throughout to those grown from the large medium seeds (35.5 mgm. grade).

The average green weight data for the plants grown from the grades of seeds which produced the highest and the lowest yields are plotted to form the graphs of figure 1. The graphs representing the average green weight data corresponding to the remaining three seed-weight grades are here omitted since they occupy positions intermediate between the two graphs shown in figure 1, and do not intersect them at any point.

It is clearly apparent from the graphs of figure 1 that the advantage, with respect to green weights, in favor of the plants grown from the heavier seeds over those from the lighter seeds, is not only maintained throughout the entire growth period but is also gradually, though not very greatly, augmented as the plants become older. The average green weights of the plants grown from the heavier seeds were at the first and last growth intervals represented on the graphs 13.5 per cent and 17.1 per cent heavier, respectively, than were the corresponding weights of the plants grown from the lightest seeds employed.

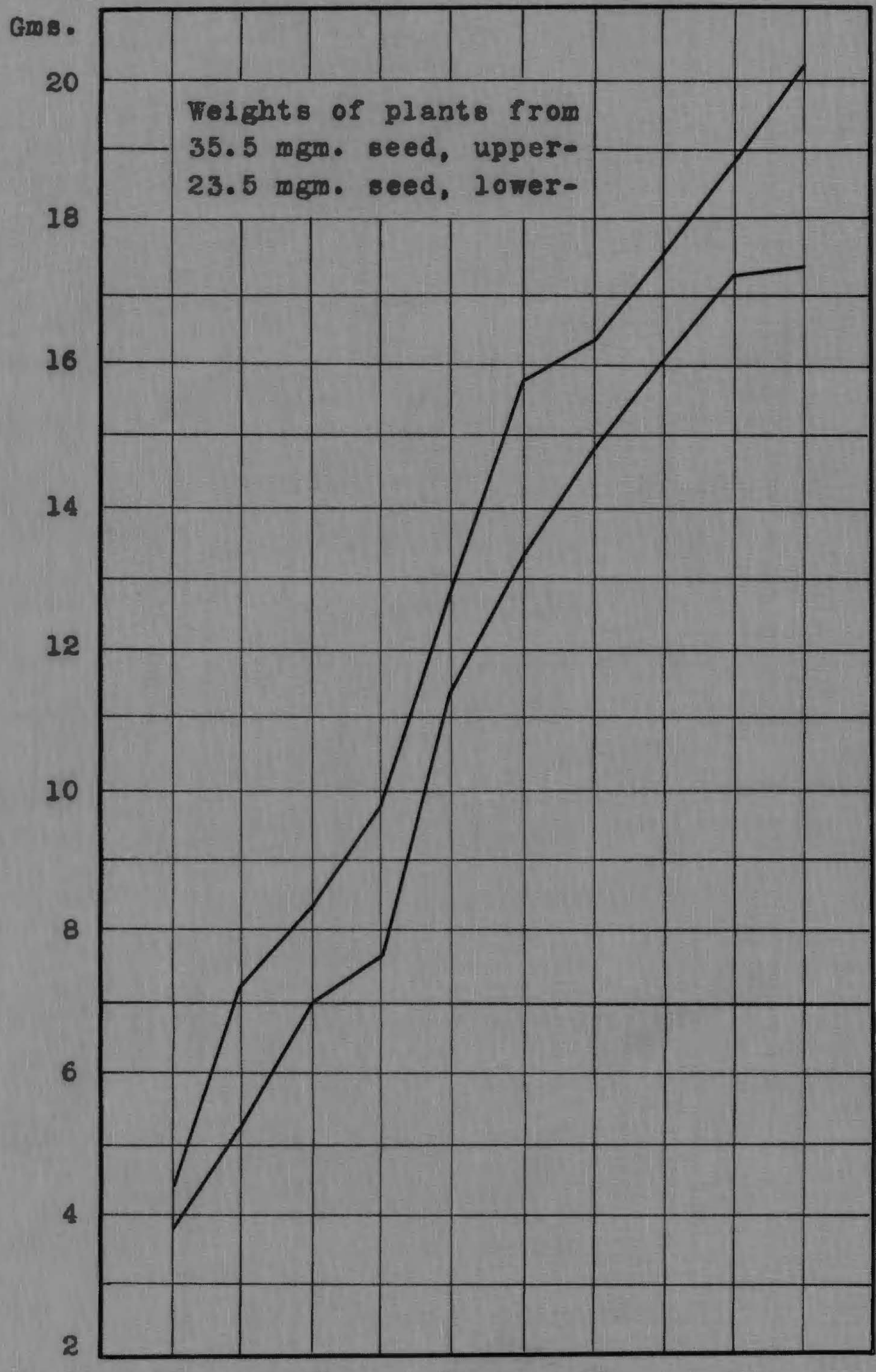

Figure 1. Graphs of average green weights of plants grown in solution cultures from seeds which produced the highest and lowest yields.

<u>Dry weights and leaf areas.</u> The absolute dry weight yields and the leaf areas of the mature plants together with the averages of these plant measurements corresponding to each seed-weight grade are presented in table 15. The average dry weight yields of tops and the average leaf areas are shown diagramatically in comparison in figure 2, but all the values are here expressed in terms of those corresponding to the lowest seed-weight grade (23.5 mgm.) taken as 1.00.

As is clearly brought out by the diagram of figure 2, the order of superiority of the plants grown from the seeds of different weights, with respect to average dry weights of tops, average total dry weights, and average leaf areas, corresponds to the order of seed weights from the lowest to the next to the highest, this relation being, therefore, in absolute agreement with that of the green weight values. No such relation, however, exists between seed weights and dry weights of roots, although the seed-weight grade corresponding to the highest average yield of tops, total yield, and leaf area corresponds also to the highest dry weight of roots. The average weight of tops, total dry weight, and leaf area obtained with the seeds from the highest yielding weight grade (35.5 mgm.) are 20.5 per cent, 19.5 per cent, and 19.4 per cent higher, respectively, than are the corresponding yield values obtained with the seeds from the lowest weight grade (2[illegible].5 mgm.).

Table 15

Dry weights and leaf areas.

Seed weights in mgms	Dry weights in grams.			Leaf area sq.cm.
	Roots	Tops	Total	
40.5	.1061	1.6615	1.7676	223.1
	.1677	2.0950	2.2627	312.2
	.0918	1.5545	1.6463	225.8
	.0728	1.2300	1.3028	202.1
	.1151	1.1257	1.2408	181.1
Av.	.1107	1.5333	1.6440	228.9
35.5	.1344	1.4615	1.5959	241.4
	.1057	1.6035	1.7092	235.8
	.1205	1.6004	1.7209	241.4
	.1040	1.7793	1.8833	221.7
	.1547	1.5026	1.6573	254.9
Av.	.1239	1.5895	1.7133	239.0
32.5	.0617	1.4425	1.5042	212.8
	.1250	1.4842	1.6092	226.9
	.1271	1.6840	1.8111	243.6
	.1224	1.3522	1.4746	221.2
	.1066	1.7814	1.8880	245.0
Av.	.1036	1.5489	1.6574	229.9
29.5	.1327	1.5057	1.6384	231.8
	.1164	1.6638	1.7802	236.9
	.1208	1.4952	1.6160	231.5
	.1294	1.4652	1.5946	227.0
	.1175	1.2745	1.3920	170.7
Av.	.1234	1.4809	1.6042	219.6
23.5	.0946	1.3587	1.4533	202.6
	.0982	1.2040	1.3022	182.6
	.1267	1.3590	1.4857	195.3
	.0909	0.9260	1.0169	147.5
	.1561	1.7540	1.9101	272.9
Av.	.1133	1.3163	1.4336	200.2

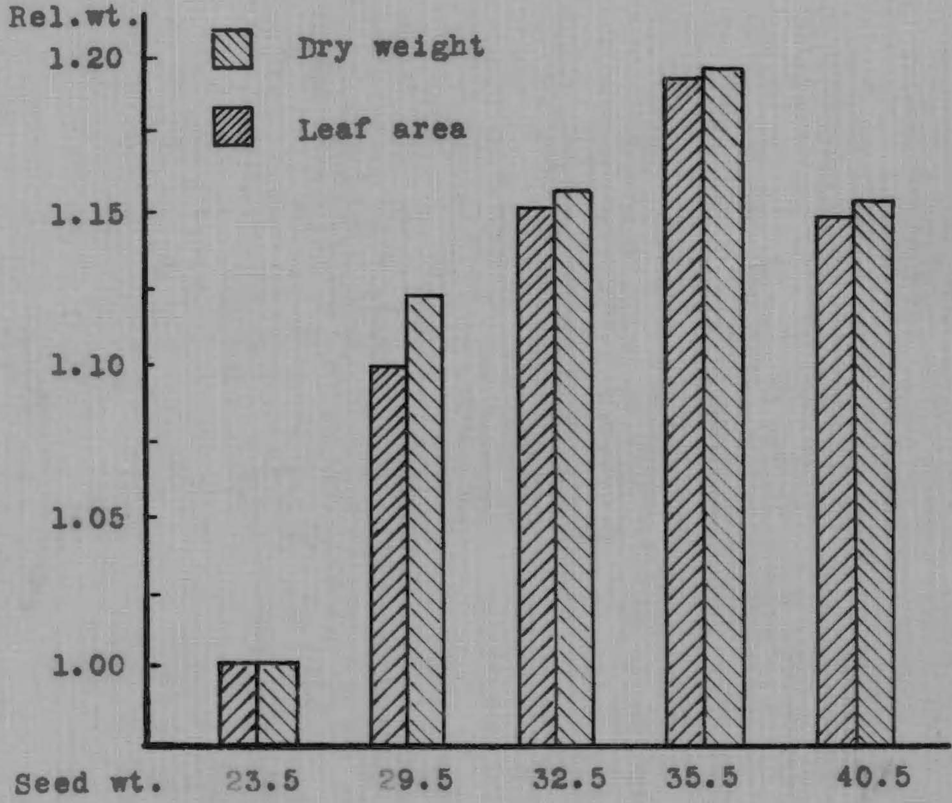

Figure 2. Diagram comparing average relative dry weights with average relative leaf areas of plants grown from seeds of different weights.

It is interesting and important to note that the average leaf areas are nearly proportional to the average dry weight yields of tops, as is apparent from the diagram of figure 2 and from the data of table 15. This is in entire accord with the work of McLean (70) and Hildebrandt (49,50); who found that the leaf areas of soybean plants at the age of four weeks are approximately proportional to the dry weight of stems and leaves. Since, as is clear from the data of table 15, the total dry weights of the buckwheat plants here used are approximately proportional to the dry weights of tops, this relation holds also between total dry weight yields (tops and roots) and leaf areas. On the other hand, no such relation is apparent between dry weights of roots and leaf areas. This follows, of course, since there is no definite correlation between the growth of tops and roots of the buckwheat plants here employed.

It is to be emphasized, of course, that the data here presented are too meager and inadequate to justify anything more than suggestion. Definite conclusions are not warranted and the purpose of the paper is achieved with a brief consideration of some of the more important points which the data have conveyed.

Discussion.

The purpose of these studies was to ascertain the effect of the weight of the seed upon the growth of the plant. During the progress of the investigations several points of interest have developed.

Although the dry weight method of comparison was used as a basis, as has been the custom, the parallel measurements of leaf area and their close approximate relative coincidence to the relative dry weights have demonstrated their reliability as criteria for determining relative growth size of plants. The leaf area method being applicable at any time during the growth of the plant and at any desired time repetition interval for an individual plant, possesses a distinct advantage over the dry-weight method.

Green weight determinations, when made at short growth intervals, give a close approximation to the rate of growth of plants, but the numerous factors affecting accuracy are difficult to control.

The quantitative measurements as determined by the three methods applied in these experiments, namely, the dry-weight method, the leaf-area method, and the green-weight method, indicate certain general conclusions which may be applied to the plants investigated,- crimson clover, radish, soybean, buckwheat, lima bean, and corn.

In most cases, speed of germination is greatest with the light seeds, and decreases as the seeds increase in weight. In the seedling stage a superiority in favor of the plants from heavy seeds is evidenced by longer hypoctyl, larger primary leaves, and more sturdy appearance. This apparent superiority is demonstrated quantitatively by a corresponding superiority in dry weight and leaf area. This superiority is frequently maintained throughout the physiological growth period of the plant, until maturity. In some cases the rate of increase in growth with respect to the plants grown from the heaviest seed weights is not so great as that of the plants from lighter seeds, and the earlier superiority of growth is not maintained. Seed production appears to be in direct order with the weight of the seed from which the plant grew. With respect to the soil cultures the range of variation in the different seed weight grades does not appear to bear any relation to the weight value of the grade, but among the buckwheat plants grown in solution culture, the plants grown from the medium weight seeds show much less range in variation than do the plants grown from the heavy or light seeds, as is demonstrated by the diagram in figure 3. In this particular series it so happens that the seeds producing the greatest crop

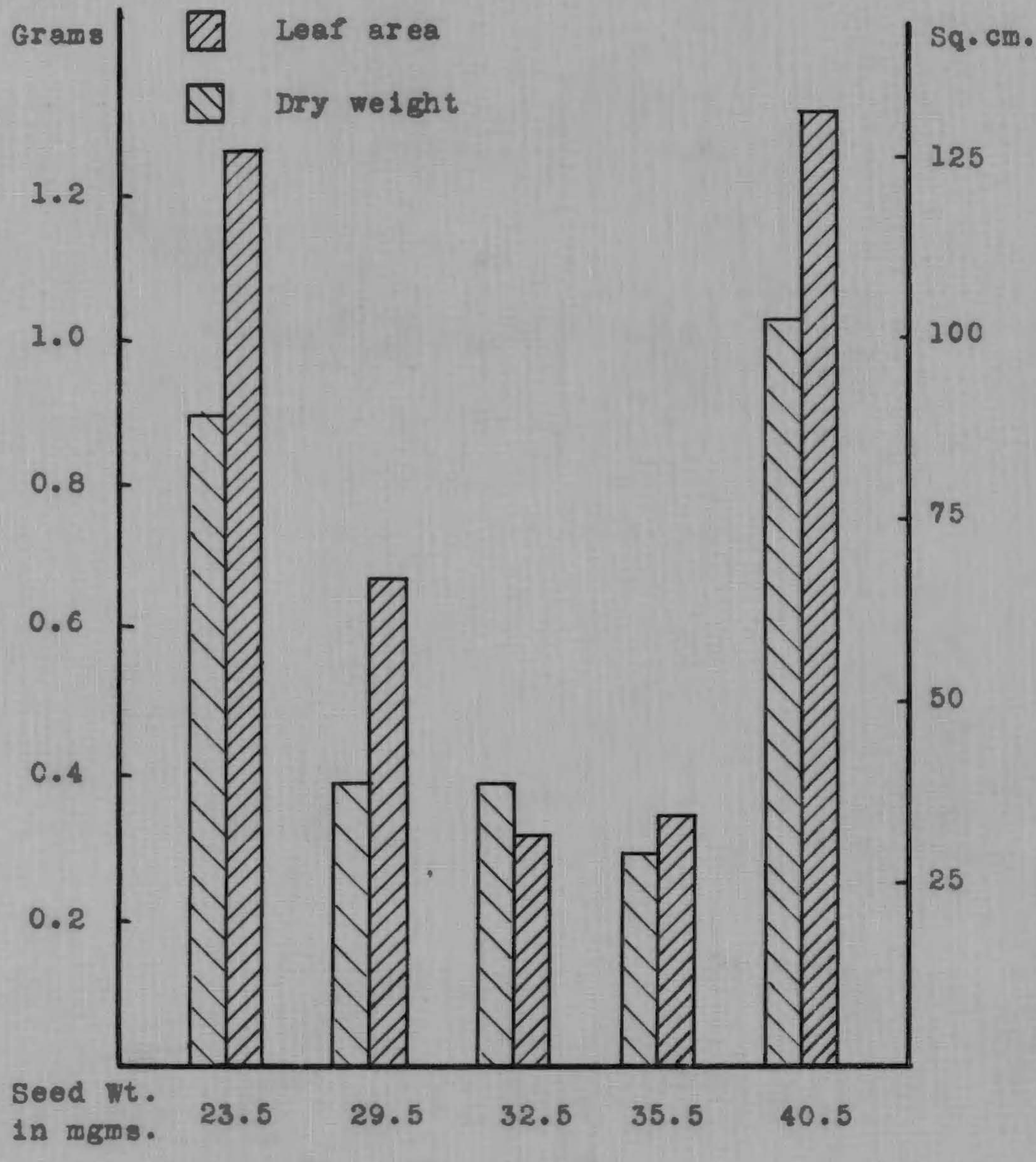

Figure 3. Diagram showing range of variation among buckwheat plants of each seed weight grade when grown in solution culture.

also produce the most uniform plants.

Summary

This series of experiments includes studies of crimson clover, radish, soybean, buckwheat, lima bean and corn in soil cultures, and of buckwheat in solution cultures. Plants were grown from seeds of different weight grades, under experimental conditions which were approximately alike for all the plants with respect to each individual experiment.

In general the results indicate:

1. The seeds of high medium weight produced better plants, from the standpoint of several quantitative plant measurements (averages only considered), than did seeds of lighter weight or abnormally heavy seeds.

2. The order of superiority of the plants grown from the heavier seeds over those grown from seeds of lighter weight corresponds to the order of seed weight, excepting the abnormally heavy seeds.

3. Under conditions which were approximately the same for all plants the superiority of those grown from heavier seeds over those grown from lighter seeds, if this superiority was maintained to maturity, decreased notably.

4. Leaf areas were approximately proportional to dry weights of tops and to total dry-weights, but no such relation

was apparent between dry weights of roots and leaf areas.

True leaf areas, as here determined, may be obtained at any time during the physiological growth period of the plant, from the seedling stage to maturity, without affecting the normal growth of the plant under observation.

5. With respect to the lima bean, the average air-dry weight of beans produced always closely approximates 44% of the total air-dry weight of tops. Hence the average large plant will invariably produce a correspondingly greater crop weight.

6. The producing power of Golden Bantam corn, with respect to number of ears and air-dry weight of stalk and husk, varies in the same order as the weight of the seed planted.

7. Germination, in general, takes place more rapidly in light seeds than it does in heavy seeds,--with the exception of the crimson clover seeds, in which case the reverse was true.

8. Seeds of a medium weight grade and those only slightly heavier are superior in germinating power by approximately 8 % over seeds of very heavy or very light weight.

References.

1. Blackman, V.H., 1919. The compound interest law and plant growth. In Ann. Bot. 33: p. 353.

2. 1920. The significance of the efficiency index of plant growth. In New Phytologist, 19: 3 and 4, pp. 97 - 100.

3. Bolley. H.L., 1901. Work with wheat in 1900. N. Dak. Exp. Sta. Rept. (11 ann.) p. 28 - 32.

4. Boss, Andrew., 1893. Heavy versus light oats for seed. Minn. Agr. Exp. Sta. Bul. 31. Ann. Rept. p. 213.

5. Brenchley, W.E., 1919. Some factors in competition. In Ann. Appl. Biol. 6: p. 142.

6. Briggs, G.E., Kidd, F. and West, C., 1920. A quantitative analysis of plant growth. In Ann. Appl. Biol. 7:

7. 1920. A quantitative analysis of plant growth. Part II. In Ann. Appl. Biol. 7: 2 and 3, p. 202.

8. 1921. Methods in the quantitative analysis of plant growth. A reply to criticism. In Ann. Appl. Biol. 7: 4, p. 403.

9. Brown, E.B., 1922. Effects of mutilating the seeds on the growth and productiveness of corn. U.S. Dept. Agr. Bul. 1011.

10. Burgerstein, A., 1912. Bohnenpflanzen, aus groszen und aus kleinen Samen erzogen. Verhandl. d. Zool.-bot. Gesellsch. in Wien. 62.

11. Burnett, L.C., 1912. Some data for oat growers. Iowa. Exp. Sta. Bul. 128. pp. 105 - 110.

12. Clark, V.A., 1904. Seed selection according to specific gravity. N.Y. Agr. Exp. Sta. (Geneva) Bul. 256.

13. Cobb, N.A., 1903. Seed wheat. In Agric. Gaz. New. So. Wales. V. 14, Part I. p. 145.

14. Cummings, M.B., 1914. Large seed a factor in plant production. Vt. Agr. Exp. Sta. Bul. 177, pp. 90 - 173.

15. Degrully, L., 1898. On the selection of seeds by their specific weight. Prog. Agr. et Vit. 30, No. 42. pp. 453 - 55.

16. Delassus, M. 1911. Influence de la suppression partielle des réserves de la graine sur le dévelopment de la plante. In Compt. Rend. Acad. Sci. (Paris) t. 153, No. 26, p. 1494 - 97.

17. 1913. Influence de la grosseur des graines sur le dévelopment général et l'anatomie des plantes. In Compt. Rend. Acad. Sci. (Paris) t. 157.

18. Ducomet, V., 1921. A propos des semis de pommes de terre. Jour. Soc. Nat. Hort. France. 22: 126 - 31.

19. Duggar, B.M., 1911. Plant Physiology. New York, 1911.

20. Edler, 1900. Einfluss der Korngrösse des Saatgutes auf den Ertrag. Deutsch, Landw. Presse, 99: pp. 1186-7. Landw. Zeitschr. Rhein-Provinz 2: 1. (E.S.R. 13, p. 37.

21. Finlay, Wm. M., 1919. The size of seeds. North Scotland Coll. Agr. Bul. 23.

22. Fruwirth, C., 1917. Schweres und leichtes Saatgut bei Luzerne und Esparsette. Fühling's Landw. Ztg. 46.

23. Gardner, W.A., 1921. Effect of light on germination of light-sensitive seeds. In Bot. Gaz. 71, 249-86. Abs. Physiol. Abs. 7: 2, 143.

24. Gebhardt, Curt., 1921. Die Grossknolligkeit der Kartoffelzüchtüngen. Zeitschr. Pflanzenzücht. 8: 85-88.

25. Georgeson, C.C., 1896. Experiments with wheat. Kan. Agr. Exp. Sta. Bul. 59, p.99.

26. 1897. Experiments with oats. Kan. Agr. Exp. Sta. Bul. 74, p. 199-200.

27. Cottrell, H.M. and Shelton, Wm. 1890. Experiments with oats. Light and heavy seeds. Kan. Agr. Exp. Sta. Bul. 13, pp. 59-60.

28. Grandeau, L., 1898. Influence of the weight of seed on the yield of cereals. Jour. Soc. Agr. Brabant et Hainut, 1898, No. 47.

29. Gregory, F.G., 1917. Physiological conditions in cucumber houses. Third Ann. Rept. Exptl. Res. Sta., Nursery and Market Garden Industries Devel. Soc., Turner's Hill, Cheshunt, Herts, pp. 19-28.

30. Grenfall, C.N., 1901. Some experiments with wheat. <u>In</u> Agr. Gaz. New So. Wales, 12, p. 1053.

31. Grevenitz, B., 1829 (1830). (Determinations of specific gravities of various seeds.) Vers. Deutsher Naturf. u. Aertze zu Heidelberg. 1829. (Isis von Oken, 1830).

32. Haberlandt, F., 1866. (Favorable report on seed selection according to specific gravity.) Boehm. Centbl. fuer die ges. Landeskultur, 1866, p. 4.

33. Wissenschaft prakt. Unters. an dem Gebiete des Pflanzenbaues, I. Wien, 1875.

34. Halsted, B.D., 1917. The weight of seeds as related to their number and position. Soy beans. <u>In</u> Torreya, 57.

35. 1914. A study of the influence of pod position upon viability and vigor of seedling. N. J. Agr. Exp. Sta. Rept. 1914. (E.S.R. 34, p. 134).

36. and Owen, E.J., 1917. Environment of seed and crop production. In Plant World 20.

37. Harris, J.A., 1905. The importance of investigations of seedling stages. In Science, II. 22: 184-186. 11 Aug.1905.

38. 1912. A first study of the influence of the starvation of the ascendants upon the characteristics of the descendants. In Am. Nat. 46.

39. 1912. A first study of the relationship between the weight of the bean seed, Phaseolus vulgaris, and the time required for its germination. In Plant World 56.

40. 1913. The relationship between the weight of the seed planted and the characteristics of the plant produced.
1. Biometrika 9, 1913.
2 Biometrika 10, 1914.

41. 1917. The weight of seeds as related to their number and position. In Torreya 57.

42. 1912. The size of the seed planted and the fertility of the plant produced. In Amer. Breeder's Mag. 3: 293-295.

43. 1912. On differential mortality with respect to seed weight occurring in field cultures of Phaseolus vulgaris. In Am. Nat. 46.

44. Hellriegel, H., 1859. (Favorable report on seed selection according to specific gravity). 2. Jahresber. der Vers-Stat. Dahme, 1859, p. 71.

1883. (Effect of specific gravity of seed on yield of plant). Beitraege zu den naturwissenschaftlichen Grundlagen des Ackerbaues. Braunschweig, 1883, pp. 39-117. Abst. in Bied. Centbl. 1883, p. 530.

46. Hickman, J.F., 1897. Fiel experiments with wheat. Ohio Agr. Exp. Sta. Bul. 82, p. 231.

47. 1901. Field experiments with wheat. Ohio Agr. Exp. Sta. Bul. 129, p. 25.

48. Hicks, G.H. and Dabney, J.C., 1896. The superior value of large, heavy seed. U.S.Dept. Agr. Yearbook. pp. 305-322.

49. Hildebrandt, F.M., 1917. Leaf product as an index of growth in soy-bean. Johns Hopkins Univ. Circ. (O.S.) 293, p. 202.

50. 1921. A physiological study of climatic conditions of Maryland, as measured by plant growth. <u>In</u> Physiol. Res. 2: 8, pp. 341-405.

51. Jensen, J.L., 1899. Samenhaengen mellem Klima og Kornarternes Kernestørrelse. Tidsskr. Landbr. Planteavl. 5: 1899, pp. 138-147.

52. Jodin, V., 1897. Recherches sur la germination. <u>In</u> Annales Agronomiques, 33, 433-471.

53. Kidd, F. and West, C., 1919. Physiological pre-determinations. The influence of the physiological condition of the seed upon the course of subsequent growth and upon the yield. V. Review of literature. Chapter IV. Effect of conditions during germination and in the early seedling stage upon subsequent growth and final yield. <u>In</u> Ann. Appl. Biol. 6: 1.

54. 1919. Physiological pre-determination: The influence of the physiological condition of the seed upon the course of subsequent growth and upon the yield. IV. Review of literature. Chapter III. <u>In</u> Ann. Appl. Biol. 5: p. 220.

55. and Briggs, G.E., 1920. What is the significance of the efficiency index of plant growth? <u>In</u> New Phytologist 19: 3 and 4, pp. 88-96.

56. Kiesselbach, T.A. and Helm, C.A., 1917. Relation of size of seed and sprout value to the yield of small grain crops. Nebr. Agr. Exp. Sta. Res. Bul. 11.

57. and Ratcliff, J.A., 1917. Oats investigations. Nebr. Agr. Exp. Sta. Bul. 160.

58. Kreusler, V. et al. 1877-9. Beobachtungen über das Wachsthum der Maispflanze. Landw. Jahrb., 1877-9.

59. , Prehn, A., and Hornberger, R. 1879. Beobachtungen über das Wachsthum der Maispflanze. Landw. Jahrb. 8, p. 617. (1879).

60. Latta, W.C., 1891. Experiments with wheat. Ind. Agr. Exp. Sta. Bul. 36.

61. Lehmann, E., 1913. Ueber katalytische Lichtwirkung bei der Samenkeimung. In Biochem. Zeitschr. 50, p. 388.

62. Leighty, C.E., 1912. Correlation of characters in oats, with special reference to breeding. Amer. Breeder's Assn. Rept. 7, p. 50.

63. Lill, J.C. 1910. Relation of size, weight and density of kernel to germination.of wheat. Kan. Agr. Exp. Sta. Circ. 11, p. 3.

64. Love, H.H. 1912. A study of the large and small grain question. Amer. Breeder's Assn. Rept. 7, p. 109.

65. Lubanski, F. 1901. Selsk. Khoz. i Lyesov, 200. (E.S.R. 14, p. 432).

66. Marek, G. 1875. Das Saatgut und dessen Einfluss auf Menge und Gute der Ernte. Vienna, 1875.

67. Mazé, P. 1900. Recherches sur le rôle de l'oxygène dans la germination. In Ann. de l'Inst. Pasteur, 14, p. 350.

68. McHargue, J.S., 1920. Mineral constituents of the paired seeds of the cocklebur. In Sci. (N.S.) 52: 1332.

69. 1921. Some points of interest concenring the cocklebur and its seeds. In Ecology 2: 2.

70. McLean, F.T. 1917. A preliminary study of climatic conditions of Maryland, as related to plant growth. In Physiol. Res. 2: pp. 129-208.

71. Middleton, T.H. 1899. The effect of the size of the seed on the crop. Univ. Coll. of Wales Rept. 1899, p. 68.

72. Molliard, M., 1921. Sur le dévellopement des plantules fragmentées. In Compt. Rend. Soc. Biol. 84, 770-2. (Physiol. Abs. 7: 2, 145.)

73. Montgomery, E.G., 1912, Competition in cereals. Nebr. Agr. Exp. Sta. Bul. 127.

74. 1910. Methods of testing the seed value of light and heavy kernels of cereals. In Jour. Am. Soc. Agron. 2: p. 59-70.

75. 1908. The use of the fanning mill for selecting seed wheat and oats. Nebr. Agr. Exp. Sta. Bul. 104, p.32.

76. Myers, C.H., 1912. Variation and correlation in wheat. Amer. Breeder's Assn. Rept. 7, p. 61.

77. Nagai, Isaburo, 1921. On the relation of leaf area to productivity in soy-bean. Jour. Sci. Agric. Soc. (Jap.) [illegible], pp. [illegible].

√ 78. Nielson, P., 1895. Culture experiments with rye. Tidsskr. Landbr. Planteavl. 1, p. 1-130. (E.S.R.7: pp 204-5).

79. Nobbe, F., 1876. Handbuch der Samenkunde. Berlin, 1876.

80. Oparin, A., 1921. Das grüne Atmungspigment und seine Bedeutung bei der Oxydation der Erweitzkörper in den Keimenden Samen des Helianthus annuus. Biochem. Zeit. 124: 90-96. (Physiol. Abs. 7:1, 72.)

81. Pack, D.A., 1921. After-ripening and germination of juniper seeds. In Bot. Gaz. 71, 32-59. (Physiol. Abs. 7: 2,143)

82. 1921. Chemistry of after-ripening, germination, and seedling development of juniper seeds. In Bot. Gaz. 72: 139-150. (Physiol. Abs. 7: 6, 381).

83. Pearl, R. and Surface, F.M., 1915. Growth and variation in maize. Zeitschrift Indukt. Abstam, u Vererbungslehre 14: 97-203.

84. Priestley, J.H., 1922. Physiological studies in plant anatomy. I. Introduction. In New Phytol. 21: 2, 58.

85. and Armstead, D., 1922. Physiological studies in plant anatomy. II. The physiological relation of the surrounding tissue to the xylem and its contents. In New Phytol. 21: 2, 62.

86. and Pearsall, W.H., 1922. An interpretation of some growth curves. In Ann. Bot. 36: 239-249. (Physiol. Abs. 7: 10, 572).

87. Reed, H.S., 1920. The nature of the growth rate. In Jour. Gen. Physiol. 2: 5.

88. 1920. Slow and rapid growth. In Am. Jour. Bot. 7: 8.

89. Renz, C.F., 1826. Unters. über das sp. Gew. der Samen. Inaug. Diss. Tübingen, 1826.

90. Richardson, A.E.V., 1917. Improvement of wheat and other crops by seed selection. Jour. Dept. Agric. Victoria, 25.

91. Roemer, T., 1921. Steigerung der Wiesenerträge durch Auswahl des Saatgutes. Mitteil. Deutsch. Landw. Ges. 36: Flugbl. 59 4 p. (Apr.9). (Also) Illus. Landw. Ztg. 41: 1-2, 1921.

92. Salaman, R.N., 1921. The influence of size and character of seed on the yield of potatoes. Jour. Ministry Agric. Great Britain. 28: 43-48.

93. Salter, R.M. and McIlvaine, T.C., 1920. Effect of reaction of solution on germination of seed and on growth of seedlings. In Jour. Agr. Res. Vol. 19, No. 2, 73.

94. Sanborn, J.W., 1893. Seed selection. Utah Agr. Exp. Sta. 4th Ann. Rept. pp. 168-169.

95. Shamel, A.D., 1904. The improvement of tobacco by breeding and selection. US.D.A. Yearbook, 1904, p. 435.

96. Sherman, H., 1921. Respiration of dormant seeds. In Bot. Gaz. 72:1-30. (Physiol. Abs. 7: 6, 381.

97. Sherwin, M.E., 1923. The effect of fertilizers on germination and seedling growth. In Jour. Amer. Soc. Agron. 15: 2, p. 66.

98 Shive, J.W., 1915. A study of physiological balance in nutrient media. In Physiol. Res. 1: 7, pp. 327-397. l.c. pp. 396-397.

99. 1917. A study of physiological balance for buckwheat plants grown in three-salt solutions. N.J. Agr. Exp. Sta. Bul. 319.

100. and Martin, Wm. H., 1918. A comparative study of salt requirements for young and for mature buckwheat plants in solution cultures. In Jour. Agr. Res. 14: 4, pp. 151-175.

101. Snyder, H., 1905. Heavy and light weight grains. Minn. Agr. Exp. Sta. Bul. 90, pp. 214-218.

102. Soule, A.M. and Vanatter, P.O., 1901. Winter wheat. Tenn. Agr. Exp. Sta. Bu. 2, Vol. 14, p. 42-45.

103. 1901. Winter cereals and legumes. Tenn. Agr. Exp. Sta. Bul. 3, Vol. 14, p. 5.

104. 1903. Seed selection. Tenn. Agr. Exp. Sta. Bul. 4, Vol. 16, p. 77.

105. Stingl, Georg, 1907. Experimentelle Studie über die Ernährung von pflanzlichen Embryonen. <u>In</u> Flora, Bd. 97, H. 3, pp. 308-331.

106. Tantphoeus, C. von, 1876. Ueber die Keimung der Samen bei verschiedener Beschaffenheit derselben. Inaug. Diss. München, 1876.

107. Thunberg, T., 1921. Sur la présence des certains ferments oxydants dans les graines de phaseolus vulgaris. Arch. intern, de physiol., 1921, 18: 601-606. (Physiol. Abs. 7: 2, 142).

108. Tracy, W.W., 1904. The influence of climate and soil on the transmitting power of seeds. <u>In</u> Science (N.S.) 19.

109. Van Tieghem, Philippe, 1873. Recherches physiologiques sur la germination. <u>In</u> Ann. Sci. Nat., Bot., sér.5, v. 17, p. 205-224.

110. Voelcker, J.A., 1903. Head vs. tail corn for seed wheat. <u>In</u> Jour. Roy. Agr. Soc. Eng. vol. 64, p. 354. (also same vol. 63, p. 353, 1902).

111. 1906. Field experiments. <u>In</u> Jour. Roy. Agr. Soc. Eng. vol. 67, pp. 282-310.

112. Waldron, L.R., 1910. A suggestion concerning heavy and light seed grain. <u>In</u> Am. Nat. 44.

113. Walls, E.P., 1905. Some observations on the weight of the kernels and the size of the germ in seed corn as affecting the vigor of the resulting plant. Md. Agr. Exp. Sta. Bul. 106.

114. Webber, H.J. and Baykin, E.O., 1907. The advantage of planting heavy cotton seed. U.S.D.A. Farmer's Bul. 285, pp. 5-16.

115. Welton, F.A., 1921. Longevity of seeds. Ohio Agr. Exp. Sta. Monthly Bul. 61 and 62. (Physiol. Abs. 7: 2, 143.

116. Wenholz, H., 1915. Some factors influencing yield in maize. In Agric. Gaz. N S. Wales, 26.

117. West, C., Briggs, G.E. and Kidd, F., 1920. Methods and significant relations in a quantitative analysis of plant growth. In New. Phytol. 19: 7, p. 200.

118. Williams, C.G., 1905. Experiments with winter wheat. Ohio Agr. Exp. Sta. Bul. 165.

119. 1903. Ten years' experiments with oats. Ohio Agr. Exp. Sta. Bul. 138.

120. and Welton, F.A., 1911. Wheat experiments. Ohio Agr. Exp. Sta. Bul. 231.

121. 1913. Experiments with oats. Ohio Exp. Sta. Bul. 257.

122. Wollny, E., 1887. Unters. ueber den Einfluss des sp. Gew. etc. In Forsch. auf dem Geb. der Agr.-Phys., 1886, p. 207. (Abst. in Bied. Centbl. 1887, p. 169.)

123. 1877. Unters. ueber die Werthbestimmung der Samen, etc. Jour. fuer Landw. 1877.

124. Wollny, Ewald, 1886. Untersuchungen über die künstliche Beeinflussung der innern Wachsthumursachen. VII. Der Einfluss des Vorquellens des Saatgutes auf die Entwickelung und die Erträge der Kulturpflanzen. In Forsch. Geb. Agr.-Phys., Bd. 8. Heft 5, p. 380-391.

125. 1885. Saat und Pflege der landwirtschaftlichen Kulturpflanzen. Berlin, 1885.

126. Yokoi, T., On the salt water method of the selection of seeds. Imp. Univ. Coll. Agr. (Tokyo) Bul., Vol.3, p. 421. (Abst. Exp. Sta. Rec., Vol. 10, p. 1047.

127. Zavitz, C.A., 1907-9. The relation between the size of seeds and the yield of plants of farm crops. Proc. Amer. Soc. Agron. 1., 1907-9. pp. 98-104.

128. 1907. Seed grain selection. Rept. Ont. Dept. Agr. v. 2, pt. 1. Dept. of Farmers Inst. p. 87.