Effect of size of seed on plant production.

By

FELIKS KOTOWSKI.

The practical and theoretical importance of the quality of the seed sown upon the resulting crop was been studied fifty years ago (1875—1885) and revealed a need for a critical examination of the influence of seed weight on plant production, as it is evident from publications issued up-to-date (1914—1924).

They can be cited the papers of Arny and Garber (1) on wheat, of Brenchley (2) on peas and barley, of Harris (7) on kidney beans, of Kiesselbach (8) on wheat and oats, of Kotowski (10) on peas and broad beans, of Rotunno (15) on radishes, of Rudolfs (16) on kidney beans and of Schmidt (17, 18) on soybeans, buckwheat, radish and corn.

The general trend of the work made by these authors confirms there was a slight effect when heavier seed was utilized for planting. The yields acquired from large or medium seed as compared with yields of small seed, have given very moderate or no increase in plant productiveness.

The paramount conclusion is drawn by Kiesselbach (8), who says: (the experiments have been carried out during 17 years) — „in general the work at the Nebraska station indicates, that there will be no material or practical gain in the grain yield under farm conditions, from the practise of grading small grain seed which is reasonably free from trash and inert matter (p. 680)“. Only Cummings (3) handling with sweet pea, squash, lettuce, spinach, radish, beans and garden peas advocates the meaning“ that a distinct advantage follows the use of heavy or large seed and it will pay to discard small seed (p. 122)“. But his data are not all in favor of

the view supported herewith. It is difficult to compare Cummings' records with others, because the weight of seed planted is noticed very seldom, only mentioned as large or small one; also no statistical methods affecting reliability of conclusions are presented.

If we try to examine the records given, we can find for instances.

Sweet peas; average blossom production per plant for the season (page 95):

variety:	<i>Earliest of all</i>	<i>His Majesty</i>	<i>Gladys Unwin</i>	<i>Coccinia</i>
large seed:	114	14	22	22
small seed:	97	15	18	21

Productivity of sweet pumpkins (page 99):

	number of vines	number of fruits	total weight of fruits lbs.	weight of ripe fruits lbs.
large seed:	76	213	1084	696
small seed:	76	256	1247	386

Lettuce, average weight of head (page 102) in grams:

variety:	<i>Hanson</i>	<i>Iceberg</i>	<i>Hittinger's Belmont</i>
large seed:	392.7	405.4	170
small seed:	361.7	396.6	160

Garden peas, variety *Bliss Everbearing* (page 115):

	weight of peas, grams	average number of pods per vine	weight of peas per vine, grams
large seed:	25449	9.5	14.5
small seed:	26787	10.5	14.7

The differences in favor of large seed are small, and without knowing their errors it is quite probable they had no statistical significance and therefore did not hold up Cummings' thesis. His paper does not form an important contribution in aid to the opposite question, concerning the distinct influence of size of seed on the yield.

The effect of size of seed is not deniable in the youth of the plant. In the period of germination and later, ending with blossoming, the size of plants changes accordingly to the size of the seed (for details cfr. Arny and Garber, 1, Brenchley 2, Kotowski, 10, Rudolfs, 16). Reaching to maturity the differences involved by seed size decrease and at the time of harvest they disappear completely.

The varieties and species of plants which were the subject matter of observation, were annual plants for that the bearing time is the end of their vegetation too. Many of those are self-pollinated

and it was easy to perform experiments using hereditary uniform strains — pure lines — of them. There are no experiments accomplished with biennial plants, which may be harvested in the first season, before blossoming and which are usually propagated from cross-fertilized seeds, hereditary little uniform, known as „populations“. It was desirable to get acquainted with the response of such a plants on the seed size and for this purpose the attempt is made in this report to learn something of the product of cabbage (*Brasica oleracea capitata*), a biennial and typic cross-fertilized species, under conditions of field trials, which may help to clarify the question of the effect of size of seed on plant production in the first year of growth.

The seed of a population of *Brunswick short stem cabbage* was chosen. This strain has proved uniform and true to type when cultivated during 1923. The cabbage seeds were graded on screens and there have been discriminated two kinds of size. Large seeds, covering diameter 2.5 to 3 millimeters (average $d = 2.75$ mm) and small seeds limited to 1.5—2 millimeters of diameter (average $d = 1.75$ mm). Their volumes, when calculated as balls ($= \frac{d^3}{6} \pi$) were for 100 seeds 10850 mm³ for large and 2720 mm³ for small seeds. Their hundred seeds weight was (in average of six lots of each kind) 0.808 grams and 0.363 grams. Hence, volumes ratio was 4:1 and weight ratio 2:1, approximately. It seemed that differences between size of seeds were quite sufficient to look forward to the results involved hereby.

To attack the problem four standard treatments of cabbage culture were compared. 1. Large seed, the seed bed and the field plots fertilized; 2. small seed, the bed and the plots fertilized; 3. large seed, the bed and the plots unfertilized; 4. small seeds, the bed and the plots unfertilized.

The seed was sown in the open seed bed in the garden. The bed was divided in four parts, each of them covering on square meter; two parts received, before sowing, fertilizers supply as follows: 45 gr. of sulfate of ammonia, 80 gr. phosphate (15% P₂O₅) and 60 gr. potassic salts (40% K₂O). The cabbage seed of the first and of the second treatment was sown on them. The two remaining parts of the seed bed received no fertilizers and therefore the treatments third and fourth have been kept on them.

The experiment was started March 28, 1925, sowing on each part of the bed 25 grams of cabbage seed in broadcast. The germination began, and the seedlings rose up the ground April 7, at once on all parts of the bed, although the germination was more

quickly when large seeds were planted; nevertheless after four weeks growth, the parts of the bed were very uniform covered with seedlings, which differed in size very much on each part of the bed. To appreciate these marks of distinction, owing to the size of seed and to the fertilizers, measurements and weighings of cabbage seedlings were performed May 27, before planting them into the field plots.

The cabbage was transplanted May 28, and it must be noticed that seedlings from outside rows were invariably discarded, this aim was to prevent the most uniform stock of plant as possible. Each treatment grew on four parallel plots, alike in shape and being 50 square meters in size. The seedlings derived from fertilized bed were transplanted on eight fertilized plots. A moderate food supply took place on these plots, consisting of: 1.6 kg sulfate of ammonia, 2.8 kg phosphate and 2.8 kg potassic salts per 100 square mt. The seedlings originated from unfertilized bed, were not furnished with nutrient salts. It may be mentioned, the field prepared for cabbage culture in 1925, was manured with farmyard (± 50.000 kg per ha) in the fall 1923, and the foregoing crop, early potatoes in 1924, did not exhaust much of it and decrease the soil fertility. The experiment has been carried out on 16 plots, placed to sandy soil with good water conditions and sufficient organic matter. The plots are ranged in two zones, of eight plots; on each other they were 150 plants set 50 by 55 cm. Shallow cultivation was given during the season and weeds were kept down by hand hoeing after cultivation ceased. No evidence of fungus infection and of injurious insects was found on examination during summer.

The harvest time of cabbage, October 5, and partially October 1, finished the vegetation in 1925, and the critical study of the yield might throw some light on the resolving topic. The problem of the effect of size of seed in cabbage is considered in this report in three sections: 1) the appreciation of seedlings; 2) the value of plot yields and 3) the description of cabbage plant, yielded from each treatment.

1. The appreciation of seedlings.

The young plants, after cleaning in water the roots from the soil and exhausting moisture with blotting paper, were weighed and the length and the breadth of blade of the largest leaf were determined. The differences in regard to these characters are recorded in Table I and Table II. The seedlings in sixty days stage are

also photographed (cfr. Fig. 20), they present average specimens of every kind.

It shows at a glance from that photograph, that the amount of the food stored in the seed is of major importance for early growth, however the beneficial effect of fertilizing is doubtless. A consideration of Table I indicates there are unquestionably signi-

Fig. 20. Seedlings of Brunswick short stem cabbage, photographed May 28, 60 days stage. II a large seed fertilized bed, Ia large seed unfertilized bed; II b small seed fertilized bed; Ib small seed unfertilized bed.

ficante differences in favor of large seed. The ratio of the seedling weight obtained from large seed as compared with that resulted from small seed is: 230:100, that is quite the same as the ratio of

Table I.

Frequency distributions of seedling weights; 60 days stage (27. V.); $\%$ of the number of plants.

Origin and treatment of seedlings	-2λ	-1λ	V	+1λ	+2λ	+3λ	+4λ	+5λ	+6λ	+7λ	Average weight of seedling gr.	Number of plants weighed
Large seeds; the bed nonmanured	—	—	44.3	26.7	13.7	9.2	4.6	1.5	—	—	2.6	129
Small seeds; the bed nonmanured	—	—	44.5	28.2	20.3	4.7	1.6	0.7	—	—	1.1	128
Large seeds; the bed manured	1.5	15.5	24.8	22.5	20.2	5.4	4.6	1.6	1.6	4.3	4.6	129
Small seeds; the bed manured	4.7	16.4	38.3	19.5	11.7	7.0	1.6	0.8	—	—	2.0	128

hundert seeds weight: 220:100. The relation between weight of seedlings developed on fertilized and unfertilized bed is narrower than the mentioned above, it is: 178:100. This fact points out that the development process of cabbage is dependant in high degree

Fig. 21. Graph N 1 Large seed. Graph N 2. Small seed. Continual line — the fertilized seed bed; dotted line — the unfertilized seed bed.

through its first period (for instance 60 days) on food quantity offered by the seed, and this relation is of higher degree than that of increase of nutrient salts in the soil. This conclusion is in accord with Rudolfs (16) opinion regarding the like behavior of kidney beans.

The frequency distributions of seedling weight imply some interesting questions. They are presented on Table I as a mean to facilitate the comparison of the four treatments. The number of individuals in every class is submitted in percent of all individuals weighed in each lot; the deviations from the mode (V) are calculated in class units (λ), which were chosen for large seed seedlings $\lambda = 1$ gram, for small seed seedling $\lambda = 0.5$ gram. The numbers computed herewith are also plotted in graphs N 1 and N 2.

Different factors may influence the rate and the form of development, hence the size and weight of the young plants if they are grown from several lots of graded seed sown broadcast in the bed. The result will always be that the variation in such a group is continuans and that the variation of resulting plant in respect to such a character as weight, when expressed graphically, will yield a typically normal Quetelet's curve. And really that is the case happened, concerning the curves of seedling weight when the seedlings developed on fertilized bed (cfr. graph N 1 and 2, continual line) without regard to the seed size.

Some peculiarities pass as we consider the variation of the weight of seedlings kept on unfertilized bed. The curves here observed are not in any case Quetelet's or binomial curves, illustrated with two branched deviations from the mode; they are shaped as one branched curves, in which the mode lies at the lower range end, and the deviations from the mode are exclusively positive (cfr. graph N 1 and 2, dotted line). What is the matter of this extraordinary behavior of variability, distinguishing in a wide way the two means of development? As far as I suggest, following explanation may support to understand this fact. The addition of nutrient salts to the soil of the bed, changes the opportunities of the development of the young plants. They profit during early growth of the food accumulated in seed leaves and of diluted salts too. It is obviously there are favorable conditions for increase size and hence we meet the greater average weight of seedling and some of them became extremely big ($+6\lambda$, $+7\lambda$). In the other case, the soil fertility is poorer, in lack of nutrient salts, therefore the young plants when they start to grow are needed to cover their food requirements only from the seed supply. It is quite probable these are alike, and causing that, all seedlings or most of them approach to the same weight, what corresponds to initial seed weight and the seedlings occur larger from heavy and smaller from light seed. In these lots, the mode gives the lower limit of variation and deviations

that are noticed may found their origin in favorable opportunities delivered for seedlings in the latter period of growth, when food-stuff of seed is exhausted completely.

It is evident, that more detail analysis of the stated data is wanted, but that does not relate closely to the aim and scope of this report and should be the subject matter of an investigation in progress.

The weight of seedlings is appreciated as green weight, but, of course, the differences secured now, does not disappear when brought out in dry weight. This meaning is not verified in response to our seedlings, it will be suggested that *per analogiam* on conclusions gained by Brenchley (2) and Schmidt (17, 18). Some data from Brenchley paper upon peas and barley are cited below.

Harbinger peas, grown for 92 days, in nutrient solution never changed; (35—45 gr. 100 seeds) large seed: dry weight, averages of ten plants, 0.776 gr.; (15—20 gr. 100 seeds) small seed: dry weight, averages of ten plants, 0.387 gr.

Barley, grown for 67 days, solution never changed; (4—6 gr. 100 seeds) small seed: dry weight, average of ten plants, 0.820 gr.

Schmidt's data on radish, in pot culture for 56 days: (1.65 gr. 100 seeds), large seed: dry weight of one plant 0.068 gr. (0.68 gr. 100 seeds), small seed: dry weight of one plant 0.041 gr.

Table II.

Measurements of the largest leaf of cabbage seedlings; 60 days stage.

Origin and treatment of seedlings	Length of the blade			Breadth of the blade			Σc
	A cm	$\pm \sigma$ cm	c %	A cm	$\pm \sigma$ cm	c %	
Large seeds; the bed nonmanured	5.4	1.4	25.8	4.1	0.9	22.8	48.6
Small seeds; the bed nonmanured	4	0.9	22.5	2.8	0.6	22.4	44.9
Large seeds; the bed manured	6.9	1.3	19.2	5.3	0.8	15.0	34.2
Small seeds; the bed manured	5.3	0.8	14.7	3.4	0.7	19.2	33.9

The size of the first, best developed leaf is also settled with the size of the seed planted. Reference to Table II, shows the ratio: length of the blade belonging to seedlings of large seed to that of the small seed: 133:100, in regard to breadth, the ratio stated is: 152:100. These ratios does not change if we compared the lots of fertilized and unfertilized parts of seed bed. The coefficient of shape

(e. g. ratio: length: breadth) indicates it is some blade elongation in seedlings attained of heavy seeds (coeff. of shape 1.31) contrary to that of light seeds (coeff. of shape 1.50). The variability of the blade (cfr. coefficients of variation) was not alike in all treatments. When the soil fertility increased (fertilized bed) the variability decreased ($\Sigma c = 68.1$) if the soil was poorer (unfertilized bed), the variability was greater ($\Sigma c = 93.5$). The same manner of reaction of variability to soil fertility is related by Myers (13) for wheat, by

Fig. 22. Brunswick short stem cabbage 4. VIII. 1925. Large seed, the bed and the field plots fertilized; from sowing time 128 days, after transplanting into the field 68 days.

Love (12) for peas and buckwheat, by Show (19) for kidney beans and also by Kotowski (9) in his report on rye.

Our appreciation of the cabbage seedling might be at an end. A short review upon further development of the plants during summer must precede the evaluation of the cabbage yield in autumn; it is necessary to know it for gathering proper estimation of later facts. The most important thing done, was that, the differences observed in seedlings became invisible between plants derived from large and small seeds. The best proof for reliability of this condition are photos (fig. 22, 23, 24 and 25) taken August 4, as heads begun to form, on specimens of average size of each treatment.

Fig. 23. Brunswick short stem cabbage. 4. V.II. 1925. Small seed; the bed and the field plots fertilized; from sowing time 128 days, after transplanting into the field 68 days.

Fig. 24. Brunswick short stem cabbage. 4. VIII. 1925. Large seed; the bed and the field plots unfertilized; from sowing time 128 days, after transplanting into the field 68 days

In this moment the life vigor seems to come to an equilibrium and the plants, divided regarding the seed origin, did not show great discrepancies. The same fact, the smoothness of differences of plants resulted from large and small seed was noted by Brenchley (2), who says: (à propos his pea culture cited above) — „a month later after 17 weeks growth in the original nutrient solution the difference between plants from the light and heavy seeds was still very marked, though the discrepancy not quite so large as at earlier date. Reckoning the weight of the plants from the lightest seeds as 100, after 13 weeks, the ratio of the weight of the heaviest to the lightest was 225:100, and after 17 weeks only 167:100. This probably indicates that the larger plants had almost exhausted their food supply

Fig. 25. Brunswick short stem cabbage. 4. VIII. 1925. Small seed; the bed and the field plots unfertilized; from sowing time 128 days, after transplanting into the field 68 days.

and were growing less rapidly, while the smaller plants had more available food left and were utilising it, thus decreasing the comparative advantage gained by the larger plants" — (page 228) and further passus about barley: „In the earlier stage of growth steady gradation in size was apparent according to the weight of the seed but, gradually this became less visible, though the difference was still marked if the plants from the lightest seeds were placed alongside those from the heaviest. By harvest time little difference could be observed as the plants were so large that minor variations were obscured" (page 230).

In cabbage culture now reported, the same could be observed; approaching at the harvest time, for instance in the beginning of September, a month later the photos presented hereby, the two sets of cabbage plants from light and heavy seeds, growing on fertilized field plots were hardly distinguishable from one other, and those planted on unfertilized field plots were alike too.

2. The value of cabbage yield.

The cabbage was harvested 5. X., that means 190 days after sowing in the seed bed and 130 days after setting into the field. The green weight of each plot was determined and these records are called rough yield (brutto yield). Great economical estimation have data relating to the quantity of marketable heads reported herewith; they are obtained by trimming the heading plants and rejecting leaves that failed to form heads as well stalks.

In interpreting the field work can be made facilities, when are applied statistical methods. For this purpose the arithmetic (A) means of yields are given in Table III, accomplished with standard errors (e), standard deviations (σ), coefficients of variation (c) and with the trial exactness measurements expressed: $m\% = \frac{100 e}{A}$. The last magnitude is not very high, its value: $m\% = 3.17$ for green weight averaging the whole records. It suggests the trials are performed quite well, if the are known field experiments not bad appreciated which $m\% = 6-7$.

They are very striking results grouped in Table III, because they show at a glance there is no gap in cabbage production in first year vegetation, due in respect to grade seeds in heavy and light. It is very easy to draw this conclusion, without any statistical calculations, hence the differences among the green weight yields are smaller than their errors.

A really advantage manifests, when supplying the field with fertilizers, but that was not our main idea to investigate the fertilization response and therefore could be neglected in this report. The yield of marketable heads is alike through plots placed on fertilized field. We meet a distinct difference in favor of plants succeeded from small seeds ($+17.5 \pm 4.5$ kg), considering the marketable heads yield of nonfertilized plots. If we ask what contributes to such an effect we can answer it was involved by the high percent of marketable heads in regard to the whole plant weight. The strain of Brunswick short stem cabbage cultivated without fertilizers possessed 41% of whole yield in rejected leaves and stalks, if plants derived

from light seeds, against 50% of refuse parts, if plants originated from heavy seeds. The same occurred on fertilized soil. It may be cited, for comparison, that some strains of Brunswick cabbage yielded in our field trials in 1921, 1922 and 1923 had given refuse parts in amount of 47–52% of whole yield. I suggest, that it could be understood, if remembered, the seed sown in those trials was used with eliminating the light seed and this treatment caused a distinct decrease of marketable heads percent. In consequence, there will be no practical gain in cabbage yield under truck farming conditions from the apply of large size seed of cabbage and the reject of small seed.

The further question arises, does the size of the seed affect the heading process in the cabbage? The resolve will be found in Table III, in supervision of percent plants failed to form heads. Of course, they were but few plants who produced only leaves instead of heads, and it was not dependant from size of seed, rather there should be noticed advantages in heading process involved by fertilizing as it is evident from differences in favor of fertilized plots ($+6.8 \pm 2.5\%$ and $+2.9 \pm 1.4\%$).

Great uniformity of life vigor and immunity against fungous diseases and injurious insects could be observed on cabbage plants on every plot. The ravages done by them illustrates the column (cfr. Table III) of plants lost, which data are small and did not vary according to size of seedlings nor soil fertility. This behavior of cabbage liked that of kidney bean, reported by Harris' (5 and 6) opinion, that kidney bean seedlings, as well from large or from small seed behaved the same viability.

3. The description of cabbage plant.

The description was made basing on 196 individuals of each treatment accounted in four lots of 50 specimens of each plot. Characters taken into consideration were:

1. Weight of leaves, which failed to form heads, rejected by trimming.
2. Weight of trimmed marketable head.
3. Horizontal diameter of the head (d_1).
4. Vertical diameter of the head (d_2).
5. Volume of the head $= \frac{d_1^2 \cdot d_2}{6} \cdot \pi$.
6. Weight of whole plant (excepting roots).

Table III.

The harvest time: 5. X. 1925	Total yield of the green weight per one plot (area 50 sq. m)			
Origin and treatment of plants	$A \pm e$ kg	$\pm \sigma$ kg	c %	$\frac{100 e}{A}$
Large seeds; the bed and the plots nonmanured	175 ± 6.9	13.9	7.9	3.9
Small seeds; the bed and the plots nonmanured	177 ± 4.7	9.5	5.4	2.6
Large seeds; the bed and the plots manured (N + K + P)	235 ± 8.4	16.9	7.2	3.6
Small seeds; the bed and the plots manured (N + K + P)	231 ± 6.0	12.0	5.2	2.6

7. Percent of marketable heads in whole plant weight.

8. Coefficient of the head shape (ratio: $\frac{\text{horizontal}}{\text{vertical}}$ diameters).

9. Coefficient of the head firmness (ratio: $\frac{\text{volume}}{\text{weight}}$ of head).

In order to obtain the desired data in comparable form and easily present the biometrical method was used (Pearl, 14). The subject matter is arranged in two divisions. In the first (a) division the means, standard deviations and coefficients of variability is studied. In the second (b) division degree of interrelation between characters of cabbage are shown by correlation coefficients and correlation ratios.

a) The means and variability of characters.

Reference to Table IV shows the conformity and discrimination among plants resulted from every treatment. An estimation of differences three times greater than their errors is only made when leased on conclusions reported hereby. The plants developed from large seed, regarding that of small seed, had an increase in the weight of leaves rejected by trimming, a decrease of percent heading leaves in the whole plant weight and possessed smaller firmness. However, the weight of cabbage head, the weight of the whole plant (excepting roots), the size of diameters, and the shape of

Yield of marketable heads per one plot (area 50 sq. m)				Percent marketable heads in total yield (average)	Percent of plants non heading (average)	Percent of plants lost on one plot (average)	Number of heading plants on one plot (average)	Σc
$A \pm e$ kg	$\pm \sigma$ kg	c %	$\frac{100 e}{A}$					
82.5 ± 3.3	6.6	8.0	4.0	50 ± 1.7	15.0 ± 2.0	2.5 ± 0.5	123	15.9
100 ± 3.0	6.1	6.0	3.0	50 ± 0.6	10.7 ± 1.2	1.8 ± 0.3	131	11.4
124.5 ± 6.5	13.1	10.5	5.2	53.5 ± 1.3	9.1 ± 1.5	1.8 ± 0.5	131	17.7
136 ± 2.5	5.0	3.7	1.8	60 ± 1.3	7.8 ± 0.7	3.6 ± 1.8	133	8.9

head were alike for plants of both kinds of seed size. The set of cabbage acquired from small seeds was superior to that of large seeds, because, its weight of head equally, it inhabited better qualities as marketable goods, which did not pass over in olericulture without gain.

The variability of characters was broad when affected weight and narrow in respect to size. Variability did not change on the influence of soil fertility ($\Sigma c = 329.5$ and $\Sigma c = 330.6$). This conduct of adult cabbage plant is different as that stated for seedlings and for other plant species recorded by Love (12), Myers (13) and Shaw (19).

b) Correlated characters in cabbage.

The assembled data also offered the opportunity to study the interrelations of plant characters for which are presented in Table V the coefficients of correlation (r) and the correlation ratios (η). The quantitative examination of correlations in cabbage was made, first probably, by the author of the present report, (Kotowski, 11) in his description of some commercial varieties of cabbage, where it has been studied 29 interrelations and 17 correlation coefficients were given. At that time there were distinguished two kinds of correlations: physiological correlations, almost very high, but no significant to breeding work, and essential breeding correlations, which presence facilitates the breeding treatment.

Table IV.

The harvest time: 1. X. 1925		The arithmetic mean $\pm$ stan-		
Origin and treatment of plants		Weight of leaves which failed to form heads; re- jected by trim- ming	Weight of trim- med marketable head	Weight of the whole plant (without roots)
		gr.	gr.	gr
Large seeds; the bed and the plots nonmanured		498 $\pm$ 11.3	925 $\pm$ 26.3	1410 $\pm$ 34.3
Small seeds; the bed and the plots nonmanured		388 $\pm$ 9.4	990 $\pm$ 29.3	1372 $\pm$ 39.2
Large seeds; the bed and the plots manured (N + P + K)		551 $\pm$ 13.8	1263 $\pm$ 38.6	1800 $\pm$ 48.5
Small seeds; the bed and the plots manured (N + P + K)		452 $\pm$ 11.7	1341 $\pm$ 36.8	1780 $\pm$ 42.5
Coefficients				
Large seeds; the bed and the plots nonmanured		34.0	40.0	34.3
Small seeds; the bed and the plots nonmanured		34.0	41.5	40.0
Large seeds; the bed and the plots manured (N + P + K)		35.4	43.0	38.0
Small seeds; the bed and the plots manured (N + P + K)		36.5	39.0	33.7

In the account of correlations performed now, only to the latter kind is paid attention, and hence 10 importante pair of characters are submitted. For each pair three computations were prepared: r , $\eta_{\frac{x}{y}}$ and $\eta_{\frac{y}{x}}$. In many cases the r were lower than the η . It arises in the mind, that some of low values for r may be due to non linear regression. For to be convinced of that, the straitness of regression line was proved by means of Blakeman's test (cfr. Pearl, 14). There was, however no many indications that a curve of a higher order would describe the results better than a straight line and we may conclude in most cases the regression was certainly linear, excepting five interrelations:

1. Weight of rejected leaves and weight of marketable head (for small seeds, fertilized plots).

standard error ($A \pm e$); $n = 196$ plants					
Percent of marketable head in whole plant weight	Horizontal diameter of head	Vertical diameter of head	Coefficient of the head shape	Coefficient of the head firmness	
%	cm	cm			
64.8 ± 0.05	16.5 ± 0.2	8.6 ± 0.1	1.93 ± 0.013	0.74 ± 0.005	
72.7 ± 0.06	16.2 ± 0.2	8.7 ± 0.1	1.88 ± 0.016	0.79 ± 0.005	
69.3 ± 0.07	18.1 ± 0.2	9.3 ± 0.1	1.97 ± 0.016	0.76 ± 0.006	
75.6 ± 0.05	18.2 ± 0.2	9.6 ± 0.1	1.92 ± 0.017	0.79 ± 0.005	
of variation					Σc
—	16.7	14.7	10.1	10.8	160.6
—	16.3	14.8	12.3	10.0	168.9
—	15.8	16.3	11.2	10.7	170.4
—	14.3	13.9	12.9	9.9	160.2

2. Weight of rejected leaves and coefficient of head firmness (for small seeds, unfertilized plots).

3. Horizontal diameter of head and coefficient of head shape (for small seeds, fertilized plots).

4. Horizontal diameter of head and coefficient of head firmness (for small seeds, fertilized plots).

5. Horizontal diameter of head and coefficient of head firmness (for large seeds, unfertilized plots).

It is interesting that non-linear regression occurs, when plants from small seeds are studied and when correlations appointed to characters expressed in formulas (coefficients of shape and of firmness) instead of direct measurements.

There is following arrangement of correlations, basing on their average numerical value (the first the highest):

Table V.

Correlated characters in Brunswick short stem cabbage		Large seeds; the bed and the plots nonmanured		
X	Y	$r \pm e$	$\eta_{\frac{x}{y}} \pm e$	$\eta_{\frac{y}{x}} \pm e$
1. Weight of leaves which failed to form heads, rejected by trimming	Weight of the trimmed, marketable head	$+.593 \pm .045$	$+.593 \pm .045$	$+.605 \pm .045$
2. Weight of leaves which failed to form heads, rejected by trimming	Coefficient of the head shape	$.315 \pm .064$	$.393 \pm .060$	$.336 \pm .063$
3. Weight of leaves which failed to form heads, rejected by trimming	Coefficient of the head firmness	$.003 \pm .071$	$.072 \pm .071$	$.119 \pm .070$
4. Weight of the trimmed marketable head	Coefficient of the head shape	$.254 \pm .067$	$.297 \pm .065$	$.297 \pm .067$
5. Weight of the trimmed marketable head	Coefficient of the head firmness	$.097 \pm .070$	$.117 \pm .070$	$.237 \pm .067$
6. Horizontal diameter of head	Percent of marketable head in whole plant weight (without roots)	$.531 \pm .051$	$.575 \pm .048$	$.574 \pm .048$
7. Horizontal diameter of head	Coefficient of the head shape	$.417 \pm .059$	$.430 \pm .058$	$.420 \pm .059$
8. Horizontal diameter of head	Coefficient of the head firmness	$-.118 \pm .070$	$-.226 \pm .067$	$-.356 \pm .062$
9. Percent of marketable head in whole plant weight (without roots)	Coefficient of the head firmness	$.091 \pm .070$	$.278 \pm .066$	$.255 \pm .067$
10. Coefficient of the head shape	Coefficient of the head firmness	$.059 \pm .071$	$.202 \pm .068$	$.213 \pm .067$

1. Horizontal diameter of head and percent of marketable head in whole plant weight.

2. Weight of leaves, rejected by trimming and weight of marketable head.

3. Horizontal diameter of head and coefficient of the head shape.

4. Weight of leaves, rejected by trimming and coefficient of the head shape.

5. Weight of marketable head and coefficient of the head shape.

Small seeds; the bed and the plots nonmanured			Large seeds; the bed and the plots manured (N + P + K)			Small seeds; the bed and the plots manured (N + P + K)		
$r \pm e$	$\eta_{\frac{x}{y}} \pm e$	$\eta_{\frac{y}{x}} \pm e$	$r \pm e$	$\eta_{\frac{x}{y}} \pm e$	$\eta_{\frac{y}{x}} \pm e$	$r \pm e$	$\eta_{\frac{x}{y}} \pm e$	$\eta_{\frac{y}{x}} \pm e$
$+.330 \pm .051$	$+.580 \pm .047$	$+.580 \pm .047$	$+.332 \pm .063$	$+.431 \pm .058$	$+.369 \pm .062$	$+.541 \pm .051$	$+.714 \pm .035$	$+.567 \pm .048$
$.286 \pm .065$	$.388 \pm .060$	$.295 \pm .065$	$.389 \pm .060$	$.408 \pm .059$	$.435 \pm .058$	$.388 \pm .060$	$.391 \pm .060$	$.428 \pm .058$
$.081 \pm .071$	$.525 \pm .052$	$.255 \pm .067$	$.159 \pm .059$	$.264 \pm .066$	$.191 \pm .069$	$.147 \pm .070$	$.187 \pm .069$	$.302 \pm .065$
$.250 \pm .067$	$.310 \pm .064$	$.363 \pm .062$	$.123 \pm .070$	$.307 \pm .065$	$.216 \pm .068$	$.286 \pm .065$	$.377 \pm .061$	$.313 \pm .064$
$.198 \pm .068$	$.240 \pm .067$	$.332 \pm .063$	$.281 \pm .065$	$.328 \pm .064$	$.363 \pm .062$	$.212 \pm .068$	$.283 \pm .065$	$.238 \pm .067$
$.607 \pm .045$	$.690 \pm .037$	$.635 \pm .042$	$.607 \pm .045$	$.705 \pm .064$	$.660 \pm .040$	$.480 \pm .055$	$.541 \pm .050$	$.516 \pm .052$
$.396 \pm .060$	$.465 \pm .056$	$.505 \pm .053$	$.322 \pm .064$	$.380 \pm .060$	$.391 \pm .060$	$.543 \pm .050$	$.734 \pm .033$	$.550 \pm .050$
$+.004 \pm .071$	$.253 \pm .067$	$.194 \pm .069$	$.145 \pm .070$	$.253 \pm .067$	$.237 \pm .067$	$.073 \pm .071$	$.144 \pm .070$	$.137 \pm .070$
$.092 \pm .070$	$.184 \pm .069$	$.195 \pm .069$	$.180 \pm .069$	$.251 \pm .067$	$.378 \pm .061$	$.144 \pm .070$	$.288 \pm .065$	$.210 \pm .068$
$.195 \pm .069$	$.197 \pm .069$	$.226 \pm .067$	$.159 \pm .069$	$.270 \pm .066$	$.269 \pm .066$	$.202 \pm .068$	$.269 \pm .066$	$.330 \pm .063$

6. Weight of marketable head and coefficient of the head firmness.

7. Percent of marketable head in whole plant weight and coefficient of the head firmness.

8. Weight of leaves rejected by trimming and coefficient of the head firmness.

9. Coefficient of the head shape and coefficient of the head firmness.

10. Horizontal diameter of head and coefficient of the head firmness.

Table VI.

Correlated characters in Brunswick short stem cabbage		The arithmetic mean of correlation coefficients for plants harvested in 1925	The arithmetic mean of correlation coefficients for plants harvested in 1921 and 1922
X	Y	$r \pm e$	$r \pm e$
1. Weight of leaves which failed to form heads; rejected by trimming	Weight of the trimmed marketable head	$+ .497 \pm .054$	$+ .210 \pm .068$
2. Weight of leaves which failed to form heads; rejected by trimming	Coefficient of the head shape	$+ .345 \pm .063$	$(+ r < 3 e)$
3. Weight of leaves which failed to form heads; rejected by trimming	Coefficient of the head firmness	$(+ .007 \pm .071)$	$(- r < 3 e)$
4. Weight of the trimmed marketable head	Coefficient of the head shape	$+ .228 \pm .068$	$(+ r < 3 e)$
5. Weight of the trimmed marketable head	Coefficient of the head firmness	$(+ .197 \pm .069)$	$(- r < 3 e)$
6. Horizontal diameter of head	Percent of marketable head in whole plant weight (without roots)	$+ .557 \pm .049$	$+ .530 \pm .051$
7. Horizontal diameter of head	Coefficient of the head shape	$+ .420 \pm .059$	$+ .470 \pm .056$
8. Horizontal diameter of head	Coefficient of the head firmness	$(+ .026 \pm .071)$	$- .490 \pm .054$
9. Percent of marketable head in whole plant weight (without roots)	Coefficient of the head firmness	$(+ .127 \pm .070)$	$(+ r < 3 e)$
10. Coefficient of the head shape	Coefficient of the head firmness	$(+ .153 \pm .070)$	$- .320 \pm .064$

The correlations counted hereby, are quite large, as it becomes evident if to made averages belonging to every plant treatment, though we have for correlation ratios for plants from large seeds and fertilized plots: $\eta = +0.360$; for plants from small seeds and fertilized plots: $\eta = +0.392$; for plants from large seeds and non-fertilized plots: $\eta = +0.318$; for plants from small seeds and non-fertilized plots: $\eta = +0.383$.

In condensed form on Table VI are compared correlations stated for several strains of Brunswick short stem cabbage cultivated

The arithmetic mean of correlation ratios for plants harvested in 1925		The determination of coefficients, referring to their height											
		r				$\eta \frac{x}{y}$				$\eta \frac{y}{x}$			
		L.N.	S.N.	L.M.	S.M.	L.N.	S.N.	L.M.	S.M.	L.N.	S.N.	L.M.	S.M.
$\eta \frac{x}{y} \pm e$	$\eta \frac{y}{x} \pm e$												
$+ .58 \pm .047$	$+ .58 \pm .047$	α	α	β	α	α	α	β	α	α	α	β	α
$+ .39 \pm .061$	$+ .37 \pm .062$	β	γ	β	β	β	β	β	β	β	γ	β	β
$+ .26 \pm .066$	$+ .22 \pm .068$	δ	δ	δ	δ	δ	α	γ	δ	δ	γ	δ	γ
$+ .35 \pm .062$	$+ .30 \pm .065$	γ	γ	δ	γ	γ	β	β	β	γ	β	γ	β
$+ .24 \pm .067$	$+ .29 \pm .065$	δ	δ	γ	γ	δ	γ	β	γ	γ	β	β	γ
$+ .63 \pm .043$	$+ .59 \pm .046$	α	α	α	β	α	α	α	α	α	α	α	α
$+ .50 \pm .054$	$+ .46 \pm .056$	β	β	β	α	β	β	β	α	β	α	β	α
$(+ .11 \pm .070)$	$+ .05 \pm .071$	δ	δ	δ	δ	γ	γ	γ	δ	β	δ	γ	δ
$+ .25 \pm .067$	$+ .26 \pm .066$	δ	δ	δ	δ	γ	δ	γ	γ	γ	δ	β	γ
$+ .23 \pm .067$	$+ .26 \pm .066$	δ	δ	δ	γ	γ	δ	γ	γ	γ	γ	γ	β

during 1921 and 1922 (cfr. Kotowski, 11) with those acquired in 1925.

There is little conformity among these data. For instance correlation *sub* 8 was distinct negative and now it is low but positive; the same happened with correlation *sub* 10; correlations *sub* 1 and 2 are of equal size in strains proved earlier and now.

To give a short and clear review, correlations have been written on Table VI after determining their height: α —very high (0.750—0.500); β —moderate (0.499—0.300); γ —low, but certain

(0.299—0.200) and δ — low but incertain, almost $< 3e$ (0.199—0.001). The advantage of calculating correlation ratios (η) instead of correlation coefficients (r) is given at hand. Many of interrelations classified at the group δ , if counted as r , should be dislocated at the group γ , β or even α , if counted as η . Therefore many doubtful correlations could be appreciated as doubtless, when the latter calculating methode has been applied.

The effect of the four standard treatments of cabbage culture might be studied in connection of their influence on the degree of correlative junction. For this aim it is desirable to divide the correlations in two parts: one containing α and β coefficients and other containing γ and δ . This division is shown in the brief summary added below.

	Plants from large seeds, unfertilized plots	Plants from small seeds unfertilized plots
Coefficients α and β :	13	14
Coefficients γ and δ :	17	16
	Plants from large seeds, fertilized plots	Plants from small seeds fertilized plots
Coefficients α and β :	16	16
Coefficients γ and δ :	14	14

This item argues, there was no influence of the size of seed on the degree of correlations calculated from resulting plant. It supports either the conclusion, there was an effect of soil fertility on correlation height, because they were greater on richer soil (fertilized plots) than on poorer one (unfertilized plots).

Summary.

This paper is to be regarded as a first attempt to determine the effect of size of seed of cabbage on the resulting crop. The investigations concerning cabbage (variety: Brunswick short stem) had an aim to study the behavior of a biennial and cross-pollinized plant species during the first vegetation year. Observations for a number of seasons and for a number of commercial varieties of cabbage should be made to settle definitely the subject touched in this paper. From the data presented, however following conclusions seem justified.

1. The size of seed influenced the size of seedling in 60 days stage (cfr. fig. 20).

2. The effect of size of seed disappeared during the time of field growth of cabbage. Some phase of that process is illustrated on fig. 21, 22, 23 and 24.

3. The productiveness of cabbage was not dependant on the size of seed planted. From small seeds developed plants giving yields as high as those from large seeds ones. The quality of the yield in question was better when small seeds were sown: in that case the head firmness was greater as well as the percentage of marketable heads.

4. There will be no practical gain in cabbage culture under truck farming conditions from applying the large seed and rejecting the small seed.

5. The size of the seed did not influence the variability and the degree of correlations stated on adult cabbage plant.

6. The increase of soil fertility diminished the variability of seedling characters.

7. Higher correlations have been noticed on cabbage plant grown on richer soil.

Institute of Olericulture and Vegetable Breeding, College of Agriculture, Warsaw.

Bibliography.

1. Arny, A. C. and Garber, R. J. Variation and correlation in wheat with special reference to weight of seeds planted. Journ. of Agr. Research. 14, 1918.

2. Brenchley, W. E. Effect of weight of seed upon the resulting crop. Annals of Appl. Biology. 10, 1923.

3. Cummings, M. B. Large seed a factor in plant production. Vermont Agr. Exp. Sta. Bull. 177, 1914.

4. Gregory, F. G. The increase in area of leaves and leaf surface of *Cucumis sativus*. Annals of Botany. 35, 1921.

5. Harris, J. A. On differential mortality with respect to seed weight occurring in field cultures of *Phaseolus vulgaris*. American Naturalist. 46, 1912.

6. — Supplementary studies on the differential mortality with respect to seed weight in the germination of garden beans. American Naturalist. 47, 1913.

7. — The relationship between the weight of the seed planted and the characteristics of the plant produced. Biometrika. 10. 1914.

8. Kiesselbach, T. A. Relation of seed size to yield of small grain crops. Journ. of American Soc. of Agronomy. 16, 1924.

9. Kotowski, F. Effect of seed sowing time and manuring in rye (polish' english summary). Roczn. Nauk. Roln. 6, 1921.

10. — Der Wert eines Individuums in reiner Linie (polish, german summary). „Kosmos“ 47, 1922.

11. — Description of some commercial varieties of cabbage (polish, english summary). Roczn. Nauk. Roln. 10, 1923.
12. Love, H. H. Studies of variation in plants. Cornell University, Agr. Exp. Sta. Bull. 297, 1911.
13. Myers, C. H. Effect of fertility upon variation and correlation in wheat. Annual Report of Amer. Breed. Associat. 7, 1912.
14. Pearl, R. Introduction to medical biometry and statistics. Philadelphia and London, 1923.
15. Rotunno, N. A. Effect of size of seed on plant production with special reference to radish. Botanical Gazette. 78. 1924.
16. Rudolfs, W. Influence of temperature and initial weight of seeds upon the growth rate of *Phaseolus vulgaris* seedlings. Journ of Agr. Research. 26, 1923.
17. Schmidt, D. A study of plant growth in relation to the weight of seed. 43 Annual Report of New Jersey State Agr. Exp. Station 1923.
18. — The effect of the weight of the seed on the growth of the plant. New Jersey Agr. Exp. Sta Bull. 404, 1924.
19. Shaw, J. K. The effect of fertilizers on variation in corn and beans. American Naturalist. 47. 1913.
20. Urbain, A. Influence des matières de réserve de l'albumen de la graine sur le developpement de l'embryon. Revue générale de botanique. 32, 1920.

(Wpłynęło do redakcji 30 listopada 1925 r.).