CORRELATIONS BETWEEN ANATOMICAL CHARACTERS IN THE SEEDLING OF PHASEOLUS VULGARIS

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(Received for publication January 17, 1921)

INTRODUCTION

In an earlier paper[1] we traced the course of the vascular bundles throughout the dimerous and trimerous seedlings of *Phaseolus vulgaris* and measured the variation occurring at different levels.

The chief results of that paper were (*a*) the demonstration of the profound differentiation of dimerous and trimerous seedlings in their internal (vascular) as well as in their external characters, (*b*) the demonstration that the number of bundles at a given level in the seedling is a highly variable rather than a constant character, and (*c*) that the various organs or regions of the plant body (particularly, in the present case, those which are separated by the vascular anastomoses at the cotyledonary node) differ widely in the magnitude of their variability as to bundle number.

In this paper we propose to consider in quantitative terms the degree of interrelationship between the vascular structures in the different regions of normal and abnormal seedlings. The results of such an investigation will evidently be of considerable morphological interest, since many of the problems of organic form are fundamentally problems of correlation.

Two morphological problems at once present themselves for consideration:

First, is there a high correlation between the vascular topography of two different levels of the same internode, *i.e.*, is the number of vascular bundles constant throughout the length of an internode or is there more or less extensive splitting or anastomosis within the length of such a conventional morphological unit?

Second, is there a definite correlation between the vascular topography below a node and the vascular topography above it, or is the vascular system so fully reorganized at the nodal anastomosis of bundles that, in bundle number, successive internodes are practically independent of one another?

With the present material, these questions may be answered by determining the coefficients of correlation for bundle number between (1) the base and the mid-region of the hypocotyl, and (2) between the various levels of the hypocotyl and the mid-region of the epicotyl. It is these

[1] Harris, J. Arthur, Sinnott, E. W., Pennypacker, John Y., and Durham, G. B. The vascular anatomy of dimerous and trimerous seedlings of *Phaseolus vulgaris*. Amer. Jour. Bot. 8: 63–102. 1921.

problems which we propose first to consider. We shall also compare the normal and abnormal seedlings as to the correlations which they exhibit, and shall touch briefly on the problem of the correlation between bundle number in seedlings from the same parent plant.

The frequency distributions of bundle number are in many cases of very narrow range and very skew. There has, therefore, been considerable question as to the formulae to be employed. It has seemed best, for various reasons which need not be detailed here, to employ the usual method of product-moment correlation.

Presentation and Analysis of Data

The series of data considered here are in large part the same as those discussed in our earlier paper, but have in some cases been supplemented by the examination of additional sections. These have been included when the dimerous and trimerous seedlings were not true siblings. In lines 75, 93, and 98, the series compared were obtained from the same mothers. In so far as the data are the same as those used earlier, the variation constants for the different characters have already been presented and discussed and require no further comment here. The data from which measures of interrelationship may be computed are given in our fundamental tables A to L. We have, therefore, merely to deduce and discuss the correlation coefficients.

Correlation between Bundle Number at Different Levels in the Same Internode

We first turn to the problem of the relationship between the number of bundles—primary double bundles, intercalary bundles, and total bundles—at the base of the hypocotyl and the number in the central region of the hypocotyl. The reader who cares to do so may reconstruct the 24 correlation tables necessary for a consideration of these relationships from our fundamental tables A–L.

Table I. *Coefficients of correlation between number of primary double bundles, number of intercalary bundles, and total bundles at base of hypocotyl, and number of bundles in central region of hypocotyl*

Character of Seedlings and Line	N	Correlation for Primary Double Bundles r_{ph}		Correlation for Intercalary Bundles r_{ih}		Correlation for Total Bundles r_{bh}	
Trimerous							
Line 75	142	+.378±.049	7.79	+.329±.051	6.51	+.649±.033	19.8
Line 93	155	+.233±.051	4.55	+.204±.052	3.92	+.469±.042	11.1
Line 98	183	+.321±.045	7.17	+.253±.047	5.42	+.586±.033	17.9
Line 139	106	+.417±.054	7.71	+.097±.065	1.50	+.531±.047	11.3
Line 143	221	+.556±.031	17.8	+.305±.041	7.40	+.753±.020	38.3
Dimerous							
Line 75	142	+.362±.049	7.35	+.668±.031	21.3	+.797±.021	38.0
Line 93	155	+.641±.032	21.0	+.390±.046	8.50	+.753±.023	32.2
Line 98	183	+.666±.028	24.0	+.555±.035	16.1	+.786±.019	41.4
Line 139	305	+.344±.034	10.1	+.898±.008	119.7	+.925±.006	168.3
Line 143	420	+.530±.023	22.5	+.634±.020	32.2	+.802±.011	68.5

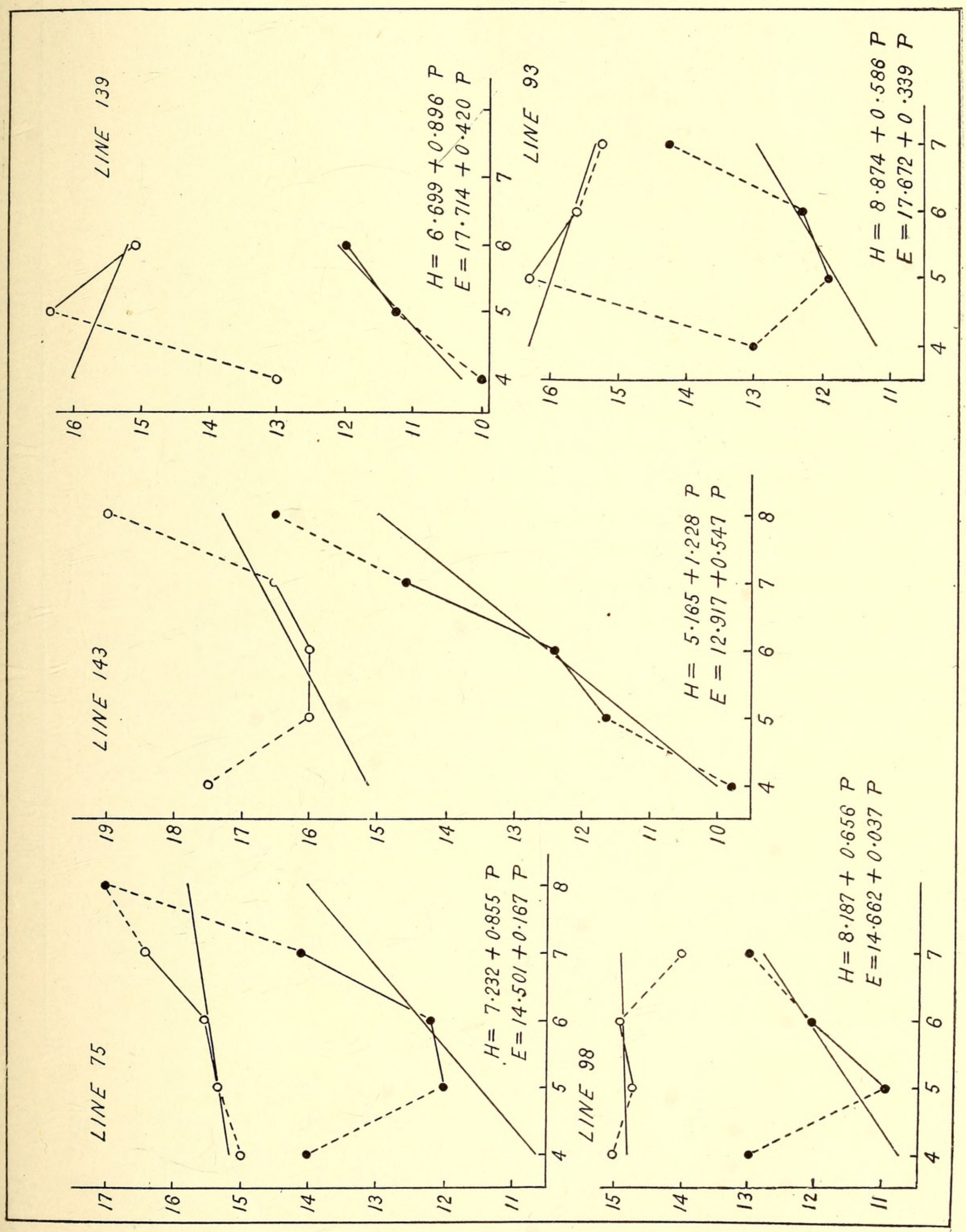

DIAGRAM 1. Regression of number of bundles in central region of hypocotyl and in central region of epicotyl on number of primary double bundles at base of hypocotyl in trimerous seedlings. Empirical means represented by solid dots for hypocotyl and by circles for epicotyl.

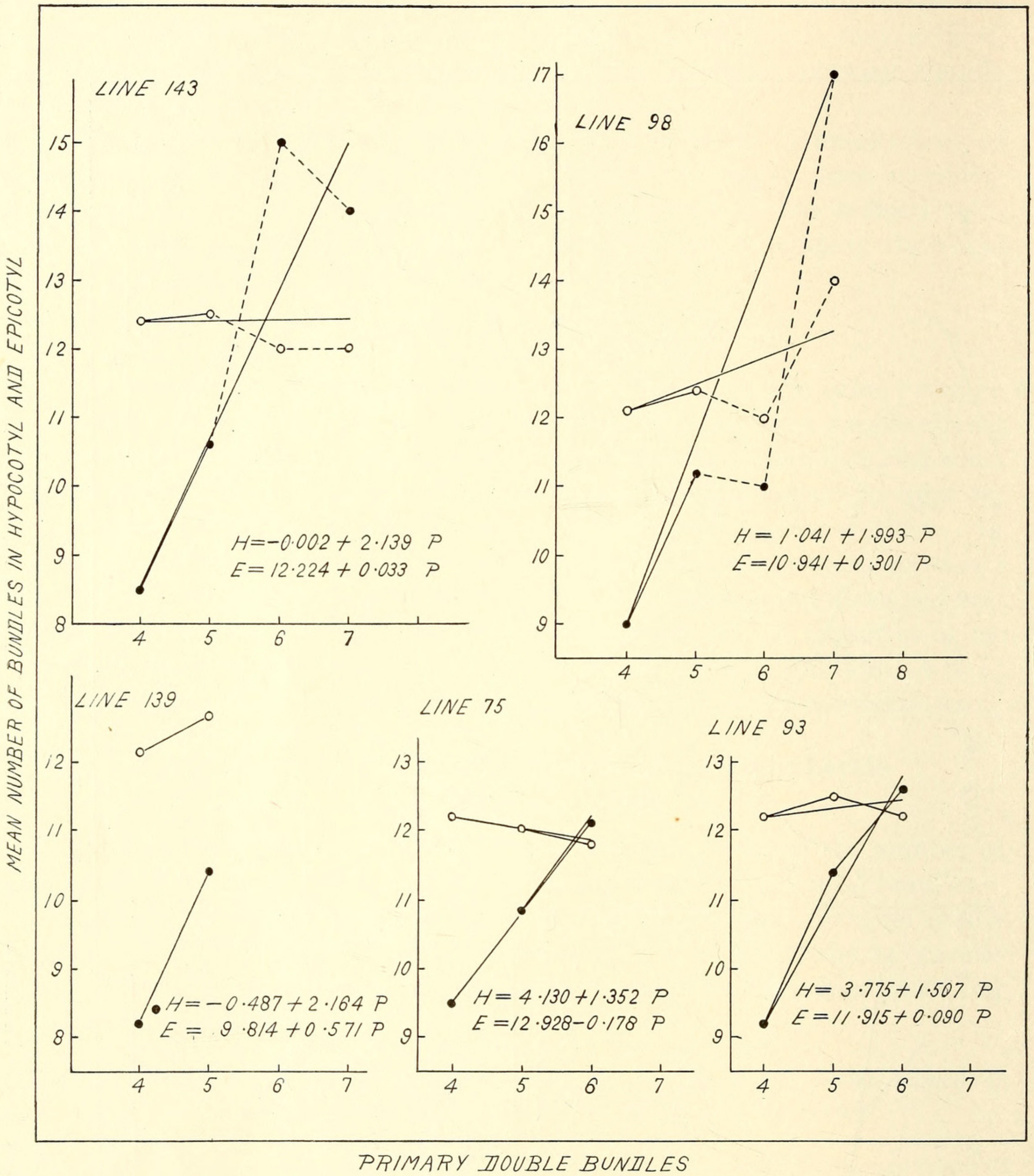

DIAGRAM 2. Regression of number of bundles in central region of hypocotyl and in central region of epicotyl on number of primary double bundles at base of hypocotyl in dimerous seedlings. Empirical means represented by solid dots for hypocotyl and by circles for epicotyl.

The correlation coefficients between the two classes of bundles which have been recognized at the base of the hypocotyl and the total number of basal bundles (*i.e.*, the sum of the number of primary double bundles and the number of intercalary bundles in the base of the hypocotyl) and the number in the central region of the hypocotyl, appear in table 1.

The correlations are without exception positive in sign and of a material order of magnitude. They have been expressed in terms of regression on diagram 1 for trimerous seedlings and on diagram 2 for dimerous seedlings of the five lines.[2]

Primary Double Bundles and Mid-region of Hypocotyl

The constants showing the relationship between number of primary double bundles and number of bundles in the central region of the hypocotyl, r_{ph}, are shown in the first section of table 1. They are positive and statistically significant in all cases in both dimerous and trimerous seedlings. The average value of the coefficient for the five lines investigated is +.3810 for trimerous seedlings and +.5086 for dimerous seedlings.

Diagram 2 shows that in the case of the normal plants of lines 75, 93, and 143 a straight line represents very well indeed the changes in the mean number of bundles in the hypocotyl with variations in the number of primary double bundles at the base of the hypocotyl. In line 98 the agreement is apparently not so good. This is, however, attributable to the fact that of the 183 plants only two have more than 5 primary bundles. Of these two, one plant is recorded as having 8, which is twice the normal number. In line 139 only plants with two classes of seedlings, those with 4 or 5 primary bundles, are available, and since the regression line must connect the two means it is idle to discuss linearity of regression.

Turning to the trimerous plants represented in diagram 1, we note that because of the small number of plants with other than 5 or 6 primary double bundles the distribution of the empirical means is very irregular indeed. There is some suggestion of non-linearity, but the number of seedlings in the more extreme classes is so small for every line that little stress is to be laid upon them.

In both normal and abnormal plants the slope of the regression line is rather steep, showing a material change in the number of bundles in the central region of the hypocotyl with variations in the number of primary double bundles at the base of the hypocotyl.

Intercalary Bundles and Mid-region of Hypocotyl

The correlation between the number of intercalary bundles and the total number of bundles in the hypocotyl, r_{ih}, are shown in the second

[2] The equations on the diagrams show the regression of the number of bundles in the central region of the hypocotyl, H, and in the central region of the epicotyl, E, on the number of primary double bundles, P, at the base of the hypocotyl. The empirical means for the hypocotyl are represented by solid dots, while those of the epicotyl are represented by circles. In both cases the empirical mean number of bundles for the same organ are connected by solid lines when the number of sections averaged was five or more, but by broken lines when the number available was four or less. Fortunately for purposes of graphical representation, the mean number of bundles in both hypocotyl and epicotyl can be drawn on the same diagram. Only the lower lines in each of the five panels of the two diagrams require consideration for the moment.

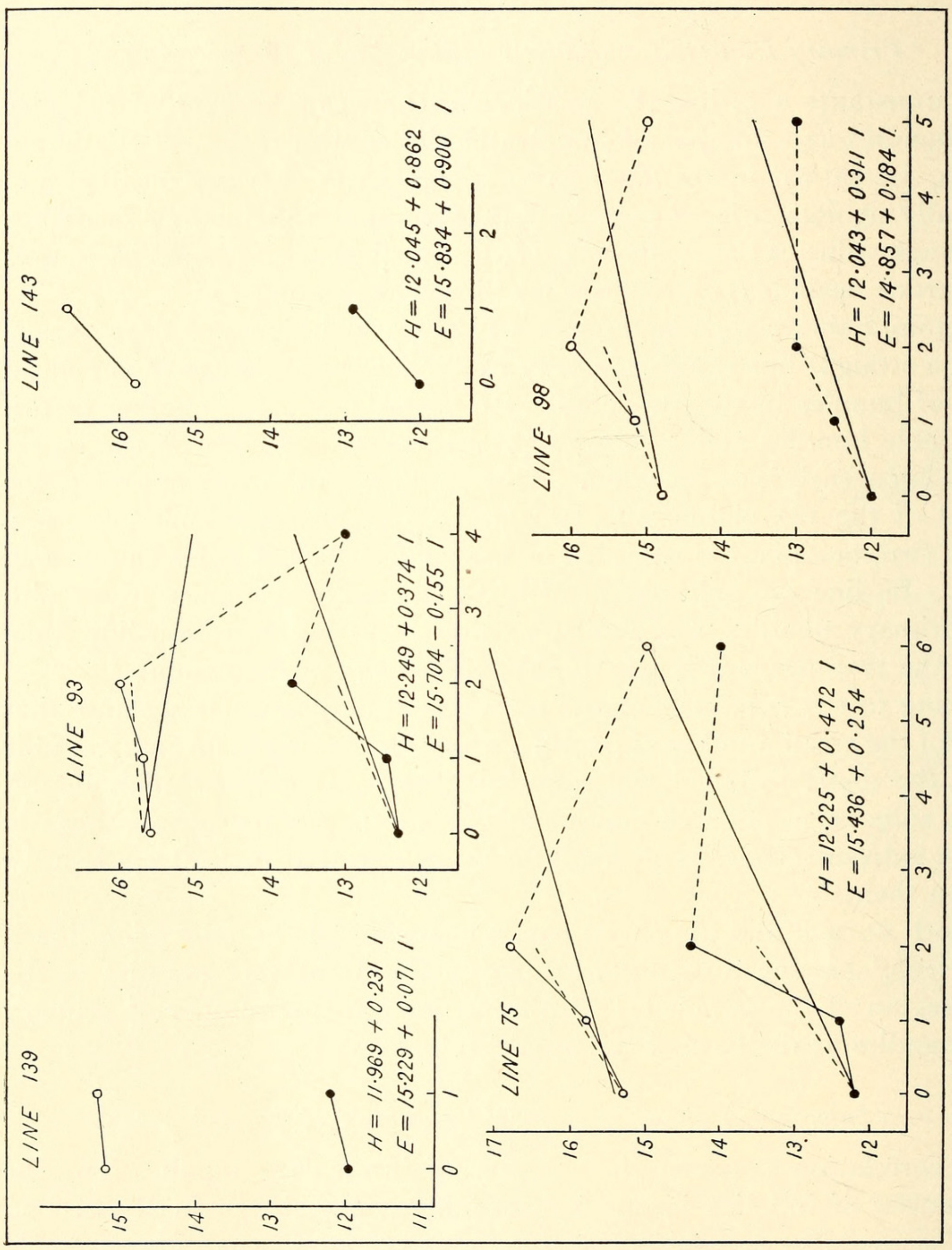

DIAGRAM 3. Regression of number of bundles in central region of hypocotyl and in central region of epicotyl on number of intercalary bundles at base of hypocotyl in trimerous seedlings. Empirical means represented by solid dots for hypocotyl and by circles for epicotyl.

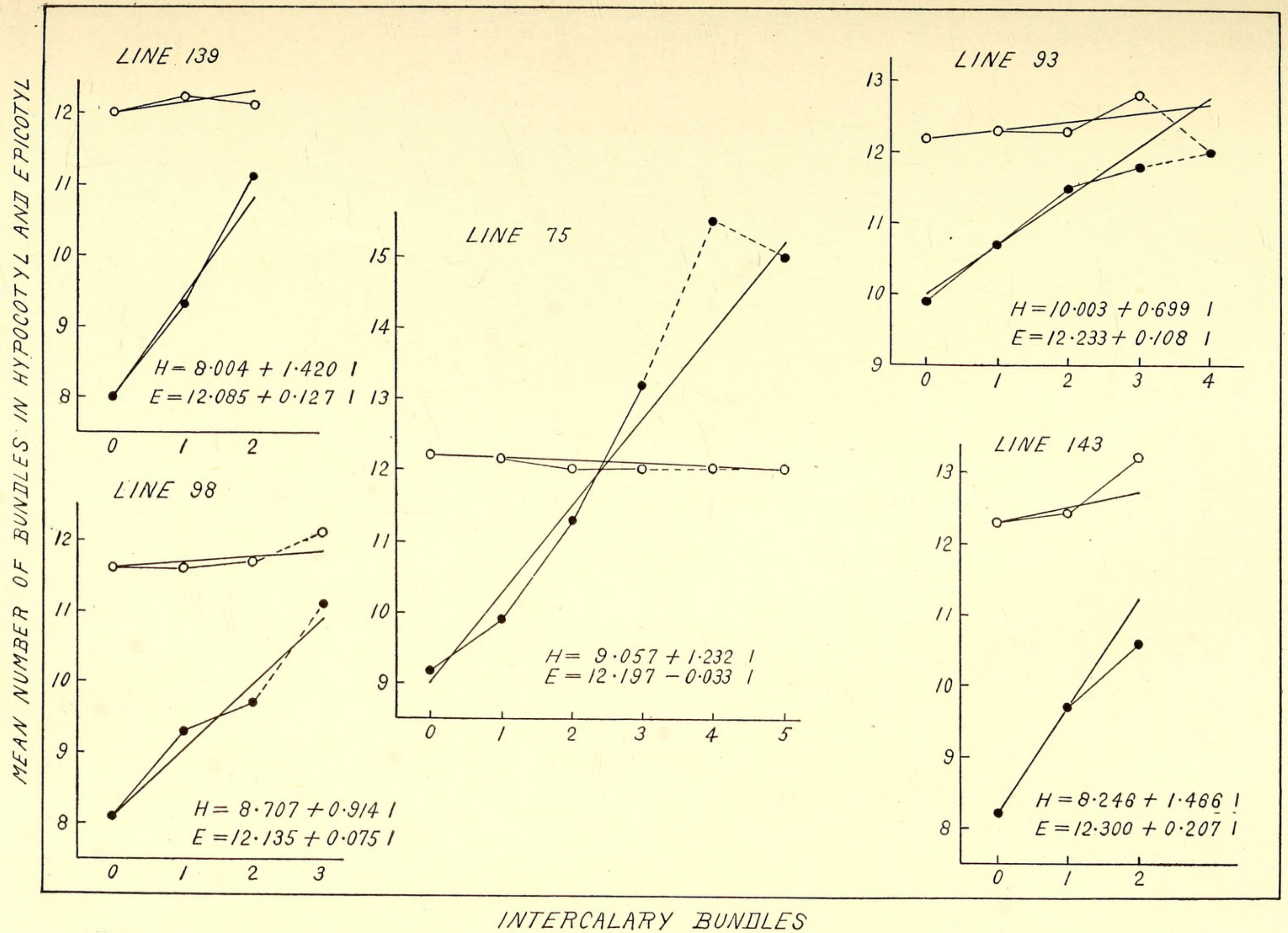

DIAGRAM 4. Regression of number of bundles in central region of hypocotyl and in central region of epicotyl on number of intercalary bundles at base of hypocotyl in dimerous plants. Empirical means represented by solid dots for hypocotyl and by circles for epicotyl.

section of table 1. The straight-line equations showing the regression of the number of bundles in the central region of the hypocotyl are recorded and represented graphically on diagram 3 for trimerous seedlings and on diagram 4 for dimerous seedlings. These diagrams, like the two preceding, also give the regression equations and their graphic representation for the epicotyl which will be discussed in a subsequent section.

The correlation coefficients are positive in all cases, and with one exception may be considered statistically significant. They show, however, a considerable irregularity from line to line, presumably because of the varying range and distribution of number of intercalary bundles. The average value of the coefficient is +.2376 for trimerous seedlings and +.6290 for dimerous seedlings.

Turning to the graphs, we may note that for the dimerous plants the agreements between the empirical and the theoretical means are very good indeed. The slope of the lines for the hypocotyl is very steep.

The graphs for the trimerous plants show far greater irregularities because of the generally small number of the strands but the occasional occurrence of plants with a larger number. Reference to the tables will show that in line 75 there is one seedling with 6 intercalary bundles whereas the remaining 141 seedlings have only 0, 1, or 2 intercalary bundles. In line 93 there is only one seedling with more than 2 intercalary bundles and it has 4. In line 98 all the frequencies with two exceptions fall on 0 or 1 intercalary bundle.

The correlations and equations have been recalculated, leaving these extreme cases out of account. The regression straight lines based on all the material are represented by solid lines. Those in which the extreme class were omitted are represented by broken lines.[3] The removal of these aberrant cases has increased the agreement between the observed and the theoretical means but the fit is still far from satisfactory. The only conclusion which can be drawn from these diagrams is that there is a considerable degree of positive correlation between the number of the intercalary bundles and the number of bundles in the hypocotyl.

Total Basal Bundles and Mid-region of Hypocotyl

The correlations between total bundles (primary double bundles + intercalary bundles) at the base of the hypocotyl and the number of bundles in the central region of the hypocotyl, r_{bh}, are shown in the third section of table 1. The straight-line regression equations are given and represented graphically as the lower figures in each panel of diagram 5 for trimerous seedlings and diagram 6 for dimerous seedlings.

As might be expected on *a priori* grounds, these coefficients agree with those for primary double bundles and for intercalary bundles in sign, and

[3] For the curtailed series the regression equations are: Line 75, $H = 12.194 + 0.654\,I$; Line 93, $H = 12.238 + 0.462\,I$; Line 98, $H = 12.030 + 0.473\,I$.

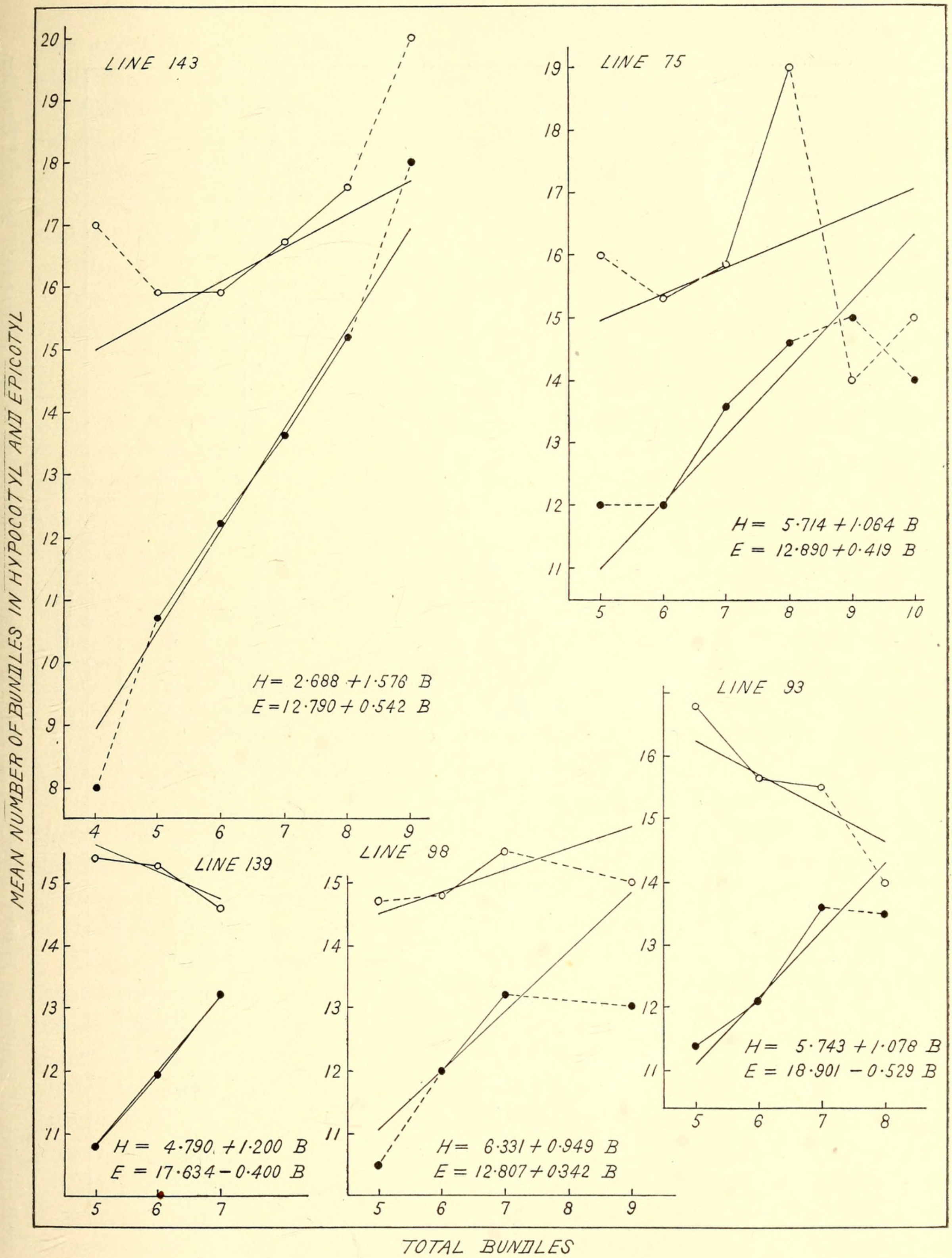

Diagram 5. Regression of number of bundles in central region of hypocotyl and in central region of epicotyl on total number of bundles at base of hypocotyl in trimerous seedlings. Empirical means represented by solid dots for hypocot yl and by circles for epicotyl.

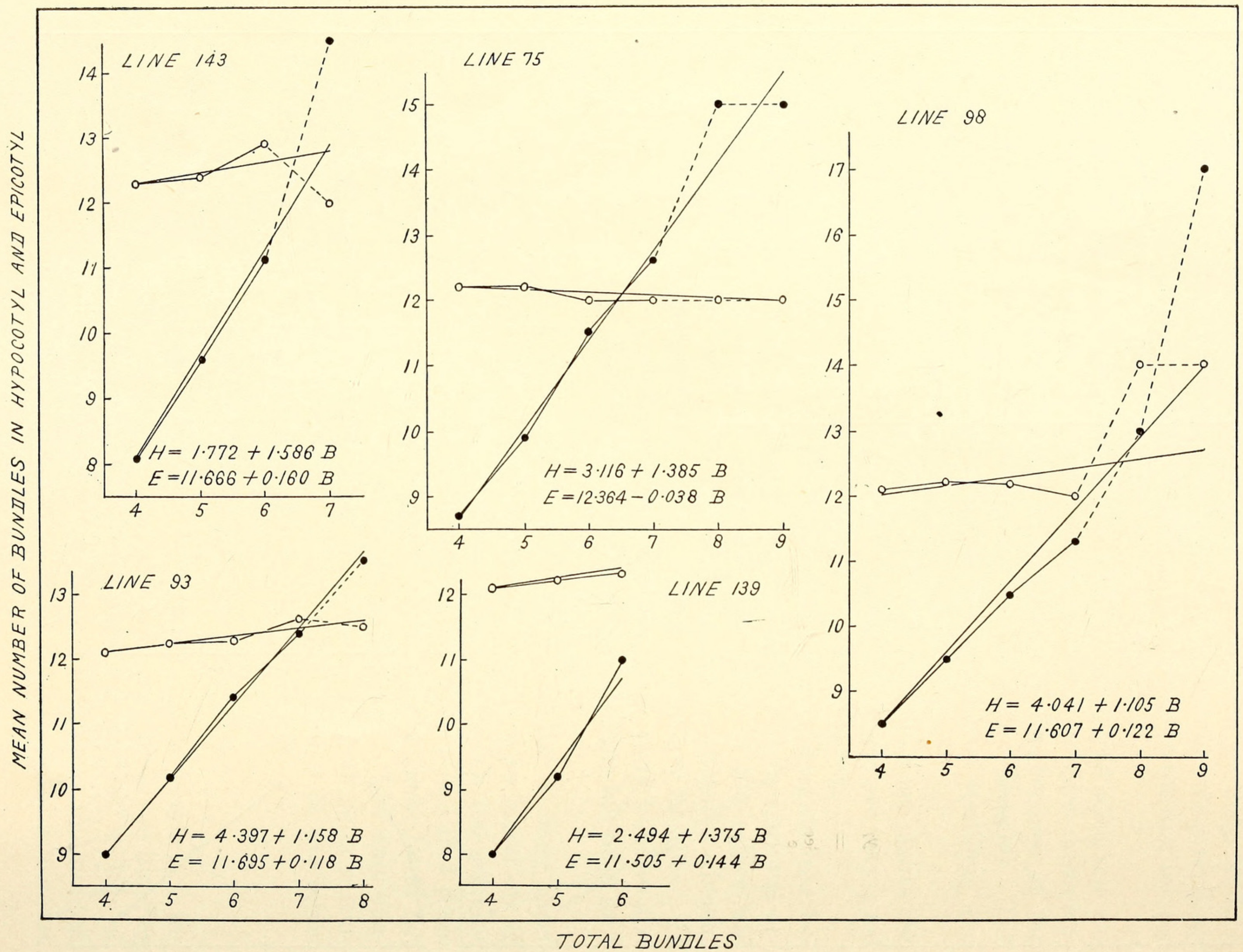

DIAGRAM 6. Regression of number of bundles in central region of hypocotyl and in central region of epicotyl on total number of bundles at base of hypocotyl in dimerous seedlings. Empirical means represented by solid dots for hypocotyl and by circles for epicotyl.

are in general somewhat higher than those for either of these two classes. The average value of the 5 coefficients for trimerous seedlings is +.5976 while that for dimerous seedlings is +.8126.

Turning to the diagrams, we note that the straight lines and the empirical means are in excellent agreement, considering the small number of seedlings, in the case of the normal plants, but show greater irregularities in the case of the abnormal plants. This is due to a considerable extent to the greater concentration of the frequencies into two classes in the case of the trimerous seedlings.

We may now consider the relative magnitudes of the three correlations which we have been studying. Table 2 shows the differences existing between the various correlations, *i.e.*, the possible differences between the correlation for primary bundles and hypocotyledonary bundles, r_{ph}, for intercalary bundles and hypocotyledonary bundles, r_{ih}, and for total bundles at the base of the hypocotyl and hypocotyledonary bundles, r_{bh}.

TABLE 2. *Comparison of correlations between the various types of bundles at the base of hypocotyl and the number of bundles in the central region of hypocotyl*

Character of Seedlings and Line	$r_{bh} - r_{ph}$		$r_{bh} - r_{ih}$		$r_{ph} - r_{ih}$	
Trimerous						
Line 75	+.271±.059	4.59	+.320±.061	5.25	+.049±.071	0.69
Line 93	+.236±.066	3.58	+.265±.067	3.95	+.029±.073	0.40
Line 98	+.265±.056	4.73	+.333±.057	5.84	+.068±.065	1.05
Line 139	+.114±.071	1.61	+.434±.080	5.43	+.320±.084	3.81
Line 143	+.197±.037	5.32	+.448±.046	9.74	+.251±.051	4.92
Dimerous						
Line 75	+.435±.053	8.20	+.129±.037	3.49	−.306±.058	5.28
Line 93	+.112±.040	2.80	+.363±.051	7.11	+.251±.056	4.48
Line 98	+.120±.033	3.64	+.231±.040	5.78	+.111±.045	2.47
Line 139	+.581±.035	16.6	+.027±.010	2.70	−.554±.035	15.8
Line 143	+.272±.026	10.5	+.168±.022	7.64	−.104±.030	3.47

For both dimerous and trimerous seedlings, the correlations between the total bundles at the base of the hypocotyl and the number of bundles in the central region of the hypocotyl are higher throughout than those for either of the two separate types of bundles (primary bundles and intercalary bundles) individually considered. In general, the differences are sufficiently large in comparison with their probable errors to be considered statistically significant.

The comparison of the magnitudes of the correlations between numbers of primary double bundles and of vascular elements at higher levels, and between numbers of intercalary bundles and of vascular elements at higher levels, shows that in 7 of the 10 comparisons the closer correlation of hypocotyledonary bundles is with the primary double bundles.

Lines 75, 139, and 143 present exceptions. In the normal plants of these lines the correlation between intercalary bundles and total bundles in the hypocotyl is apparently significantly higher than that between primary double bundles and total bundles in the hypocotyl.[4]

The fact that the number of bundles in the central region of the hypocotyl is about equally correlated with the number of primary double bundles and with the number of intercalary bundles at the base of the hypocotyl shows that both types of bundles are of about equal significance in determining the number of bundles in the central region of the hypocotyl.

From the foregoing discussion it is clear that there is a rather close relationship between number of bundles at the base and the number in the central region of the hypocotyl. This might, we believe, have been expected on *a priori* morphological grounds. The interesting feature of the results seems to be that the correlations are not larger. The results show that there is a very large amount of irregularity in the division of primary strands or in the formation of intercalary bundles, or in both, as one passes the short distance from the base of the hypocotyl to the central region.

Correlation between Bundle Number in Different Internodes

The data available for a consideration of the problem of the correlation between bundle number in adjacent internodes cover (A) the correlation between the three classes of bundles at the base of the hypocotyl [primary double bundles (p), intercalary bundles (i), and total bundles (b)] and the number of bundles in the central region of the epicotyl; and (B) the correlation between the number of bundles in the central region of the hypocotyl and in the central region of the epicotyl.

(A) The coefficients showing the relationship between the numbers of primary double bundles, of intercalary bundles, and of total bundles at the base of the hypocotyl, and the number of bundles in the central region of the epicotyl, appear in table 3.

The regression equations showing the actual change in number of epicotyledonary bundles associated with variation in the number of primary double bundles are given and are represented with the empirical means of arrays on diagram 1 for trimerous plants and on diagram 2 for dimerous plants.

The graphs for the theoretical lines and the empirical means for the number of bundles in the epicotyl of both normal and abnormal plants show relatively little relationship between the number of bundles at the base of the hypocotyl and the number in the epicotyl. The differences in the slope of the lines for primary basal bundles and the number of bundles in central regions of hypocotyl and epicotyl show in a most striking manner the dif-

[4] In line 75 the range of primary double bundles is only 3 while that of intercalary bundles is 6. In line 139 the primary double bundles fall in two classes only, with but 3 of the 305 frequencies on 5 as compared with 302 on 4 bundles. The correlation coefficient in such a case can have but little value. In line 143 practically all of the primary double bundles fall in two classes while the intercalary bundles are limited to three classes. Irregularity of results must be expected under such conditions.

ferences between correlations for groups of bundles lying on the same side and those lying on different sides of the nodal complex.

(1) The correlation coefficients between primary double bundles and number of bundles in the epicotyl, r_{pe}, as set forth in the first section of table 3, are in part positive and in part negative in sign. For the most part they can not be considered statistically significant. The average value of those for trimerous seedlings is $-.0226$ while that for dimerous seedlings is $+.0768$.

(2) For the correlation between the number of intercalary bundles and the number of bundles in the epicotyl, r_{ie}, shown in the second section of table 3, the coefficients are not in general certainly significant in com-

TABLE 3. *Coefficients of correlation between number of primary double bundles, number of intercalary bundles and total number of bundles at base of hypocotyl, and number of bundles in central region of epicotyl*

Character of Seedlings and Line	N	Correlation for Primary Double Bundles r_{pe}		Correlation for Intercalary Bundles r_{ie}		Correlation for Total Bundles r_{be}	
Trimerous							
Line 75........	142	$+.053\pm.056$	0.93	$+.126\pm.056$	2.27	$+.182\pm.055$	3.33
Line 93........	155	$-.087\pm.054$	1.61	$-.055\pm.054$	1.01	$-.148\pm.053$	2.79
Line 98........	183	$+.008\pm.050$	0.70	$+.070\pm.050$	1.42	$+.099\pm.049$	2.01
Line 139.......	106	$-.105\pm.064$	1.63	$+.016\pm.065$	0.25	$-.095\pm.065$	1.47
Line 143.......	221	$+.018\pm.045$	0.40	$+.233\pm.043$	5.44	$+.190\pm.044$	4.34
Dimerous							
Line 75........	142	$-.115\pm.050$	2.07	$-.043\pm.057$	0.75	$-.054\pm.056$	0.96
Line 93........	155	$+.084\pm.054$	1.55	$+.132\pm.053$	2.48	$+.167\pm.053$	3.16
Line 98........	183	$+.239\pm.047$	5.08	$+.109\pm.049$	2.21	$+.205\pm.048$	4.29
Line 139.......	305	$+.164\pm.038$	4.37	$+.145\pm.038$	3.84	$+.175\pm.037$	4.68
Line 143.......	420	$+.012\pm.033$	0.38	$+.134\pm.032$	4.15	$+.121\pm.032$	3.73

parison with their probable errors. Two of the ten are indeed negative in sign. The coefficients for line 143 in both trimerous and dimerous seedlings and possibly that for line 139 in the dimerous seedlings may be significant. The fact that eight of the ten coefficients are positive suggests that there is a slight relationship between the number of intercalary bundles at the base of the hypocotyl and the number of vascular elements in the central region of the epicotyl. The general average is $+.0780$ for the trimerous and $+.0954$ for the dimerous.

This suggestion is only slightly strengthened by inspection of the two sets of diagrams on which the regression equations are presented and drawn with the empirical means. Diagram 3 pictures the results for trimerous seedlings while the comparable representations for dimerous seedlings are shown on diagram 4. These show that while the slope showing the change in the number of bundles in the hypocotyl associated with variations in the number of intercalary bundles at the base of the epicotyl is very steep, it is practically nothing for the epicotyl, thus indicating a very close relationship in the former case but the practical absence of interdependence in the latter.

As explained above (p. 346), the slopes for the trimerous seedlings are very greatly influenced by certain aberrant individuals. When these are removed we obtain the equations represented by the broken lines in the figures.[5] The results for the relationship between the number of intercalary bundles and the number of bundles in the epicotyl indicate a positive correlation in all 3 cases when the one extreme plant is removed.

(3) The coefficients of correlation between total bundles (double bundles plus intercalary bundles) at the base of the hypocotyl and the number of bundles in the central region of the epicotyl, r_{be}, are shown in the third section of table 3, and are represented graphically in terms of regression in the upper figures of each panel of diagram 5 for trimerous seedlings and of diagram 6 for normal seedlings. The very gentle slope and the differences in direction of the lines for the epicotyl of the trimerous plants, together with the irregularity of the empirical means, serve to emphasize the slightness of the relationship between total bundles at the base of the hypocotyl and the number of bundles in the central region of the epicotyl. In the normal plantlets the means are less irregularly distributed about the theoretical lines, but the slope of the lines is very slight, and in one case the regression slope has the negative sign.

Turning to the correlation constants for more direct numerical comparison, we note that three of the ten constants are negative. The general average is +.0456 for the trimerous and +.1228 for the dimerous seedlings.

Looking back over diagrams 1–6, one cannot but be impressed by the difference in the slope of the lines showing the changes in number of bundles in the hypocotyl and in the epicotyl respectively associated with variations in the number of bundles at the base of the hypocotyl. The lines for the hypocotyl, without exception, indicate an increase in the number of bundles in the central region of the hypocotyl with an increase in the number of bundles at the base of the hypocotyl. The lines for the epicotyl occasionally show a decrease. Furthermore, the slopes of the lines for the hypocotyl are in general conspicuously steeper—thus indicating closer dependence upon the number of basal bundles—than those for the epicotyl.

Turning to table 4 for a numerical comparison of the correlations between the systems of bundles on the same side and on different sides of the cotyledonary node, we note that without exception the coefficients of correlation measuring the interrelationship between the number of vascular elements at the base of the hypocotyl and in the central region of the epicotyl are markedly lower than those measuring the correlation between the number of vascular elements in the base of the hypocotyl and in the central region of the hypocotyl.

(B) We now have to consider the problem of the correlation between the numbers of bundles in the central regions of the hypocotyl and of the

[5] When the extreme cases are omitted the equations are: Line 75, $E = 15.378 + 0.591\,I$; Line 93, $E = 15.670 + 0.096\,I$; Line 98, $E = 14.840 + 0.394\,I$.

TABLE 4. *Differences between correlations for three classes of bundles at base of hypocotyl and the number of bundles in the central regions of hypocotyl and epicotyl, respectively*

Character of Seedlings and Line	$r_{pe} - r_{ph}$		$r_{ie} - r_{ih}$		$r_{be} - r_{bh}$	
Trimerous						
Line 75........	$-.325 \pm .074$	4.39	$-.203 \pm .075$	2.71	$-.467 \pm .064$	7.29
Line 93........	$-.320 \pm .074$	4.32	$-.259 \pm .075$	3.45	$-.617 \pm .068$	9.07
Line 98........	$-.313 \pm .067$	4.67	$-.183 \pm .069$	2.65	$-.487 \pm .059$	8.25
Line 139.......	$-.522 \pm .084$	6.21	$-.081 \pm .092$	0.88	$-.626 \pm .080$	7.83
Line 143.......	$-.538 \pm .055$	9.78	$-.072 \pm .059$	1.22	$-.563 \pm .048$	11.7
Dimerous						
Line 75........	$-.477 \pm .070$	6.81	$-.711 \pm .065$	10.9	$-.841 \pm .059$	14.3
Line 93........	$-.557 \pm .062$	8.98	$-.258 \pm .070$	3.69	$-.586 \pm .057$	10.3
Line 98........	$-.427 \pm .055$	7.76	$-.446 \pm .060$	7.43	$-.581 \pm .052$	11.2
Line 139.......	$-.180 \pm .051$	3.53	$-.753 \pm .039$	19.3	$-.750 \pm .037$	20.3
Line 143.......	$-.518 \pm .040$	12.9	$-.500 \pm .037$	13.5	$-.681 \pm .033$	20.6

epicotyl of the plant. The correlation surfaces are given in tables A–L. The results are set forth in table 5.

TABLE 5. *Coefficient of correlation between number of bundles in central region of hypocotyl and central region of epicotyl*

Line	Trimerous			Dimerous		
	N	r	r/E_r	N	r	r/E_r
75.....	416	$+.012 \pm .033$	0.36	416	$-.017 \pm .033$	0.52
93.....	557	$+.075 \pm .028$	2.68	557	$+.162 \pm .028$	5.79
98.....	345	$+.090 \pm .036$	2.50	345	$+.225 \pm .035$	6.43
139.....	106	$-.061 \pm .065$	0.94	305	$-.187 \pm .037$	5.05
143.....	143	$+.256 \pm .042$	6.10	420	$+.107 \pm .033$	3.24

The correlations are positive with the exception of that for dimerous plants of line 75 and of that for both dimerous and trimerous plants of line 139, which are negative in sign. Only one of the negative coefficients may be considered statistically significant in comparison with its probable error. Several of the positive coefficients are large enough in comparison with their probable errors to be considered possibly significant. The average correlation for the trimerous plants is $+.074$ while that for the dimerous plants is $+.058$. The correlations for the trimerous and dimerous plants can not be considered to differ significantly.

The generally positive sign of the constants suggests that seedlings which have a larger number of bundles in the hypocotyl have on the average a larger number of bundles in the epicotyl. This is the condition actually found in the series studied, but the difficulties in the interpretation of the probable error in cases in which the correlation coefficient is so small should make one cautious in generalizing the results obtained.

How slight the relationship between the numbers of bundles in the two organs is, may be shown by the regression lines giving the change in the mean number of bundles in the epicotyl associated with variations in the number of bundles in the hypocotyl and in the mean number of bundles in the hypocotyl associated with variations in the epicotyl. The straight line equations are as follows:

	Dimerous	Trimerous
Line 75,	$H = 10.325 - .068E$	$H = 12.055 + .009E$
	$E = 12.347 - .008H$	$E = 15.267 + .016H$
Line 93,	$H = 5.736 + .401E$	$H = 11.501 + .050E$
	$E = 11.494 + .065H$	$E = 14.273 + .112H$
Line 98,	$H = 1.374 + .648E$	$H = 11.408 + .042E$
	$E = 11.388 + .078H$	$E = 12.538 + .195H$
Line 139,	$H = 4.105 + .338E$	$H = 12.492 - .033E$
	$E = 11.254 + .103H$	$E = 16.591 - .113H$
Line 143,	$H = 6.677 + .161E$	$H = 9.279 + .187E$
	$E = 11.737 + .072H$	$E = 11.810 + .349H$

All of these lines have been drawn, but it seems unnecessary to publish more than three sets.

The comparison between the empirical and the theoretical mean number of bundles in the epicotyls of seedlings classified according to the number of bundles in the hypocotyl is made for three lines on diagram 7. Conversely, the comparison of the actual mean number of bundles in the hypocotyl for plants with various numbers of bundles in the epicotyl is made on diagram 8.

The slight slope of the lines and the irregularity of the empirical means show in a very convincing manner the laxness of the relationship between the numbers of bundles in the central regions of hypocotyl and epicotyl.

These results are of decided morphological significance. The profound difference between the correlations for the hypocotyl and for the epicotyl emphasizes the completeness of the loss of individuality of the bundles at the cotyledonary node. Whereas the number of bundles in the central region of the hypocotyl is quite closely correlated with the number at the base of the hypocotyl, there cannot be asserted to be any significant correlation in bundle number between either the base or the central region of the hypocotyl and the central region of the epicotyl, when we deal with seedlings of the same gross morphological structure. In other words, the reorganization of the vascular system at the node is so complete that the portion of the system which is above the node shows practically no relation to the portion which is below the node.

Comparison of Correlation in Trimerous and Dimerous Seedlings.

In examining the results of the preceding tables the reader may have noted that the coefficients for the dimerous are preponderantly higher than those for the trimerous plants. This result is clearly brought out in table 6

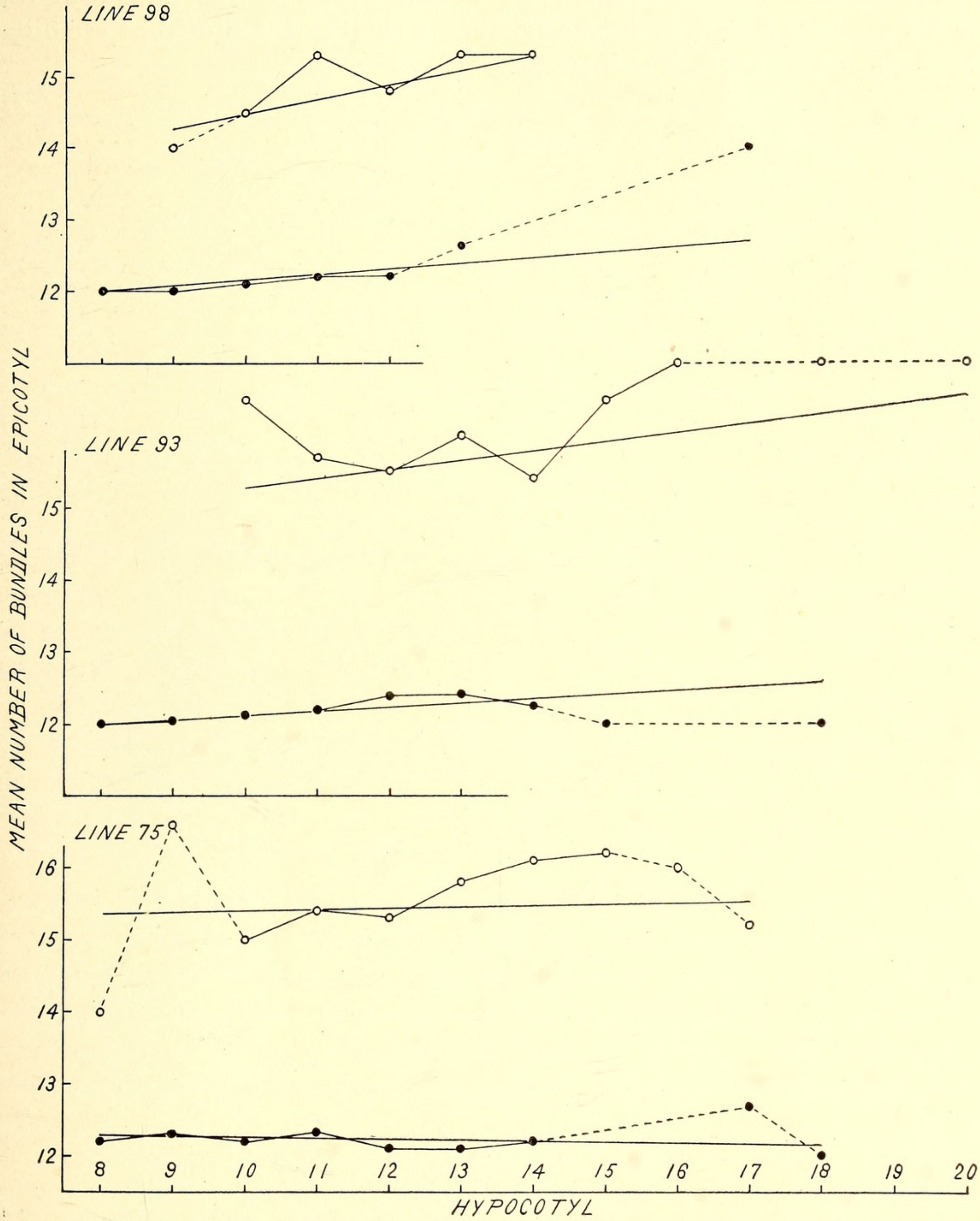

DIAGRAM 7. Regression of number of bundles in central region of epicotyl on number of bundles in central region of hypocotyl. Empirical means represented by solid dots for dimerous seedlings and by circles for trimerous seedlings.

in which the differences between the coefficients for the two classes of plants are shown.

The differences in this table are generally negative, thus indicating that the correlations are lower in the trimerous than in the dimerous seedlings. The exceptions are of some interest.

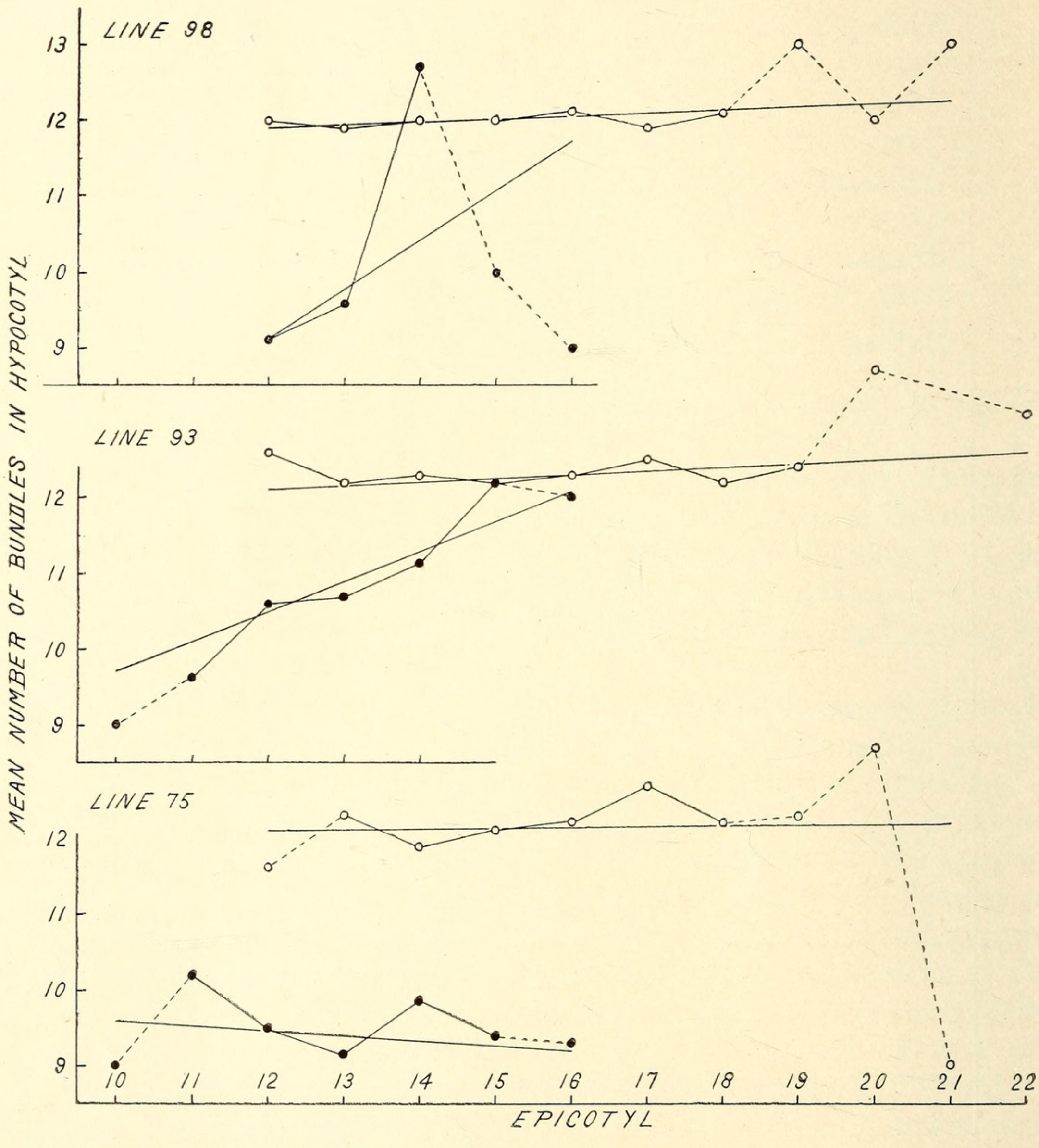

DIAGRAM 8. Regression of number of bundles in central region of hypocotyl on number of bundles in central region of epicotyl. Empirical means represented by solid dots for dimerous seedlings and by circles for trimerous seedlings.

There are only 4 exceptions among the 15 correlations between the numbers of vascular elements in the basal region of the hypocotyl and in the central region of the hypocotyl, as shown in the upper section of the table. These are without exception insignificant in comparison with their probable errors. There are 9 exceptions among the 20 correlations be-

TABLE 6. *Comparison of correlations for trimerous and dimerous seedlings. Differences only (trimerous less dimerous) are given. See tables* 1 *and* 3 *for constants*

	Correlation Coefficient Compared					
	r_{ph}		r_{ih}		r_{bh}	
Line 75	+.016±.069	0.23	−.339±.060	5.65	−.148±.039	3.79
Line 93	+.408±.060	6.80	−.186±.069	2.69	−.284±.048	5.92
Line 98	−.345±.053	6.50	−.302±.058	5.21	−.200±.039	5.13
Line 139	+.073±.064	1.14	−.801±.066	12.1	−.394±.047	8.38
Line 143	+.026±.039	0.67	−.329±.046	7.15	−.049±.022	2.23
	r_{pe}		r_{ie}		r_{be}	
Line 75	+.168±.075	2.24	+.169±.080	2.11	+.236±.079	2.99
Line 93	−.171±.076	2.25	−.187±.075	2.49	−.315±.075	4.20
Line 98	−.231±.069	3.35	−.039±.070	5.57	−.106±.069	1.53
Line 139	−.269±.074	3.64	−.129±.075	1.72	−.270±.075	3.60
Line 143	+.006±.056	0.11	+.099±.054	1.83	+.069±.055	1.25
	r_{he}					
Line 75	+.029±.047	0.62	—	—	—	—
Line 93	−.087±.040	2.18	—	—	—	—
Line 98	−.135±.050	2.70	—	—	—	—
Line 139	+.126±.075	1.68	—	—	—	—
Line 143	+.149±.053	2.81	—	—	—	—

tween the numbers of vascular elements on different sides of the cotyledonary node as shown in the central and lower section. The exceptions occur, in short, among the relationships which in both types of seedlings are practically zero in intensity.

We have no explanation to offer of this greater intensity of correlation in the sub-cotyledonary region of the normal seedling. The result is stated as one of the matters of fact demonstrated by the investigation.

Correlation between Bundle Number in Siblings

The question will naturally arise as to whether the variability in number of bundles in both hypocotyl and epicotyl and the correlation between bundle number in these two internodes may be due to a differentiation of the parent plants from which the seeds were obtained, either in their genetic composition or because of environmental influences. This problem presents many difficulties. Some light may be thrown upon it in the following manner.

An abnormal and a normal seedling were taken from the same parent plant. Thus it is possible to determine in our series the correlation between the number of bundles in the hypocotyl of an abnormal plant and in the hypocotyl of a normal plant derived from the same parent. If a differentiation of the parent plants due to either genetic or physiological factors is the underlying proximate cause of the variability and correlation in bundle number in seedlings which we have studied, there should be a correlation between the number of bundles in the seedlings derived from the same plant.

The correlations between the numbers of bundles in the hypocotyls and epicotyls of the normal and abnormal seedling, *i.e.*, of dimerous and trimerous seedlings, from the same parent plants are given in table 7.[6]

TABLE 7. *Correlations between bundle number in offspring of same parent plant*

Character of Plant and Organs Compared		Line and Correlation		
Trimerous	Dimerous	Line 75	Line 93	Line 98
Hypocotyl	Hypocotyl			
	C. S. H.	+.0540±.0406	+.1703±.0327	−.0512±.0529
	Storrs	+.2151±.0540	+.0553±.0540	+.0853±.0495
Epicotyl	Epicotyl			
	C. S. H.	−.0037±.0407	−.0027±.0336	+.1222±.0522
	Storrs	+.0685±.0563	+.0432±.0541	+.0401±.0498

The coefficients are low throughout. Nine of the 12 are positive while 3 are negative in sign. Only 2 of the 12 can be reasonably regarded as significant. Both of these are positive. There is, therefore, a suggestion of a positive correlation between the anatomical characters of seedlings from the same parent. The values are too low, however, to justify the conclusion that there is a measurable differentiation in the genetic or physiological characteristics of the parent plants affecting bundle number in the offspring seedling.

The absence of correlation here connotes an absence of (sororal or fraternal) inheritance in bundle number.

SUMMARY

In an earlier paper we have shown that the number of vascular elements at different levels in the seedling of *Phaseolus vulgaris* is subject to considerable variation and that the amount of variation may itself differ from level to level. This is true both in normal seedlings with two cotyledons and two primordial leaves and in variant seedlings with three cotyledons and a whorl of three primordial leaves. These two types of seedlings are profoundly differentiated in vascular anatomy as well as in superficial structure.

The purpose of the present paper is to consider the correlations between the number of bundles in the various regions of the seedling. The characters considered are (1) number of primary double bundles, of intercalary bundles, and of total bundles at the *base* of the hypocotyl, (2) number of bundles in the *central region* of the hypocotyl, and (3) number of bundles in the central region of the epicotyl.

1. There is a substantial correlation between each of the three classes of bundles at the base of the hypocotyl and the number of bundles in the central region of the hypocotyl. In the normal seedlings the coefficients

[6] It has not seemed worth while to publish the tables upon which these very slight correlations are based. For purposes of comparison the series sectioned at Cold Spring Harbor and at Storrs are both given.

average +.509 for primary double bundles and hypocotyledonary bundles, +.629 for intercalary bundles and hypocotyledonary bundles, and +.813 for total bundles and hypocotyledonary bundles. In the trimerous plants these correlations average +.381, +.238, and +.598, respectively.

The correlations for normal plants are generally higher than those for abnormal plants.

2. The correlation between each of the three classes of bundles at the base of the hypocotyl and the number of bundles in the central region of the epicotyl is low. The coefficients are sometimes positive and sometimes negative in sign. On the basis of the data available it is impossible to assert that there is any correlation at all between the numbers of bundles in these two regions.

3. The correlation between the numbers of bundles in the central region of the hypocotyl and in the central region of the epicotyl is likewise very low. The coefficients are generally not significant in comparison with their probable errors. If there be any correlation at all between the numbers of bundles in these two regions it is very slight indeed.

These results for correlation fully substantiate the conclusions drawn in an earlier paper that there is a *complete reorganization of the vascular system at the cotyledonary node.*

4. The correlation between the number of bundles (either hypocotyledonary or epicotyledonary) in siblings is, if it exists at all, very low. The differentiation of the parent plants through either genetic or environmental factors cannot, therefore, be considered to be the source of the variation and correlation in bundle number demonstrated in this and in our preceding paper.

Conclusions

These results, and others for which the reader must turn back to the body of the paper, justify the emphasis at this point of the following general conclusions:

a. The vascular structures of the seedling are not constant but are decidedly variable within the species. They show different degrees of variability within the individual organism.

b. Seedlings differing in external form are profoundly differentiated in their internal anatomy. This differentiation is evident both in mean number of bundles and in the degree of variability in bundle number. In short, the external form and the internal structure of the seedling are highly but not perfectly correlated.

c. The different anatomical characters of the seedling are interrelated with varying degrees of intensity. Between some there is a very strong correlation, but between others practically none at all.

The quantitative measurement and interpretation of such relationships, by means of the biometric methods hitherto little applied in the field of vascular morphology, will make possible material advance in the investigation of the fundamental problems of morphogenesis.

TABLE A. *Data for correlation between bundle number at the base of the hypocotyl and in the central regions of hypocotyl and epicotyl in trimerous seedlings*

Base*	Line	Hypocotyl													Epicotyl											Totals
		8	9	10	11	12	13	14	15	16	17	18	19	20	12	13	14	15	16	17	18	19	20	21	22	
(4)+0...	143	2																	1		1					2
(4)+1...	139			1												1										1
	143		1		1		1														3					3
(4)+4...	93						1									1										1
(4)+5...	98						1											1								1
(4)+6...	75							1										1								1
(5)+0...	75					1													1							1
	93			1	1	3												1	1	2		1				5
	98			3		1											1	3								4
	139			1	2	1										1		1		1		1				4
	143			11	2	1				1					2		3	3	3	1		3				15
(5)+1...	75			2	2	3	1										2	3	1	2						8
	93				6	3		1							1		1	1	3	1	2	1				10
	98			1	3	2										1	2	2	1							6
	139			1	1	1	1											1	1		2					4
	143				11	13	2	4			1					2	2	9	6	5	3	1	2	1		31
(5)+2...	75						1				1						1		1							2
	93						1	2									1			1	1					3
	98						1												1							1
(6)+0...	75				6	90	8	3								5	19	43	22	11	6		1			107
	93				2	102	10	4	1					1		6	14	47	25	15	8	3	1		1	120
	98				4	145	8	3							6	13	36	67	26	8	3		1			160
	139			1	5	81	3	1	1							4	21	35	21	8	2	1				92
	143					121	7	4	1	1					3	7	14	34	31	22	19	3	1			134
(6)+1...	75					1	9	2										6	3	1		1	1			12
	93						8	3							1			6	2	1	1					11
	98						7	3									3	3	2		1	1				10
	139					1	2	2								2		1	2							5
	143					1	11	12	1									5	5	8	3	2	2			25
(6)+2...	75					1			1														2			2
	93							1										1								1
(7)+0...	75							7										4	2	1						7
	93							3	1								2		1	1						4
	98						1										1									1
	143							5										2	2	1						5
(7)+1...	143								3	1								1	1		1			1		4
(7)+2...	75								1								1									1
(8)+0...	75										1									1						1
	143								1												1					1
(8)+1...	143											1											1			1

* Numbers in parentheses are of *primary double bundles*; those following are of *intercalary bundles*.

TABLE B. *Data for correlation between bundle number at the base of the hypocotyl and in the central regions of hypocotyl and epicotyl in dimerous seedlings*

Base	Line	Hypocotyl										Epicotyl							
		8	9	10	11	12	13	14	15	17	18	10	11	12	13	14	15	16	Tot.
(4)+0 ...	75	40	17	7	4			1				1	1	59	4		2	2	69
	93	12	13	6	3									29	4	1			34
	98	57	31	9										88	8			1	97
	139	269	1											250	18	2			270
	143	262	21	6	2									229	43	13	4	2	291
(4)+1 ...	75		14	13	3								2	22	3	2		1	30
	93		14	17	3	1	1	1						31	3	3			37
	98	2	26	13	1	1								37	5	1			43
	139		22	3	1									21	4	1			26
	143	1	61	27	10		2		1					72	17	11	1	1	102
(4)+2 ...	75			2	4	3	1							9	1				10
	93			9	2	2								11	2				13
	98		3	13	6	1								19	3		1		23
	139			2	2	1	1							5	1				6
	143			3	1	1								3		1		1	5
(4)+3 ...	75				2	1					1			4					4
	93				3	2								3		1	1		5
	98				2									2					2
(4)+4 ...	75							1		1				2					2
	93					1								1					1
(4)+5 ...	75						1			1				2					2
(5)+0 ...	75		1	8	2	1	1							12	1				13
	93		1	13	4	3	1							18	1	2	1		22
	98			2	3	1								4	1	1			6
	139			1										1					1
	143		1	11		1								8	5				13
(5)+1 ...	75				2	2								4					4
	93			1	6	7	3	1						12	3	1	2		18
	98			1	5	1	1							7	1				8
	139			1	1									1		1			2
	143				4	2	1							4	1	2			7
(5)+2 ...	75					1								1					1
	93					5	3	1						6	1	2			9
	98					1								1					1
(5)+3 ...	75							1						1					1
	93							1						1					1
	98						1									1			1
(6)+0 ...	75				1	3		1					1	4					5
	93				1	8	1							9	1				10
	98				1									1					1
(6)+1 ...	75					1								1					1
	93						1	2						2	1				3
	143								1					1					1
(6)+2 ...	93							2						1		1			2
(7)+0 ...	143							1						1					1
(8+1) ...	98									1						1			

TABLE C. *Correlation between numbers of bundles in hypocotyl and epicotyl of trimerous plants of line 75*

Hypocotyl	Epicotyl										
	12	13	14	15	16	17	18	19	20	21	Totals
8	......	......	1	......	......	......	......	......	......	......	1
9	......	......	1	1	......	......	......	......	......	1	3
10	......	......	......	5	......	......	......	......	......	......	5
11	1	......	6	12	12	3	2	......	......	......	36
12	2	15	48	120	62	21	19	3	2	......	292
13	......	......	5	13	10	7	4	1	......	......	40
14	......	......	1	10	7	8	2	......	1	......	29
15	......	......	1	2	......	1	......	......	1	......	5
16	......	......	......	......	1	......	......	......	......	......	1
17	......	1	......	1	1	1	......	......	......	......	4
Totals	3	16	63	164	93	41	27	4	4	1	416

TABLE D. *Correlation between numbers of bundles in hypocotyl and epicotyl of dimerous plants of line 75*

Hypocotyl	Epicotyl							Totals
	10	11	12	13	14	15	16	
8	....	....	116	17	6	4	....	143
9	1	2	78	13	5	2	2	103
10	....	....	74	10	....	1	1	86
11	....	1	29	4	2	2	....	38
12	....	1	22	1	1	1	....	26
13	....	....	6	1	....	....	....	7
14	....	....	8	....	1	....	....	9
15	....	....	....	....	....	....	....	....
16	....	....	....	....	....	....	....	....
17	....	....	2	....	1	....	....	3
18	....	....	1	....	....	....	....	1
Totals	1	4	336	46	16	10	3	416

TABLE E. *Correlation between numbers of bundles in hypocotyl and epicotyl of trimerous plants of line 93*

Hypocotyl	Epicotyl											Totals
	12	13	14	15	16	17	18	19	20	21	22	
10	....	....	....	3	1	1	3	....	....	....	....	8
11	....	....	3	14	7	4	3	1	....	....	....	32
12	3	14	33	170	92	38	26	5	1	....	....	382
13	1	4	5	30	15	6	16	3	1	....	1	82
14	1	....	5	17	9	2	3	1	....	....	....	38
15	....	....	1	2	5	2	....	....	2	....	....	12
16	....	....	....	....	....	1	....	....	....	....	....	1
17	....	....	....	....	....	....	....	....	....	....	....	....
18	....	....	....	....	....	1	....	....	....	....	....	1
19	....	....	....	....	....	....	....	....	....	....	....	....
20	....	....	....	....	....	1	....	....	....	....	....	1
Totals	5	18	47	236	129	56	51	10	4	....	1	557

TABLE F. *Correlation between numbers of bundles in hypocotyl and epicotyl of dimerous plants of line 93*

Hypocotyl	Epicotyl							
	10	11	12	13	14	15	16	Totals
8		1	31	2				34
9	1	1	85	3	3			93
10		3	147	14	3	2		169
11		1	88	14	2			105
12			78	5	9	3	1	96
13			31	4		4		39
14			16		1	1		18
15			1					1
18			2					2
Totals	1	6	479	42	18	10	1	557

TABLE G. *Correlation between numbers of bundles in hypocotyl and epicotyl of trimerous plants of line 98*

Hypocotyl	Epicotyl										
	12	13	14	15	16	17	18	19	20	21	Totals
9			1								1
10		1	1	4							6
11		1	2	4	3	1	1				12
12	8	20	58	157	41	8	4		1		297
13		2	6	8	1		2	1		1	21
14			1	3	4						8
Totals	8	24	69	176	49	9	7	1	1	1	345

TABLE H. *Correlation between numbers of bundles in hypocotyl and epicotyl of dimerous plants of line 98*

Hypocotyl	Epicotyl					Totals
	12	13	14	15	16	
8	107	6				113
9	103	6			1	110
10	71	4	1	1		77
11	26	5	1			32
12	7	2				9
13	2		1			3
17			1			1
Totals	316	23	4	1	1	345

TABLE I. *Correlation between numbers of bundles in hypocotyl and epicotyl of trimerous plants of line 139*

Hypocotyl	Epicotyl							
	13	14	15	16	17	18	19	Totals
10	2				1	1		4
11	1	1	2	1	2		1	8
12	4	19	32	20	5	3	1	84
13		1	2	2	1			6
14	1		2					3
15				1				1
Totals	8	21	38	24	9	4	2	106

TABLE J. *Correlation between numbers of bundles in hypocotyl and epicotyl of dimerous plants of line 139*

Hypocotyl	Epicotyl			Totals
	12	13	14	
8	249	18	2	269
9	20	3		23
10	5	1	1	7
11	2	1	1	4
12	1			1
13	1			1
Totals	278	23	4	305

TABLE K. *Correlation between numbers of bundles in hypocotyl and epicotyl of trimerous plants of line 143*

Hypocotyl	Epicotyl										
	12	13	14	15	16	17	18	19	20	21	Totals
8					1		1				2
9							1				1
10	2		2	2	2	1		2			11
11			2	2	5	2	1	1	1		14
12	3	9	14	35	31	22	19	3			136
13			1	6	5	5	2	1	1		21
14				7	4	6	4	1	2	1	25
15				2			3			1	6
16					1			1	1		3
17						1					1
18									1		1
Totals	5	9	19	54	49	37	31	9	6	2	221

Table L. *Correlation between numbers of bundles in hypocotyl and epicotyl of dimerous plants of line 143*

Hypocotyl	Epicotyl					Totals
	12	13	14	15	16	
8	205	42	10	4	2	263
9	65	11	7	....	....	83
10	32	8	5	....	2	47
11	9	3	4	1	....	17
12	3	....	1	....	....	4
13	1	2	....	....	....	3
14	1	....	....	....	....	1
15	2	....	....	....	....	2
Totals	318	66	27	5	4	420