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Analyses of Agricultural Yield. Part II. The Sowing-Date Experiment with Egyptian Cotton, 1913

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IX. *Analyses of Agricultural Yield.* Part II.—*The Sowing-Date Experiment with Egyptian Cotton,* 1913.

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INTRODUCTORY.

In the general introduction* to these analyses we defined our purpose as being statistical investigation of the yield, in terms of the different stages of the plant's development, by means of careful records of all these stages throughout the development season.

In the spacing experiment† we examined the effect of providing the cotton plant with various volumes of soil, and found that the method of field cultivation practised in this respect by the Egyptian native cultivator gives the highest yield obtainable from a given area, though the space allowed to each individual plant is very much less than it could profitably utilise if growing isolated.

In the present experiment we are concerned with the effects produced by sowing the crop at various times, from a month before the conventional date until up to a month after it. The earliest sown plants will bear the impress of environmental experiences additional to those which all the sowings receive in common after the last sowing has been made. In addition, it may be expected that these latter experiences shared in common may produce effects of different degrees, according to

* 'Phil. Trans.,' B, vol. 206, pp. 104–112.

† *Ibid.*, pp. 112–180.

whether they are acting upon young or old plants. All variables other than these were eliminated from the experiment as far as was possible.

The result of the experiment again confirms a native custom, which in this case is against very early sowing. There appears to be, indeed, an optimum sowing date; sowings made before this date are no better, and may be worse, than normal sowings; sowings made after this date come later to maturity, and are therefore inferior as a crop. The dates actually employed were at weekly intervals from February 15, 1913, to April 12, 1913, being nine successive sowings altogether, each sowing being distributed in five plots duly scattered in a chess-board arrangement.*

The year 1913 was abnormal in three respects, so far as the cotton crop of Egypt was concerned. The spring weather was almost entirely devoid of the excessively hot days, with maximum shade temperatures exceeding 37° C., which usually occur sporadically at this season. The Nile flood was the latest and lowest known for a century, and a very severe autumnal attack of boll-destroying insect pests was experienced by the whole country. Rather more careful analysis is, therefore, needed than was the case in the spacing experiment (described in Part I), in order to bring out the underlying principles, independently of these extraneous and accidental circumstances.

One point with regard to the agricultural application of these results may be advisably emphasised at this stage of the account, namely, the practice of re-sowing. The field germination of the early sowings is not so successful as that of the later ones; blank spaces in the field are, therefore, filled up some three to four weeks after the original sowing. These re-sown seedlings necessarily correspond closely to other sowings made at the same time, and not to the original sowings among which they have been inserted. The technical consideration of such early sowings must obviously take into account the re-sown plants among them. On the other hand, in order to arrive at the pure principles of the matter, our attention must be confined to the original sowings.

Therefore, throughout this account, our methods and treatment have been so arranged as to deal with those plants alone which were sown on the date assigned to them. At the end of the account we have applied final corrections to allow for the re-sowing. In point of fact, the result of such corrections is almost negligible, amounting to an alteration of only a little over one per cent., at the most, in the final yield of the average plant.

Outline of the Evidence Obtained.

It may simplify further discussion if we sketch at this point the general results obtained, by the aid of fig. 1, which embodies them in graphic form.

* For photographs of these experimental plots on various dates, see Plates XI and XII in 'The Development and Properties of Raw Cotton,' London, 1915, by the senior author.

The diagram comprises the whole season from left to right, weekly intervals being marked on the scales above and below. Each of the nine successive sowings* is represented separately, one below the other. The sloping portion of the thick line (A) on the left hand intersects the horizontal base line of each sowing-graph at the date on which the sowing was made. For such a line, which shows the dates on which the average plants of each set were in the same condition, we propose to use the designation "Isophytic Line."

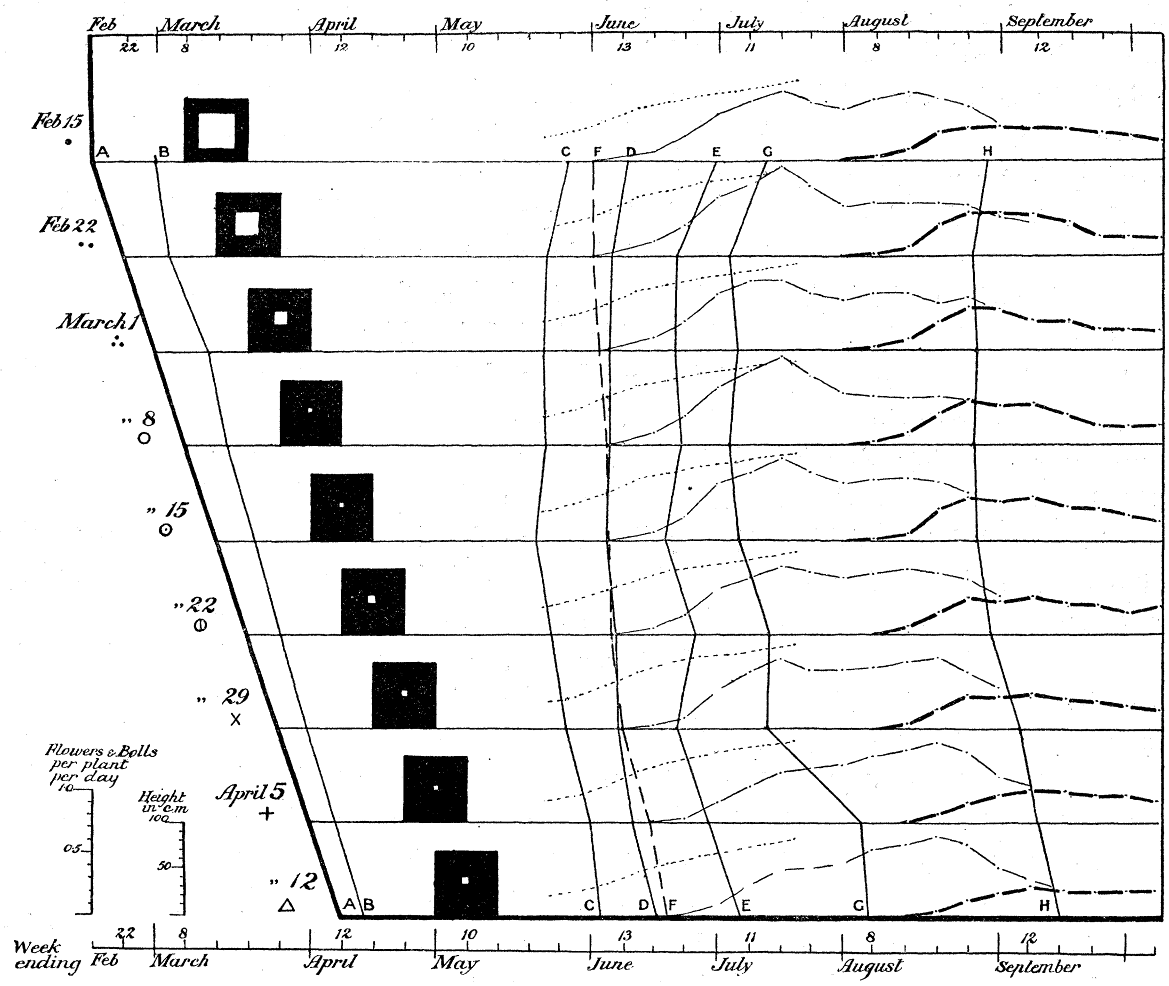


FIG. 1.—Isophytic Lines; a Summary of the Experimental Results.

* In the diagrams illustrating this communication a uniform graphic notation has been employed. Owing to the overlap of the various curves, a series of variously dotted lines plotted together would be confusing. If the curves were "stepped" above one another, their relative forms would not be easily comparable. Simple thin lines are therefore employed to connect the observed points on the ordinates, and these points are marked by various symbols, as follows (see also fig. 1):—

Group of three early sowings: One dot, two dots, and three dots respectively.

Group of three middle sowings: Blank circle, dotted circle, and double semicircle.

Group of three late sowings: Oblique cross, vertical cross, and triangle.

These may be conveniently memorised for reference by noting that early sowings are marked by dots, middle ones by circles, and late sowings by right-line symbols.

The seedlings appear above ground a few days after sowing. This date is marked on each base line, and the nine points are joined together, giving the second isophytic line (B). From the position of this line with regard to the line A, it is evident that late sowings complete their "field germination" much more rapidly than early sowings.

The mere rapidity of germination is less important agriculturally than the percentage of "holes" successfully established from holes actually sown. This is shown in fig. 1 by the black squares with white centres, representing counts made when the seedlings were well established. The white centre is of the same area, relatively to the rest of the square, as the proportion of failures was to the original holes sown. There are practically no failures after March 1 sowing, but the earliest sowings lost a notable proportion, which had to be re-sown.

From this point there are no detailed records till those of height begin at the end of May. Thenceforward the mean height of the main stem in each sowing, as recorded each week, is indicated by a dotted line, the value of the ordinates in centimetres being given on a scale outside the left-hand lower corner of the diagram.

Three isophytic lines for height are drawn between points at the foot of the ordinates representing 30 cm., 50 cm., and 70 cm. respectively. The first one (C) runs very smoothly, showing that the sowings of March 15 were the first to reach this height of 30 cm., that earlier sowings were slightly later in so doing, and later sowings much later. This latter portion of the line is not, however, parallel to the line showing dates of field germination. Thus each late sowing grew more rapidly than its predecessor. The lines for 50 cm. (D) and 70 cm. (E) are similar.

The mean flowering rates per plant per day, in each weekly period, are shown for each sowing as a flowering-curve (thin line). Two isophytic lines are plotted for this feature. The first is dotted (F), and shows the mean date of appearance of the first flower; here the earliest sowing is the earliest to flower, but the advantage is trivial, some three days covering the differences between sowings made over a period of five weeks. This line crosses the 50 cm. height line. The second isophytic line drawn for flowering (G), on the other hand, is closely similar to the height lines; it represents the day on which a mean flowering-rate of 0·5 flowers (p.p.p.d.*) was first attained. Again, there is practically no difference between the first five sowings.

On the right of the diagram come the bolling-curves, drawn with a heavy line, also with an isophytic line (H) traced across them, which in this case marks the dates when the average plant of each sowing had ripened five bolls. Again, the first five sowings are almost identical, while the later ones reach this total of production at successively later dates.

It is obvious that these isophytic lines are merely the observed portions of lines which could be traced through the whole year, if sowings were made from January to

* Per plant per day.

December. The January and December sowings have been found by us to succumb almost entirely to unusual parasites, owing to the low temperature, so that the isophytic lines in their case would bend outwards to the right to infinity, both above and below, if they were produced beyond the limits of this diagram. If such sowings could be preserved from parasites, the lines would probably enter the diagram (fig. 1) from above fairly parallel and vertical, while they would pass out below towards the right, and then turn downwards and parallel again, to join on to those of the next season.

This diagram may be taken as also representing some results which we obtained in 1911, preliminary to the present experiment, without any other than trifling differences.

Regarding these curves from the view-point of plant physiology, the main problem before us is to account for the nature of the depressant factor which is clearly operative, since plants of the early sowings attain only to the same development as those of later sowings, though having a longer time in which to develop.

The immediate object of the present communication is to explain the twice observed form of these isophytic lines. The optimum sowing date already mentioned is of course that one which brings most of these lines furthest to the left, and especially line H; or better, it is the last date before they begin to turn to the right, which in this experiment is clearly March 15. Even March 22 is as good in this respect as is February 15. The summary of these results in the form of total yield in the conventional three pickings, unanalysed, is given in fig. 11.

Early Investigations.

The general opinion of agricultural experts in Egypt, as distinct from that of the native cultivators and landowners themselves, tends rather towards planting early. It seems reasonable to assume that a plant which has been given more time for growth must have grown more, provided that the risk of seed-failure from early sowing (*vide infra*, p. 432) can be weathered safely.

The following statement may be quoted as representing the general opinion. "Early sown cotton grows steadily and branches better, later sown cotton is forced as it were by the greater temperature at that time, and has a tendency to make greater growth, rather than plants well branched from the bottom. It is often found in the month of June that later sown cotton has exceeded in size that sown at an earlier period. It also follows that by early sowing we have a tendency to earlier ripening."* The authority quoted was experimenting on the same piece of land which we occupied, and he sowed on February 27 to March 10, the latter being regarded as rather late sowing. We have already seen, in fig. 1, that the optimum sowing date is actually later than even March 10.

* Foaden, G. P., 'Journal of the Khedivial Agricultural Society,' 1901.

The first severe criticism of this view was provided by our former colleague, Mr. F. HUGHES. In the course of some very complete experiments in various parts of Egypt, on the manuring of cotton, he incidentally collated the dates of sowing of his plots, and the dates when the crop was ready for the first picking. The sowing-dates ranged from February 29 to April 23 in the various stations, but the date of the first picking was much the same in all. Mr. HUGHES remarks,* "Nothing could be more evident than the relations shown in the above table. It may be argued that the fields were not in the same condition when they were picked; this is no doubt true. But at the same time we have . . . a difference of nearly a month between the early sown and the late sown stations, and this is about the interval usually allowed between the first and second pickings, so that the differences can only be partially due to this cause; it is far more probable that the early sown cotton is liable to receive a check when the weather turns cold, and this is sufficient to retard its growth when the warmer weather arrives. On the other hand the late sown cotton has a clear course before it, and soon overtakes its earlier rival." We shall see later that this interpretation was almost correct, but the data could not be used extensively, because they involved a second important variable, namely, geographical position ranging from the Mediterranean to some two hundred miles up the Nile valley. At the same time the experiments were more nearly of critical value than any which had previously been performed in Egypt on cotton, and it was significant that, being so, they had reached an opinion which was distinctly heterodox for an expert.

The next step was provided indirectly by the Cotton Commission which sat on the alleged depreciation of the crop, in the year 1910. This Commission led to the production of a limited amount of statistical data, including a number of dates of sowing and first picking for three estates over a period of 20 years, by H.H. Prince OMAR PASHA TOUSSOUN, who had previously given the figures to us. These estates were situated at the apex of the Delta near Giza, in the eastern middle Delta, and in the northern Delta respectively. While subject to a number of errors, they indicated that no consistent gain could be expected by sowing before about March 10 in the first two sites, or March 25 in the north.

On the suggestions thus obtained we began a small experiment in 1911 with the facilities which were then available, in the Khedivial Agricultural Society's laboratory garden at Gezira (Cairo). The experiment gave the same results as the full investigation of 1913, with which we are now concerned, and need only be further described as regards certain points of interest. Pure strains of cotton were employed, two being Egyptian and one American Upland (King). The latter conformed in all respects to the former, except that it had, as usual, a shorter period of development in all respects; the seedlings appearing more quickly above ground, the first flower opening at an earlier date, and the maturation period of the boll being shorter; also, the

* HUGHES, F., 'Year Book of the Khedivial Agricultural Society,' 1909.

differences between sowings made too early or too late, and those made at the optimum sowing date, were much more marked than in the case of the Egyptian plants.

This 1911 experiment was arranged with wide-sown plants, in groups of four plants only, duly scattered over the area. There were only 400 plants in all, subdivided into a hundred or so of each kind. The sowings extended over seven weeks, five groups being sown of a kind in each week. Thus the scale of the experiment was so small as might appear absurd, and it is gratifying to be able to record the fact that the conclusions drawn from this experiment were in no way vitiated, nor indeed greatly amplified, by the large-scale experiment of 1913.

The use of the experiment for critical purposes by comparison of different strains was unfortunately prevented by difficulties connected with our transference to the Government service, whereby our stocks of pure-strain seed passed out of our possession during the actual sowings of 1911. Further, with such tiny plots it was not possible to prevent the irrigation of one sowing from affecting most of the previous sowings; this merely ensured that water supply was never likely to be a limiting factor in the early stages of growth, but it prevented the results from being fairly compared with field conditions, though in point of fact we now know that such comparison would have been justifiable. The sowing which gave the best result between February 28 and April 11 was that of March 22. We, therefore, assigned the optimal sowing date for the Cairo-Giza district to March 22, for the year 1911.

In conjunction with the conclusions drawn by Mr. Hughes, and with Prince Toussoun's data, it seemed fairly evident that the optimum sowing date would vary very little from year to year in any given site, that it would be later in the cooler north, and that it was actually later than the conventional date of sowing practised by the fellaheen cultivators.

With these preliminary indications in hand, we can proceed to the full sowing-date experiment of 1913.

Methods.

In general, the methods employed in 1913 were the same as for the spacing experiment of the previous year, described in Part I of these "Analyses."

No records of boll-weight or ginning out-turn were obtained, as we had both left Egypt before they could have been worked out. In any case it is doubtful whether any profitable results would have accrued from them, in view of the negative evidence, for Giza, of the spacing experiment; the differences between wide-sown and close-sown cotton plants are far greater than between early and late sown, by the time the bolling season has been reached. The number of bolls ripening is therefore taken in this experiment to represent the yield with fair exactitude.

In place of these records we collected systematic data for the course of growth of the main stem, which had been apparently uniform for all the spacings, but must obviously be dissimilar in sowings made at different times.

PLAN OF PLOTS.

Occupying the southern half of the same piece of land which was used for the Spacing Experiment in the previous year, 1912.

W

S ········ ········→

E

Wire fence.

● 46 February 15.	Δ 47 April 12.	⦶ 48 March 22.	○ 49 March 8.	Δ 50 April 12.
○ 41 March 8.	∴ 42 March 1.	●● 43 February 22.	+ 44 April 5.	× 45 March 29.
× 36 March 29.	⊙ 37 March 15.	Δ 38 April 12.	∴ 39 March 1.	⦶ 40 March 22.
●● 31 February 22.	+ 32 April 5.	● 33 February 15.	⊙ 34 March 15.	●● 35 February 22.
⊙ 26 March 15.	∴ 27 March 1.	× 28 March 29.	+ 29 April 5.	○ 30 March 8.
+ 21 April 5.	●● 22 February 22.	⦶ 23 March 22.	● 24 February 15.	Δ 25 April 12.
∴ 16 March 1.	● 17 February 15.	⊙ 18 March 15.	+ 19 April 5.	○ 20 March 8.
⦶ 11 March 22.	× 12 March 29.	Δ 13 April 12.	● 14 February 15.	× 15 March 29.
Area reserved for physiological observations.		●● 8 February 22.	⦶ 9 March 22.	∴ 10 March 1.
			○ 4 March 8.	⊙ 5 March 15.

Ditch and wire fence. (left side)

Road. (right side)

Low hedge.

N.B.—The symbols shown in each plot are those used in the diagrams to indicate each sowing. See p. 407.

The one-acre area of land was the south half of the two-acre area which had been employed for the spacing experiment in the previous year (see p. 462). It was cut up into 50 plots, of which five were reserved for physiological work, with telegraph wires running into the laboratory for operating recorders; and a belt two ridges deep was sown at the normal time all round the area. This left 45 plots, sown on nine different dates, viz., weekly from February 15 to April 12. The five plots of any one sowing were scattered over the area (see Plan of Plots, p. 412). Each plot was approximately 10 metres square.

A single group of Observation Rows was demarcated in the centre of each plot, containing about one hundred and fifty plants.

The growth records were obtained by methods which were comparatively rough. A group of 15–20 plants was measured each week in the observation rows of each plot, and the average rate of elongation of the main stem was computed for the week past, in terms of millimetres per plant per day (mm.p.p.p.d.). The measurements were obtained by merely resting the end of the measuring scale on the surface of the soil at the foot of the stem, and were therefore read only to the nearest centimetre. A parallel series of daily records was taken on the physiological plots, using a group of 100 plants, with notched pegs driven into the ground by the side of each, to receive the end of the measuring scale.

The spacing employed was the conventional one for the district, of 45 by 75 cm., as approved in the previous experiment.

These observation rows were subject to fewer chance inequalities than those used in the spacing experiment, the land having been completely cleared from the toxic grass (*Cynodon dactylon*) during the intervening winter, by the drastic process of digging up the top half-metre of soil in all infected spots, and removing all rhizomes by hand. This source of plot-to-plot error was thus eliminated, and, the spacing being constant, it was possible to provide each plot with a set of observation rows comprising approximately one hundred and fifty plants.

The only partial exception to this uniformity was in the earlier sowings, where the stand of seedlings was so poor that re-sowing was extensive. In these the rows were picked out in short sections, so as to obtain an observed group consisting of the original sowings alone (Tables I and II).

This brings us to the question of four special details peculiar to this experiment, which had best be considered separately, viz., stunting and re-sowing, irrigation, soil, and season.

Stunting.—The object of the experiment was to study the behaviour of plants sown at various times. Since the stand of seedlings was inferior in the earliest plots, these plots had to be re-sown some three weeks later, otherwise the spatial allowance to the survivors would have been greater than that to the plants in the later-sown plots, where germination was practically perfect. We know from the spacing experiment (Part I of this series) that this increased spatial allowance would increase the production per plant and lower the production per area, since the optimum spacing had been adopted. Corrections could have been applied for this, but a direct method would be more satisfactory.

Re-sowing was thus inevitable, in order to keep the spatial factor uniform in all sowings. On the other hand, such re-sown plants should not be included in the experiment, if any fair comparison between plants of various ages was desired. Lastly, since re-sowing is always practised in field-crop conditions, it was necessary to include re-sown plants in any discussion of the technical bearings of the experiment.

We ultimately decided to re-sow in the usual way, but to pick out the groups for observation so as to include none but the original sowings. The state of the re-sown plants was not directly recorded, but could be determined by comparison with the condition of the later-sown plots, to which they corresponded in age. In point of fact, it was not possible to exclude re-sown plants entirely from the observation rows of the earliest sowing, unless by breaking up the rows into fragments inconveniently small, the observation of which would be subject to error through confusing the staff of plant observers. The observed plants of this sowing actually included about 7 per cent. of re-sowns, but it will be seen later that their presence tended merely to diminish the distinctive inferiority of this particular sowing, without otherwise altering it.

With this trifling exception, the investigation is then restricted solely to plants of definite age, all grown at the same spacing.

Irrigation.—A large number of varied considerations had to be taken into account in working out the arrangement of this factor.

In ideal cultivation the water-supply should never become limiting; in practice it is advocated that the first watering after sowing should be withheld somewhat, in order "to draw the roots down in search of water." We have some reason to believe that this is yet another fallacy, but the custom of the native cultivator does not in any case give this watering until a month after sowing on such land as that at Giza. For a safeguard we had the results of 1911, when, as stated above, the seedlings were irrigated at weekly intervals.

Therefore we adhered to convention, but this brought another difficulty. Early sown cotton exists under different conditions from late sown, when young. The mean monthly temperatures and evaporations for each month of the season at Cairo (Giza) may be presented (in round numbers) in the following Table.

The evaporation from the soil surface changes even more than the evaporation from a water-surface given below, owing to changes in the intensity of insolation, whereby the surface soil becomes hotter. The loss of water from surface soil is probably quite three times as great in May as in March. Thus the late-sown cotton must be given more water in its corresponding early stages than early-sown, or—since regulation of the quantity presents technical difficulties, requiring special facilities which we did not possess—the irrigations must take place at more frequent intervals.

Month.	Temperature. Mean maximum and minimum shade.	Evaporation from a free water surface per day.
	° C.	mm.
February	14	4
March	17	5
April	20	6
May	25	7½
June	28	8½
July	29	8½
August	28	7
September	26	6
October	23	5

Opposed to this we have the greater transpiration of the older plants. Thus the early sowings are removing an appreciable quantity of water from the soil by transpiration in the middle of April, while the plants of the last sowing are scarcely out of the ground. This consideration is, however, of less importance than one might at first conjecture. Our investigations into soil-water movement, carried out in the Physiology Plots adjoining the spacing experiment in the previous year, show that even by the middle of May a normal plot is losing more water from soil-evaporation than from transpiration. The figures given in the published account* have been found actually to be under-estimates of the water loss, since they are computed on the basis of an assumed safe value of 1·0 for the specific gravity of the soil in question. This value has since been found to be 1·2, and the following Table is revised accordingly.

Loss of Water in Fortnightly Periods from the Soil of a Cotton Field.

Period centre.	Total loss in tons per acre per day.	Loss in tons per acre per day estimated as due to—	
		Soil evaporation.	Transpiration.
May 16	13·0	9·5	3·5
June 12	29·0	12·0	17·0
July 6	30·0	5·0	25·0
,, 31	42·0	2·5	39·5

Moreover, as we shall see later, the early and normal sowings in June are all of about the same height and are branched to much the same extent, so that their transpiration should then be closely similar in spite of their differences in age.

* W. L. B., "Movements of Soil Water in an Egyptian Cotton Field," 'Journal of Agricultural Science,' 1913.

Taking all things into consideration we decided to formulate an irrigation chart beforehand, showing when each plot was to be watered, and to adhere to this chart rigidly. The chart was based arbitrarily on the points just outlined, with the general idea of giving rather more water to the later sowings when they were young, and, particularly, of giving different water-allowances to each plot of any sowing. The lowest allowance was that which we estimated might involve slight risk of water-shortage for any sowing, while the highest was not excessive for good cultivation.

This chart is reproduced below, each plot being shown, and the days of irrigation marked with asterisks. It will be noticed that, with one exception, all these days are at weekly intervals. It would have been better to graduate the chart on shorter intervals, but this was practically impossible, because the sowing-date experiment had to be fitted in with the other work of a programme already over-loaded. To the same cause must be ascribed a slip in the design of the chart; the scatter of plots on the area being intended to eliminate soil variation, it would have been preferable to employ a "scatter of irrigations" superposed on the scatter of plots, instead of which the heavier irrigations were in most cases given on the same part of the area. No serious error has resulted, however.

The actual chart being rather confusing, we have reproduced it in a form which brings out more clearly one of the motives underlying it, by a table showing the water available for each sowing in each week, expressed in decimals of a complete irrigation. Thus, a plot which waited five weeks for its next irrigation had an available water-supply (for purposes of discussion only) amounting to 0·20 in each of the five weeks.

These allowances may appear somewhat low to those familiar with Egyptian cotton and it is therefore advisable to mention that we had profited by our experimental results in 1912, and altered our method of irrigation; instead of running water into groups of ten ridges at a time in the usual way, and then closing them off to proceed to the next set of ten, we opened up 50 ridges at once, and turned the same flow of water into them. In this way a much greater quantity of water is given, since the soil has time to absorb more. The method can only be tolerated by well drained land, or by land with a natural under-drainage such as was possessed* by the particular acre which we employed.

A further consideration related to seepage of water from the irrigation channels on the area. In the usual way the land is divided by banks and channels of earth, and the watering of a plot at that end of a section which is farthest from the supply channel would involve seepage of water into intervening plots. Our results would then have suffered under the same disability as in 1911, though to a less degree, and would not have represented true field conditions. The lateral seepage

* W. L. B., "A Study of some Water-Tables at Giza," 'Cairo Scientific Journal,' 1914.

CHART OF IRRIGATIONS.

Sowing date	Feb. 15.	Feb. 22.	March 1.	March 8.	March 15.	March 22.	March 29.	April 5.	April 12.
Plot	14 17 24 33 46	8 22 31 35 43	10 16 27 39 42	4 20 33 41 49	5 18 26 34 37	9 11 23 40 48	12 15 28 36 45	19 21 29 32 44	13 25 38 47 50
Feb. 15	Sown.								
,, 22	· · · · ·	Sown.							
March 1	· · · · ·	· · · · ·	Sown.						
,, 8	· · · · ·	· · · · ·	· · · · ·	Sown.					
,, 15	· · · · ·	· · · · ·	· · · · ·	· · · · ·	Sown.				
,, 22	· · · · ·	· · · · ·	· · · · ·	· · · · ·	· · · · ·	Sown.			
,, 29	· * * · ·	· · · · ·	· · · · ·	· · · · ·	· · · · ·	· · · · ·	Sown.		
April 5	* · · · ·	* · · * *	· · * * ·	· · · · ·	· · · · ·	· · · · ·	· · · · ·	Sown.	
,, 12	· · · · *	· * * · ·	* * · · ·	· · * * *	· · · · ·	· · · · ·	· · · · ·	· · · · ·	Sown.
,, 19	· · · * ·	· · · · ·	· · · · *	* * · · ·	· * * * *	· · · · *	· · · · ·	· · · · ·	· · · · ·
,, 26	· · * · ·	· · · * ·	· · · · ·	· · · · ·	* · · · ·	* * * * ·	· · · * *	· · · · ·	· · · · ·
May 3	* * · · ·	· * * · *	· * * * *	· · · · *	· · · · ·	· · · · ·	* * * · ·	· * * * *	· · · * ·
,, 10	· · · · ·	* · · · ·	* · · · ·	* * * * ·	· · · * *	· · · · *	· · · · ·	* · · · ·	* * * · *
,, 17	· · · * *	· · * * ·	· · · · ·	· · · · ·	* * * · ·	· · * * ·	· · · * ·	· · · · ·	· · · · ·
,, 24	· · * · ·	· * · · ·	· · * * *	· · · · *	· · · · ·	* * · · ·	· · * · *	· * * * ·	· · · · ·
,, 31	* * · · ·	· · · · *	· * · · ·	· * * * ·	· · · * *	· · · · *	* * · · ·	· · · · *	* * * * ·
June 7	· · · * *	* · * * ·	* · · · *	* · · · *	· * * · ·	· · * * ·	· · · * *	* · · · ·	· · · · *
,, 14	· · * · ·	· * · · ·	· · * * ·	· · · · ·	* · · · ·	· * · · ·	· · * · ·	· * * * *	· · * · ·
,, 21	· * · · *	· · · * *	· * · · *	* * * · ·	· · * * *	* · * · *	· * · · ·	· · · · ·	* * · * *
,, 28	* · · * ·	· · * · ·	* · · * ·	· · · * *	· * · · ·	· · · * ·	* · * * *	* · * · *	· · * · ·
July 2	· * * · *	* * · * *	· * * · *	* * * · ·	* · * * *	* * * · *	· * · · ·	· * · * ·	* * · * *
,, 12	* * * * *	* * * * *	* * * * *	* * * * *	* * * * *	* * * * *	* * * * *	* * * * *	* * * * *

July 2 having been interpolated in the series of Saturdays, all the plots were irrigated together on July 12. Subsequent irrigation was given (to all plots) on July 24, August 13, August 24, September 14, and October 16.

TABLE of Water-supply to each Sowing.

Water given at one irrigation taken as equal to 1·0.

Sowing.	Feb. 15.	Feb. 22.	Mar. 1.	Mar. 8.	Mar. 15.	Mar. 22.	Mar. 29.	Apr. 5.	Apr. 12.
Week.									
1	0·142								
2	0·142	0·150							
3	0·142	0·150	0·175						
4	0·142	0·150	0·175	0·187					
5	0·142	0·150	0·175	0·187	0·193				
6	0·166	0·150	0·175	0·187	0·193	0·210			
7	0·177	0·214	0·195	0·187	0·193	0·210	0·220		
8	0·202	0·290	0·245	0·233	0·193	0·210	0·220	0·240	
9	0·230	0·290	0·316	0·300	0·266	0·226	0·220	0·240	0·240
10	0·241	0·290	0·316	0·300	0·300	0·300	0·220	0·240	0·240
11	0·241	0·323	0·300	0·300	0·300	0·300	0·236	0·240	0·240
12	0·241	0·333	0·300	0·316	0·300	0·300	0·283	0·290	0·250
13	0·283	0·300	0·300	0·316	0·316	0·300	0·283	0·300	0·300
14	0·300	0·300	0·333	0·350	0·316	0·316	0·333	0·300	0·300
15	0·316	0·316	0·350	0·333	0·316	0·316	0·350	0·350	0·300
16	0·350	0·358	0·366	0·350	0·350	0·350	0·316	0·366	0·350
17	0·363	0·371	0·413	0·350	0·380	0·363	0·350	0·426	0·400
18	0·496	0·511	0·513	0·516	0·546	0·546	0·416	0·426	0·400
19	0·599	0·544	0·546	0·600	0·580	0·580	0·533	0·480	0·632

Subsequently all plots were watered identically.

of water from one irrigated plot to its neighbour is very small as compared with the vertical movement, which is aided by gravity, so that if the water could be brought safely past intervening plots, the errors from this cause would be trivial; they would be practically abolished in the observation rows, which are situated in the centre of each plot, and from which alone the records of statistical data are taken.

An inexpensive solution of the difficulty was found—concreted water-channels being out of the question—by lining the channels with bituminous felt. Flaps were cut in the side of these felt troughs opposite to each plot, were turned down when irrigation was required, and carefully puddled up afterwards. Very little water leaked through the flaps when thus closed, and the irrigation of any one plot could thus be performed without affecting its neighbours.

Soil.—The same piece of land was employed as in the spacing experiment of the previous year, but only the southern half of it. Thus in some cases it was possible to compare the same plot of land exactly; plots 18 and 34 of 1913 were sown at the same time and with the same spacing as plots 15 and 32 of 1912. Some useful technical results thus obtained are discussed later. For the present it suffices to mention that the diminution of fertility produced in this acre of land due to two successive years under cotton was very slight, and only capable of detection by careful application of our methods.

The land had been cleared in December, 1912, from the plants of the spacing experiment, and was then left in bare fallow. No manure was applied.

Season.—As with the results of the spacing experiment, so also the results of the sowing-date experiment hold strictly true for one site and for one season only. As in that case also, we are of opinion that the analysis of these local and ephemeral aspects of the experiment is sufficiently thorough to justify predictions as to the results which other sites and seasons would give, especially when combined with the 1911 preliminary results.

We do not consider that the absence of abnormally warm days during the 1913 spring has made any appreciable difference to the final results, except in one particular, which will be dealt with later, but the reasons for our opinion will more fitly be given in the next part of these Analyses.

There is another reason for our belief in this respect, which we may here summarise —and expand later on—by saying that the existence of an optimum sowing date appears to be dependent upon soil temperature, at depths which are not much affected by short-period variations in air temperature, and which therefore undergo the same seasonal temperature changes each year.

Comparison of the 1912 and 1913 curves for bolling shows distinctly more shedding to have taken place in the later part of 1913. This cannot be traced to any cause except the most evident one, namely, attack of boll-worms. These larvæ (of *Earias insulana* and *Gelechia gossypiella*) had done very little damage at Giza in 1912, as formerly noted in Part I, but in 1913 they were abundant all over Egypt, and our land at Giza suffered even more than many other places. *Gelechia* was a parasite new to Egypt, having first been found by WILLCOCKS and ANDRÉS in 1910, and by 1913 was a serious menace, no official action being capable of coping with its rapid spread. The comparison of 1912 and 1913 in these experiments is thus of further interest, in that it is a comparison of a "good year" as regards boll-worm (for this Giza site) with the very worst year on record; in our experiments a numerical statement can be assigned to the difference, with rather unexpected results.

THE EFFECT OF SOWING-DATE UPON THE CHIEF STAGES OF PLANT-DEVELOPMENT WHICH DETERMINE YIELD.

Under this heading we propose to discuss the subjects of field germination, height of main stem, flowering, and bolling, in their relation to the development of the plant with course of time, and to plants of different ages. The nature of the depressant factor which acts upon all these, and to which the principal physiological interest of the experiment relates, will be treated subsequently.

Field Germination.

We have used this convenient term to express the true germination of the seed together with the subsequent growth which brings the cotyledons above the soil-surface, establishing an independent plant.

The phenomena obviously analyse initially into rate and quantity. Field germination might be slow, but perfect; or it might be rapid, with a large percentage of failures. The first combination is rare, but the second can actually happen in the field, as we shall see.

Although the relative quantity of successful field germinations is eliminated from this experiment by restricting our observations to the original sowings (pp. 413, 460, 480), the matter is obviously one of economic importance, and a brief sketch of the controlling factors, which have been discussed by one of us elsewhere,* had best be made.

Rate.—Provided that the seed-coat can absorb ample water the limiting factor of field germination is temperature. The following data will serve to illustrate its effects :—

Germination Test.—Made by our usual method, the seed lying half immersed in water, in Petri dishes. Not sterile. Material poor, since good seed should give 95 per cent. germination. Tested for seven days at three temperatures.

Temperature.	Percentage germinating each day.								Total.
	0	1	2	3	4	5	6	7 days	
° C.									per cent.
18	—	—	23	21	14	4	1	—	63
25	—	11	30	25	5	1	—	—	72
30	—	60	12	8	2	1	—	—	83

The rate of true germination increases with rise of temperature to 30° C. The quantity also increases, but this is mainly due to the higher temperature inhibiting the action of fungi. With higher temperatures we meet new phenomena.

* W. L. B., 'The Cotton Plant in Egypt,' London, 1912, pp. 15–37.

Effect of High Temperatures.—In fig. 2 we have indicated the effect of exposing germinating cotton seed to temperatures of 30° C. (*vide supra*) and of 36–37° C. The latter temperature is only just below that at which growth ceases when the temperature is raised rapidly and maintained as a limiting factor withal. The morphological effects on the seedling are remarkable; apparently growth in length is quickly inhibited, but growth in thickness is unaffected until later. The hypocotyl, therefore, becomes turnip-shaped, with abundant lateral roots. Very soon it ceases to grow at all, and ultimately the seedling dies. The same phenomenon is shown, in a much less obvious form, by very late sowings in the field.

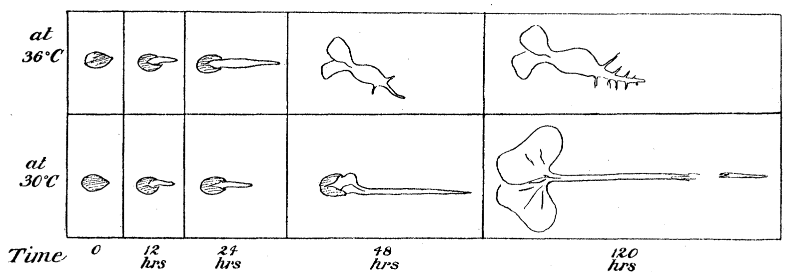


FIG. 2.—Germinating Seed.

The inhibition of growth which takes place rapidly on exposure to maximal temperatures, or more slowly on exposure to sub-maximal temperatures, has been traced by one of us, in the case of a fungus, to toxic katabolic excreta from the cell during the growth-process.* Further, there is good presumption for a view that the so-called optimum temperature for growth is due to the balance of this toxin formation against growth acceleration in all plants. The phenomenon is conspicuously displayed by the growing stems of cotton plants in Egypt on excessively hot days. For convenience in reference it has been designated Thermotoxy,† and its possible bearing on the facts ascertained in this investigation will be discussed subsequently.

Apart from this effect the rate of growth of a seedling root or stem, as manifested above in the germination tests, increases about 1·9 times for every 10° C. rise in the temperature.

It is not necessary for the moment to enter into details with regard to soil temperature, which will be given later (p. 444), except to state that the change in the mean temperature of the seed-bed is from about 14° C. in mid-February to about 23° C. in mid-April. This temperature change can only be expressed very roughly, as it is affected by shade, air-temperature, insolation, irrigation, etc. The average change, however, is of the order of 10° C. between our first sowing on February 15, and our last on April 12. This rise in temperature doubles the rate of growth, and should consequently halve the time taken for emergence of the seedling.

In this sowing-date experiment we find that sowings made on February 15 took 11 days to appear, and those made on April 12 took only five days, intermediate

* W. L. B., "Temperature and Growth," 'Annals of Botany,' 1908.

† W. L. B., 'Thermotoxy,' British Association, Dundee, 1912.

sowings taking intermediate number of days. This variation is completely explained by the change in soil temperature.

Soil temperature is thus the principal limiting factor in field germination.

An interesting example of indirect causation, where absorption of water is the true limiting factor, but is itself limited by the soil temperature, will be found discussed under "Technical Details" on p. 460.

Quantity.—The existence of a low temperature in the seed-bed does not merely bring down the rate of growth. If the temperature does not rise to the neighbourhood of 30° C. each day, the seedlings are liable to attack by a ubiquitous fungus, which is also known in America under the name of "sore-shin." It has no spore forms, and its systematic position is unknown, though one of us has some reason to regard it as a degenerate Basidiomycete.

At temperatures above 30° C. the cotton plant is immune to it. For our present purpose we may regard it simply as a factor which accentuates the normal growth-retarding effect of low temperatures. It differs, however, from the simple temperature effect in being irreversible, since if given sufficient time to act it kills the seedling root, and consequently the plant. In these experiments it was prevented from acting until the seed had been in the ground for some ten days, by a preventive dressing of naphthalene, devised by the senior author in 1906. After the naphthalene has evaporated, the seedlings are fully liable to the disease, almost solely under control of the soil temperature. Most of the present sowings were attacked by it, except the latest of all, when the soil was too warm, and these seedlings consequently possessed pure white roots, instead of the usual brown-scarred ones. In the middle sowings the temperature was high enough to prevent the fungus from killing off clusters of seedlings. In both middle and later sowings the stand of seedlings was, therefore, practically perfect. (See fig. 1 and Table I.) In the early sowings the soil temperature was frequently low enough to permit the fungus to kill all the seedlings in a "hole" here and there. Most of the failures in the first two sowings can be definitely ascribed to this cause.

It will be noted, however, that the latest sowing of all shows an increase in the number of failures, though unattacked by the fungus. This was simply due to overheating, as a modified form of the extreme phenomenon shown in fig. 3, and already mentioned. Had later sowings been made, the percentage of failure would have continued to increase, from this cause.

The factor of soil-texture was not involved in these experiments, because the land was in perfect tilth after its winter fallow. Otherwise, if the soil is lumpy, there may be mechanical resistance to the emergence of seedlings, and the water supply may be deficient because the seeds are held between clods, instead of being properly in contact with the soil.

Quantity of field germination is thus also in the main dependent upon temperature, though indirectly, through the irreversible action of a fungoid disease.

Having dealt with the causes of variation in rate and quantity of field germination, as between the various sowings, it remains to consider an indirect consequence of the latter feature, namely, the degree of fluctuation from plant to plant in after-life.

Fluctuation Resulting from Uneven Germination.—Apart from the killing of seedlings outright, many are damaged by the fungus, but survive. The worst of these are removed at the operation of thinning out, when the clump of seedlings in each "hole" is reduced in number to two only. Even so, however, since every seedling has been attacked to some extent by the sore-shin fungus, some which have been appreciably damaged must still remain. The same holds good for seedlings damaged by other causes. All such damaged seedlings may be called "stunted," or simply "stunts."

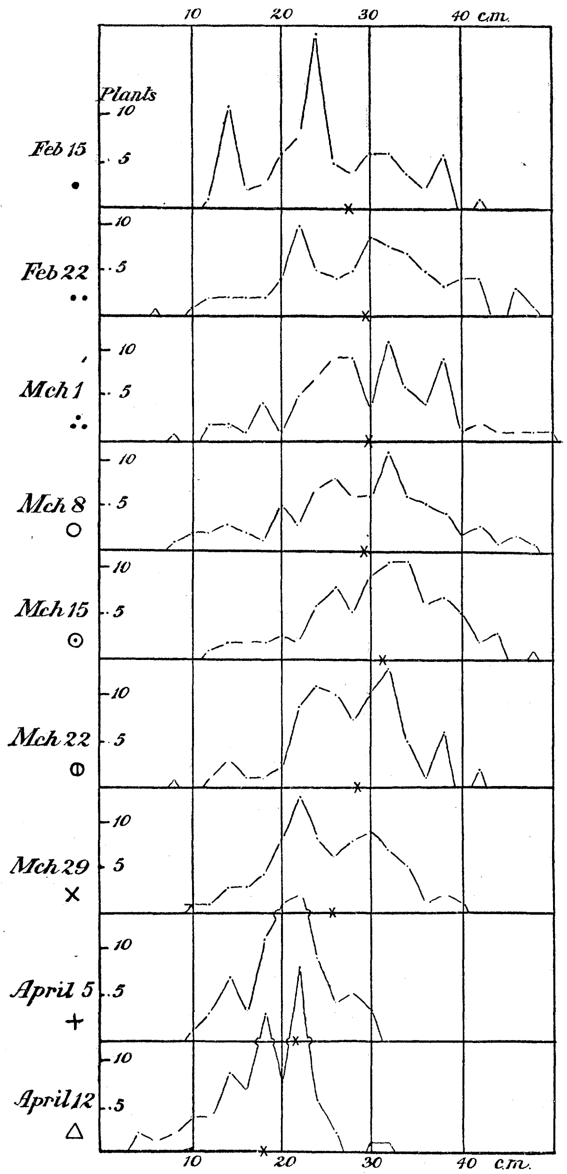
We shall have occasion to discuss another aspect of this matter subsequently (p. 441). With regard to seedling development the following points may be noted.

The method of stunting may be illustrated by the case where the phloem is affected. If the temperature allows the "sore-shin" attack to progress through the cortex, the hyphæ next select the phloem of the primary vascular bundles. If some of these are destroyed, the translocation of food from the leaves to the root is limited. The root system is only just sufficient normally to supply the amounts of water which the stem transpires at the daily maximum rate; consequently, its function being disturbed, the stem becomes short of water each afternoon, as may be seen by the wilting of seedlings thus attacked. Even if the plant recovers, it will have developed thermotoxic excreta in its growing cells, through overheating in strong sunlight with the stomata closed. Its subsequent growth will therefore be restricted, for a variable period, over and above the initial check due to deficiency of phloem tissue. It is also possible that the toxic excreta which the fungus is known to form may directly injure cells of the host, at places remote from the actual point of attack.

It is not easy to obtain a statistical expression which will do full justice to the differences thus produced by such stunting in different sowings, and we have never obtained, nor indeed seen, a convincing photograph of a cotton field. The best available evidence we possess is embodied in the height measurements. Even these minimise the effect, because they were made on the taller plant in each hole; had the second plant been included, a much wider range of deviation would be shown, since in the late sowings the two plants are more nearly of equal size than in the early sowings.

The following excerpt from the height records of a number of individual seedlings measured on May 28, should serve to illustrate the point at issue, together with the graphic presentation of the same measurements in fig. 3. About 80 plants were measured in each sowing.

Sowing-date.	Height on May 28, 1913.	Standard deviation.	Probable error.
	Mean in cm.		per cent.
Feb. 15	27·36	7·44	18·21
,, 22	29·35	8·94	20·30
March 1	29·69	8·26	18·64
March 8	29·13	8·87	20·40
,, 15	31·24	7·43	15·93
,, 22	28·31	6·48	15·33
March 29	25·61	6·29	16·45
April 4	21·21	4·47	14·12
,, 11	17·93	5·13	(19·07)



× = mean of group.

FIG. 3.—Frequency Distribution of Height on May 28, 1913.

The average probable error per cent. (or the coefficient of variation multiplied by 0·62) in the early sowings is 19·05, in the middle sowings is 17·22, and in the late sowings is only 15·28, if the last sowing of all, in which thermotoxic effects were acting (pp. 421, 467), is excluded.

Thus the experience of cultivators and the deductions of physiology and pathology are supported by statistical treatment. Late-sown cotton is much more uniform, the plant-to-plant fluctuation being less.

On the other hand, it is doubtful whether non-uniformity of early growth ultimately makes so much difference to the uniformity* of the lint which is gathered, as it is commonly assumed to do.

The Growth-curve.

With reference to the features described under this heading, there are certain difficulties of nomenclature. In one sense we may regard all the plant-development curves as curves of growth, but we have restricted the title to curves showing the rate of elongation of the stem. Further, we have confined our observations to the main stem only, using the flowering-curve for the purpose of presenting the growth phenomena of the flowering branches.

Even with this restriction of meaning there are difficulties. The "growth rate" is properly defined as the relation between time on the one hand, and the elongation of the growing organ, as related solely to those cells which are undergoing growth, on the other; it is the average length-increase of the individual cell in a given time, and can be determined only when the length of the growing region itself is known. Although we know approximately the extent to which the growing region of the main stem of a cotton plant enlarges as the plant itself grows larger, we have not sufficient systematic data to make it advisable to discuss the data of this experiment as growth rates in this correct sense; a first approximation to such discussion has been made on p. 427. Apart from this, we shall deal with the growth of the main stem in terms of "rates of elongation" simply, these being the relation between unit time and the length of the main stem, though we retain for convenience the general title of growth-curve for the records as a whole.

The height of the main stem was determined by a method which is relatively inaccurate, already described (p. 413). The average rate of elongation in each week, as expressed in millimetres per plant per day, shows a limited amount of erratic deviation, which is merely due to the imperfections of this method, to which we were perforce restricted. The use of a bench-mark peg for each plant observed would have removed these deviations almost completely. A certain amount of smoothing can be effected by grouping all the three early sowings together, and similarly grouping the middle and late sowings.

Systematic records of height were not started till May 28, when the mean height of the tallest sowings is about 30 cm. (*vide supra*, p. 424). Some casual observations

* W. L. B., 'The Development and Properties of Raw Cotton,' London, 1915.

were made before this date; these must be briefly considered, in order to show that the uniformity of height attained by the first five sowings at this time is not due to any sudden check.

On April 15, 1911, the following notes were made on the appearance of average seedlings. We quote from the 1911 notes in preference, because there had been no possibility of water-shortage, and any effects must have been due to other factors (p. 441):—

"Sowing of February 29: Third internode developed to a length of about 15 mm. Plants smaller than those of the next sowing.

"Sowing of March 7: Third internode about 10 mm. long,

"Sowing of March 14: Third internode rarely appearing, second internode 10–15 mm. long.

"Sowing of March 21: Second internode scarcely 5 mm.

"Sowing of March 28: First internode alone developed, about 15–20 mm. long.

"Sowing of April 4: Hypocotyl and seed-leaves only.

"Sowing of April 11: Not yet up."

At first sight it might appear that the sowings had developed in accordance with their respective ages, but this is not the case. Even on the assumption that all the equivalent internodes were of equal length, the first sowing has only gained 5 mm. on the second, which has gained rather less than 10 mm. on the third sowing. The third has gained more than 10 mm. on the fourth, while the fifth is 15–20 mm. taller than the sixth. Further, we see from the note on the first sowing, that the internodes in this one, at least, were actually shorter than those in the second sowing.

Moreover, as the seedling increases in height, the length of the growing zone of the stem increases, so that, other things being equal, older seedlings should elongate more in the same time. Here, on the contrary, the older the seedling the less its elongation.

It may be mentioned here that there would seem to be a real distinction between the development of nodes and the extension of internodes. To it is to be ascribed the fact that the isophytic line for "first flower" does not run parallel in fig. 1 to the isophytic line for "height, 30 cm." It may be well to add that the reason is probably of the nature of what we have called "pre-determination," to be further discussed in Part III; the differentiation of the nodes in the bud is conditioned by earlier environment than that which determines the fluctuation in internode length, and the flowering branches can only arise at pre-formed nodes.

In general terms, however, it is obvious that the elongation rate of the earlier sowings must have been slower than that of later sowings, since the latest sowings attained to any given height in a shorter time than their predecessors (fig. 1).

As the elongation rate slows down with old age, these differences are obliterated, and by the end of July all sowings are of approximately equal height.

Since height is merely the final result of growth, we will continue the discussion in terms of the latter function.

One general aspect may be noted advantageously. Since these growth events are taking place on a rising temperature-curve, up to July, it would seem at first sight that the weather which gave the "optimum" field germination would neccessarily imply "supra-optimal" temperatures for subsequent growth, which is not the case. The reason is simply that the "surface climate" changes very much with changes of a few centimetres in altitude above the soil. The point has been brought out by ecologists, notably by YAPP,* and one special feature in the case of cotton has been demonstrated by one of us.† Regarded in this way, however, it becomes very evident that the plants grown in the field from seed sown even on the optimum sowing date can merely compromise with their environment, and must be widely different from the abstract ideal of their species, which would be reached by culture in a uniform environment. They are, in a sense, abnormal. The realisation of this is essential to studies in the genetics of measurable characters.

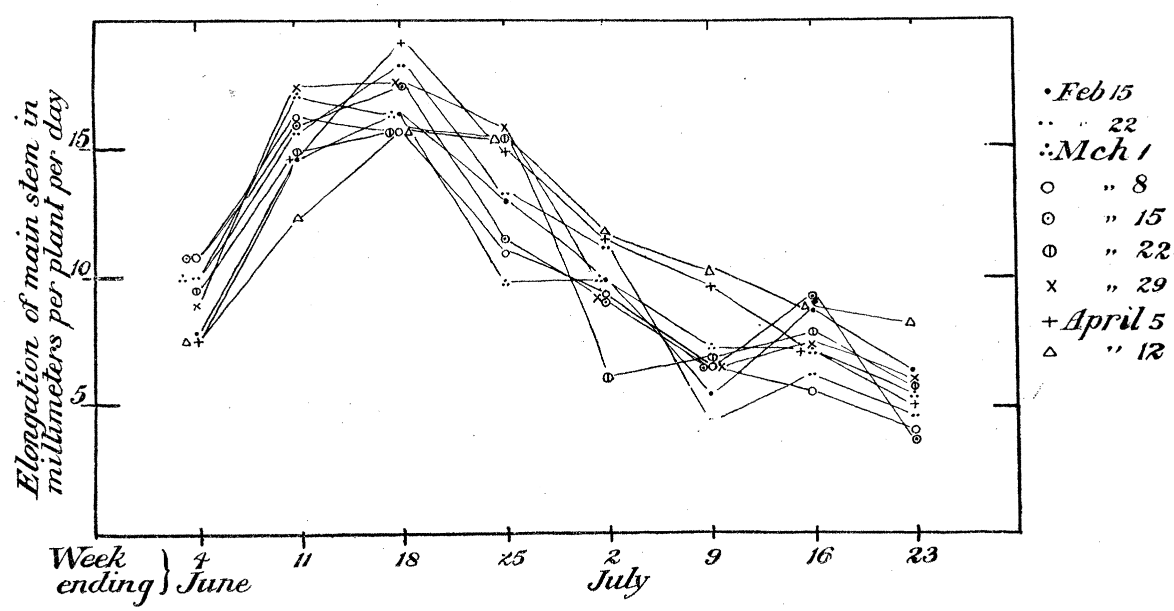


FIG. 4.—Growth-curves.

The Grouped Growth-curves.—In order to simplify discussion we may deal first with the growth-curves of fig. 4 in three groups (early, middle, and late), as in fig. 5.

This latter figure does not present the fact of the case quite fairly. In the earlier sowing, at the time when the records begin, the plants are smaller. Their stems are thinner, and the growing zone behind the terminal bud is shorter than in the larger, early-sown plants; consequently it is necessary to compare the growth-increments in

* YAPP, R. H., "*Spirea ulmaria*, and its Bearing on the Problem of Xeromorphy in Marsh Plants," 'Ann. Bot.,' 1912.

† W. L. B., "Meteorological Conditions in a Field Crop," 'Jour. Roy. Met. Soc.,' 1912.

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terms of the growing mass. We have no precise statements of this latter quantity, but the height of the young plant may be taken as an index to it, for the purpose of making a first approximation. The elongation-rates have therefore been computed as percentage-increments of the height to which the plants had attained at the beginning of each week, and are plotted in fig. 6.

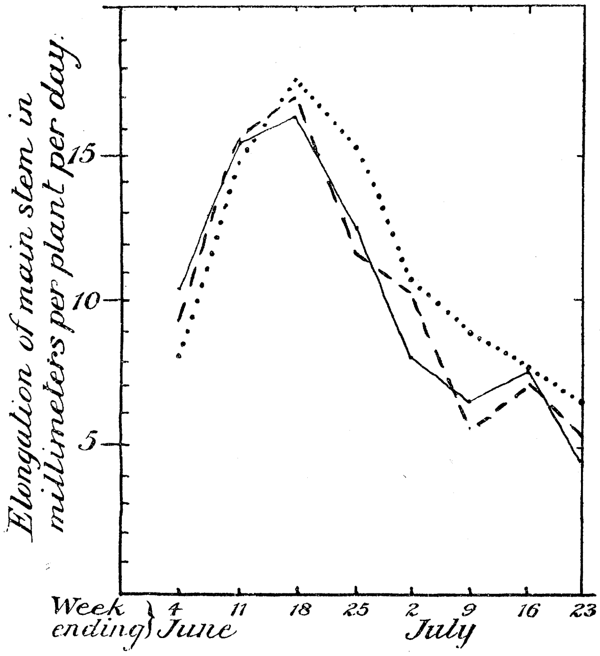


FIG. 5.—Grouped Growth-curves.

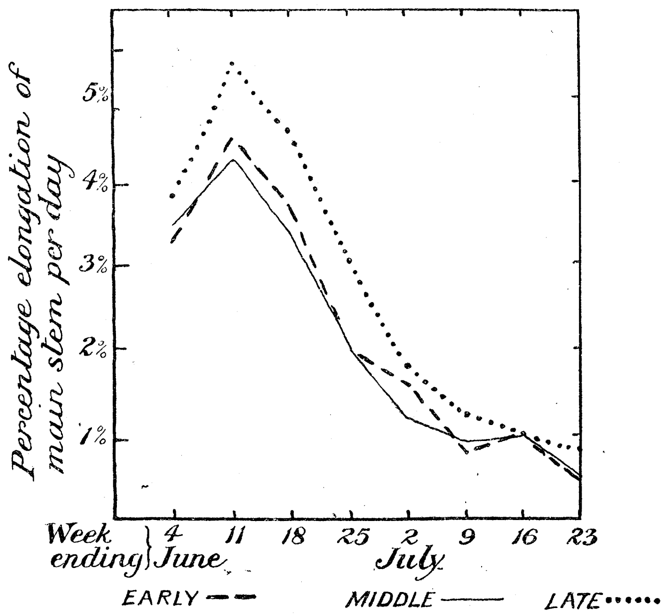


FIG. 6.—Percentage Growth-curves.

On examining these last two graphs it is clear that no significant difference exists after June in the growth-rates of the early and middle sowings. The late sowings, on the other hand, are growing much faster, both absolutely and proportionally, under the same environmental conditions.

If we now consider the course of events before the date on which these curves begin, it is obvious that a similar difference must formerly have existed between the middle and early sowings, and so back to the first appearance of the later-sown seedlings. Otherwise the early and middle sowings could not all have been of the same height at the end of May.

The problem thus resolves itself into one of determining why earlier sowing should delay the elongation-rate under the same external environment. The cause can only be internal, in the form of a residual effect left in the organism as the result of past events. Without some such cause, every day of growth would necessarily advance the development of all sowings equally ; even if the growth were extremely small until all the nine sowings were established, the early sowings would necessarily maintain this slight advantage.

In order to simplify discussion we propose to designate this cause as the depressant factor, for the time being, and subsequently to deal with it in a separate section, proceeding now to consider the other time-aspects of the evidence obtained in this experiment, in all of which the action of the depressant factor can be traced.

The Flowering-curve.

The flowering-curve is defined as a graphic presentation of the rate of flowering in successive periods on an average plant throughout the flowering season.

We propose to discuss the flowering-curve under three headings, with corresponding diagrams, namely: by groups of early, middle, and late sowings; by weekly means, as in the spacing experiment; and by daily observations.

Before doing this it is advisable to point out an abnormality of the 1913 records which was common to all Egypt in that year, and with which we shall deal in Part III. The growth-curve rose unusually quickly, presumably on account of the absence of especially hot days, already mentioned, and then fell off prematurely. The effect of this is shown on the flowering-curve as a similar rapid rise, lasting only a few days. Afterwards the curve returns to the normal horizontality at the maximum, which we discussed in Part I.

Some interesting points are brought out by comparison of these flowering-curves with those obtained in the spacing experiment, with regard to the trivial diminution in soil fertility which resulted from cultivating this particular piece of land in cotton for two successive years. Certain plots having been sown at the same date and with the same spacing in both years, an exact comparison is possible. The method and results of this comparison being more of technical interest, we have dealt with them under the heading "Technical Details" (p. 461), though in one sense they form an introduction to this examination of the flowering-curves.

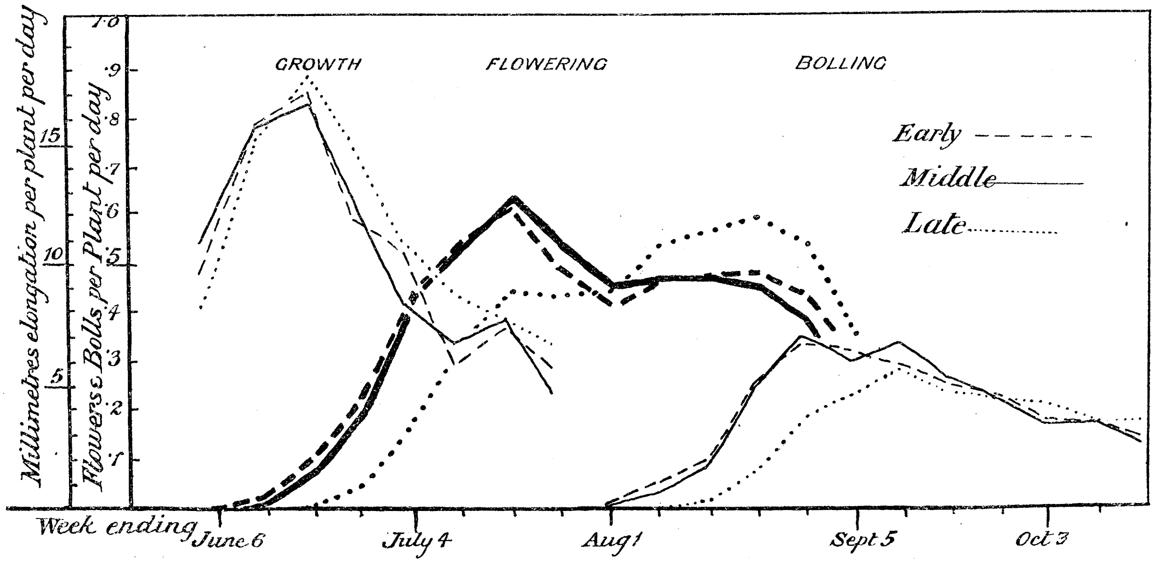


FIG. 7.—Grouped Curves.

The Grouped Flowering-curves (fig. 7).

The chief use of this figure is to show the sharp distinction between sowings made before the optimum sowing date, and those made after it. This distinction is as well marked in flowering as we have already seen it to be in growth. The early and middle sowings again give practically identical curves, whereas the late sowings not only begin flowering on a later date, but ultimately rise to a higher maximum rate. In the latter respect late sowing is curiously suggestive of the curves given by wide spacing in Part I, and should throw light on the validity of our interpretation that the maximum height is determined by soil fertility.

The Weekly Flowering-curves (fig. 8).

The curves plotted in this figure are comparable with those shown in fig. 2 (*b*) of the spacing experiment in Part I of these Analyses. The curves have been constructed by observing the number of flowers open on each day of the season, and adding up these numbers to obtain the total for each week of the season, classifying the observation rows according to their sowing-date. The weekly totals for each sowing were then divided by seven (days), and by the number of plants of each sowing observed, to obtain the mean rate of flowering per plant per day, in each weekly period, as plotted in the figure.

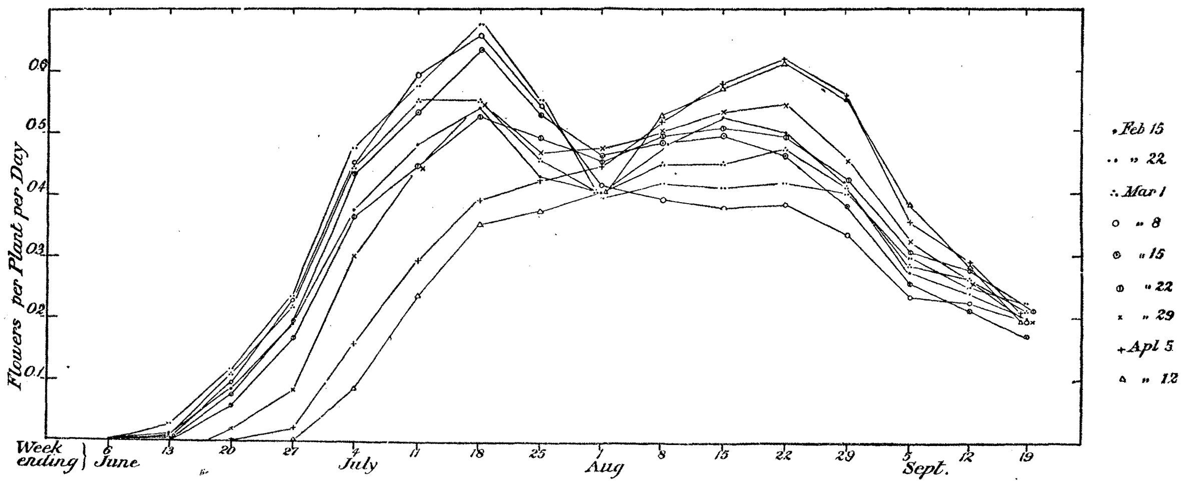


FIG. 8.—Weekly Flowering-curves.

In the first place it will be seen that although the earliest sowing (February 15, single dot) was among the first to flower, it soon lags behind, and on June 27 is flowering less than any of the next four sowings. Part of this might have been due to insufficient water supply to the seedlings; both in this sowing and in the next, those plots whose irrigation had been delayed longest after the sowing-irrigation are slightly later in flowering, and slower when flowering had begun. Discussion of this point may be taken conveniently here.

The Possibility of Water-shortage having been a Limiting Factor.—The point at issue is, whether our arrangement of irrigations (pp. 415–418) was such as to cause a general insufficiency of water supply to any set of plots, so that the observed effects of sowing at different times might have been due to this cause and not to the varying ages of the plants.

To test this we can select the wettest and the dryest plots of each sowing and compare them; in order to smooth out the plot-to-plot errors we can group them in threes, viz., early, middle, and late. The result will not be very precise, because, in the first place, only three plots are involved, instead of the 15 which the similar grouped curves of fig. 7 represent. In the second place, these plots will not be scattered evenly over the area of soil employed, owing to the slight slip in arrangement already noted (p. 416). They should, however, be sufficiently good to indicate whether any serious error had thus arisen.

The plots chosen, and the total flowers p.p.p.d. in each week are given in the following Tables:—

Plots chosen.	Early.	Middle.	Late.
Wettest	17, 35, 42	49, 37, 48	45, 44, 38
Dryest	33, 8, 10	4, 5, 9	12, 19, 50

FLOWERING p.p.p.d. each week, from June 6 to August 22.

Sowing.	State.	June.				July.				August.			
		6.	13.	20.	27.	4.	11.	18.	25.	1.	8.	15.	22.
Early	Wettest	0·004	0·019	0·098	0·280	0·280	0·299	0·251	0·220	0·170	0·165	0·117	0·166
	Dryest	0·007	0·031	0·081	0·210	0·299	0·290	0·278	0·209	0·285	0·200	0·210	0·118
Middle	Wettest	0·002	0·018	0·138	0·276	0·453	0·385	0·433	0·306	0·178	0·102	0·087	0·145
	Dryest	0·001	0·017	0·055	0·198	0·260	0·224	0·256	0·222	0·231	0·203	0·208	0·092
Late	Wettest	—	0·001	0·017	0·096	0·200	0·302	0·309	0·284	0·201	0·172	0·177	0·113
	Dryest	—	0·001	0·013	0·062	0·202	0·173	0·254	0·198	0·206	0·207	0·175	0·172

On examining these figures it will be noticed that early sowings are scarcely affected until August, when the "dry" plots appear to be less affected by the water-table. There is no significant difference between wet and dry until then. Late sowings, on the other hand, show a distinct falling away in the dry plots, on and after July 11, but the early part is still unaffected.

Middle sowings show a marked superiority of the "wet" plots, but at the time when this superiority is most marked the rise and fall of the flowering (*e.g.*, on July 11) is in the same direction in both wet and dry. Two of the plots included in "middle, wet" were very productive, for no apparent reason.

Altogether, seeing the negative evidence of the early sowings, where there was far more apparent likelihood of water shortage, and seeing also the close similarity in all three pairs as regards the beginning of flowering, we are justified in concluding that the amount of water given, even in those plots which received least water, was not so little as to affect the general result, nor were the heaviest waterings excessive for their respective sowings, and for the particular type of soil involved.

Comparison of the Rise of the Curves.—Apart from the slightly slower rise of the earliest sowing it is evident that there is no significant difference in flowering between the next three sowings, namely, those of February 22, March 1, and March 8, as shown in fig. 8. The following one, March 15 (circle with dot), is the first to stand clear of the group, but to such a slight extent that the distinction would not be visible without very good observation rows; still, it flowers at an initial rate which is attained definitely later than its predecessors. In the next sowing, March 22, this difference becomes clear, and its curve rises consistently four days later than those of the early sowings.

The sowing of March 29 (diagonal cross) increases this interval to six days, that of April 5 to 11–12 days, and the last sowing of all gives a curve which rises a fortnight later than that of the early sowings.

It will be noted that the last two sowings do not come into full flowering quite so quickly as the others, this being shown by their curves rising less rapidly. Since the sudden rise of these 1913 curves to an abnormal mode, before dropping back to the normal horizontal maximum, was a special seasonal accident (p. 419), and since the form of the flowering-curve is largely pre-determined by antecedent growth-processes, it would seem reasonable to assume that these last two sowings had not developed their flowering branches when the cause producing the abnormal mode was operative.

The fact that the sowing of March 15 is shown in these curves to flower slightly yet definitely later than the sowing of March 8, will have some interest when we come to consider the form of the curve which expresses the final yield (p. 438).

The Maximum Height of the Curve.—Neglecting until Part III the abnormal mode which is shown in the week ending on July 18, we find a fairly horizontal maximum in all the early and middle sowings during the month of August. We have delayed consideration of this part of the curve, in comparing 1912 and 1913, to the "Technical Details" (p. 462). The evidence there presented seems to accord with the tentative explanation which we gave in the spacing experiment to account for the existence of this horizontal portion, namely, that the limit of available soil-salts had been reached.

It seems that we may extend this explanation to cover the present cases, for those curves which rise highest are those which had previously been lowest. Put in another form, the limit of available soil-salts is not reached so soon in those plants which, having previously made less growth, have used up a smaller amount of the nutrient salts existing. If, as is more than probable, the only soil-salt which has here been deficient is nitrate, there is a possibility that the horizontality of the flowering-curve at the maximum might be due to nitrification by soil-bacteria coming into equilibrium with the removal of nitrogen by the plant. The researches (unpublished) of MASSEY at Khartoum indicate that nitrification is there extremely rapid in the cotton fields under conditions somewhat similar to those of Giza. Some further evidence on this matter will be presented in Part III.

Curtailment by the Water-table.—This effect is much less marked than in 1912, but we had scarcely expected it to be shown at all.

In 1912 the maximum level reached by the subsoil water in the standard well on our laboratory land was 17·70 metres A.S.L., while in 1913 it was only 17·44 metres A.S.L., the differences being due to the Nile flood, and to consequent differences in irrigation upstream of our land.* The soil surface in the experimental area lies at about 18·70 metres. Supposing the roots to have reached a depth of only 180 cm., they would have been first touched by the rising water-table on September 3, and 54 cm. would have been ultimately immersed. In 1912, on the other hand, the first contact on a similar root would have taken place on August 10, and 80 cm. would have been immersed.

These dates are only approximate, as the whole question will be dealt with in Part III, but it should be noted, in fig. 18, that the 1912 flowering-curve begins to be curtailed in the week ending August 8, while that of 1913 behaves similarly in the week ending September 5. These two pairs of dates, August 8 with August 10, and September 5 with September 3, are sufficient for our present illustration, though they are subject to corrections for critical purposes.

In the same fig. 18 it will be noticed that the 1913 curve is curtailed about 50 per cent., as the result of asphyxiating 54 cm. of root-system, whereas the 1912 curve is curtailed not less than 80 per cent., through the asphyxiation of 80 cm.

This result indicates that the lower part of the root-system is of high functional importance by July, and incidentally confirms our direct determinations on this point.†

The possibility that this root-asphyxiation may have a differential effect on sowings of various ages is the matter which principally interests us at present. At first sight it would seem that the later sowings are more severely affected, but if we consider that they were flowering more freely in the first instance, before the water-table rose, we shall see that such is not the case; the proportionate reduction is about the same in all, *e.g.*, 35 per cent. during the week ending on September 5.

Undoubtedly, had the Nile been early, a differential effect could have been detected by our methods, because the later sowings might not have extended their roots far enough below the surface to reach the water-table before it rose, and in this case the rising water would have reached the roots of the older sowings first.

* W. L. B., "A Study of Some Water-tables at Giza," 'Cairo Sci. Jour.,' 1914.

† W. L. B., "Movements of Soil-water in an Egyptian Cotton-field," 'Jour. Agric. Sci.,' 1913.

The Daily Flowering-curves (Fig. 9*).

In most of our records of flowering the observations have been taken daily. We have, however, refrained hitherto from publishing the daily observations. Those made on the spacing experiment were slightly marred by the *Cynodon dactylon* with which patches of the soil were then infested. In the sowing-date experiment this source of error had been removed, and—since the spacing was constant—the observation rows comprised a critical number of plants in almost every plot, viz., about 150.

The main features of the diagram have already been discussed on the weekly means plotted in fig. 8, and although we do not propose to deal fully with its significance until Part III of these "Analyses," certain comments may here be made.

The most striking feature is the remarkable concordance of the daily fluctuations in plants of all ages. Not merely do we find such striking movements as those of July 28, August 16 and 17, August 22, etc., but even on the early part of the curves the same identity is shown. Thus, on June 23, when the sowing of March 29 (diagonal cross) has scarcely begun to flower, its rate of flowering is accelerated along with the older sowings. Again, between July 9 and July 16, the course traced by the flowering-curve is tolerably complicated, yet only one sowing goes at all astray.

These curves are remarkable in another way. In most years, so far as our experience goes, this synchronisation becomes uncertain after mid-July, and the various spacings, varieties, sowings, waterings, etc., pursue each a semi-independent course. On examining fig. 9 more closely it will be seen that this event happened as usual on July 19, and for a few days the curves interlace in all directions; on July 25, however, they all begin to move together again, without exception, and continue to do so to the end of the diagram, excepting for a slight difference of opinion between August 2 and August 6.

It will readily be understood now why we stated in the General Introduction to these "Analyses" that the work of our native Plant Observers was, to a very considerable extent, checked by the plants themselves. We may appropriately mention here that these differences from day to day are very obvious—now that we know of their real existence—and by simply glancing over a familiar field, preferably from a slight elevation, we are able, or rather were able, to guess the flowering-rate for the day to within 0·05 flower p.p.p.d. These deviations also explain why the opinion of a casual observer as to the state of the crop is so unreliable; apart from subjective error it is evident that a person travelling past our station by train on Wednesday, July 9, 1913, would have concluded that the crop was remarkably backward, while another person on Thursday would have considered it normal, and yet another traveller on Friday would have rightly decided that it was extraordinarily prolific, or "early" (see fig. 9).

* The plot-to-plot data and computations from which this figure is drawn are too voluminous for publication *in extenso*.

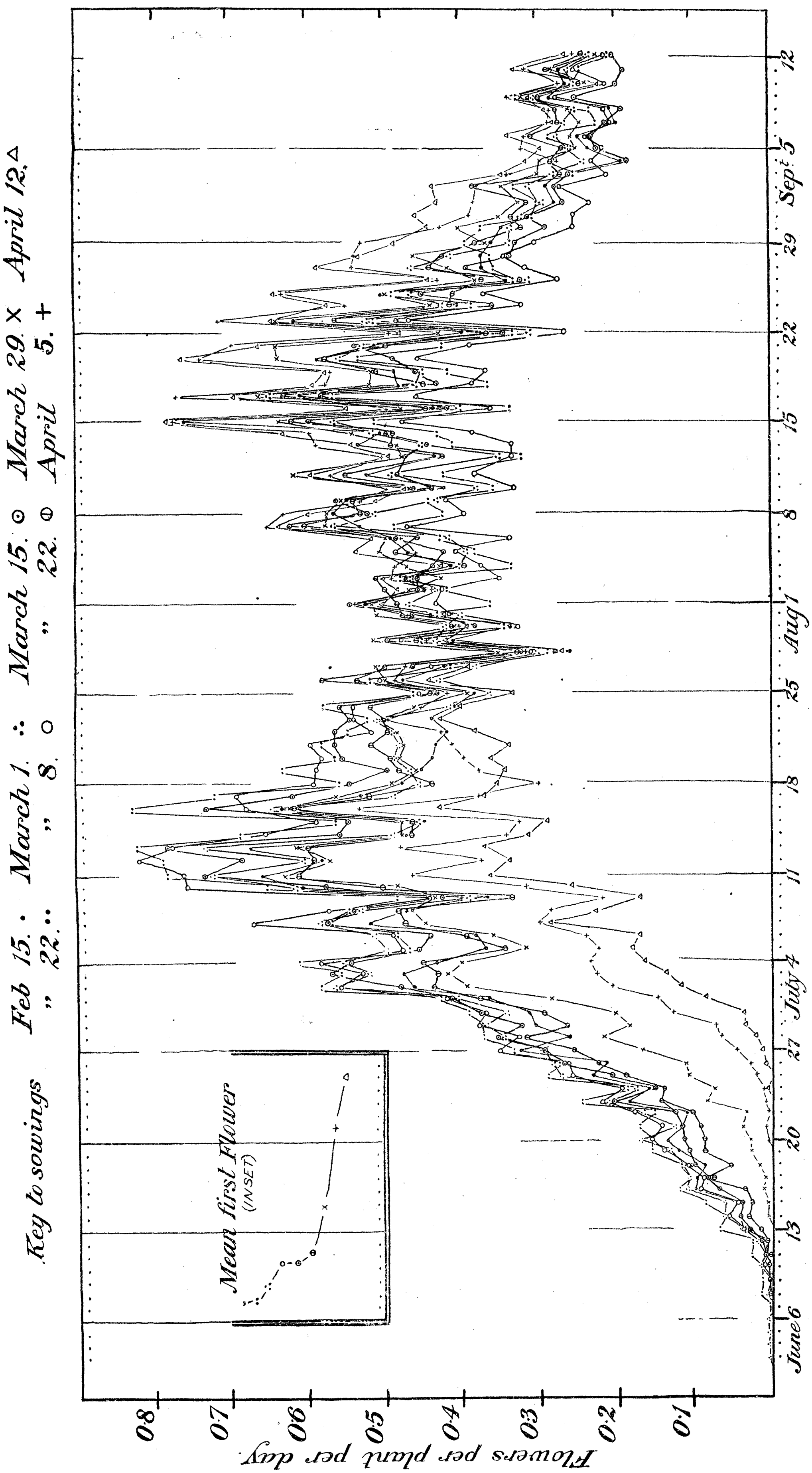


FIG. 9.—Daily Flowering-curves.

From the shortness of the period of these oscillations it might reasonably be conjectured that they were due to some near cause, such as the weather of the previous day. While there are undoubtedly some effects of this nature, such as might result from shedding of the unopened flower-buds, the greater part of these oscillations appear to be pre-determined some weeks before. To this we shall return in dealing with the effects of season in Part III.

Our principal deduction at this stage is, that these daily changes in flowering-rate are independent of the age of the plant. This in its turn indicates that all the plants have been under the control of the same environmental factors, and that any differential operation of the depressant factor has come to an end by the time the plants are forming their flowering branches.

One last feature of these curves remains to be discussed, namely, that the time-intervals separating the rising portions of the curves of the later sowings do not demonstrate any simple progression. Thus from the mean of the early sowings to the sowing of March 15 there is an interval of less than one day; from this to the next sowing is three days, then three more, the next five or six, and the last only two or three. We do not think that any significance can be attached to these small numbers of observations. It is more likely that the exact length of the intervals depends upon past meteorological accidents, experienced when the flowering branches were being first developed.

The Bolling-curve.

These curves (figs. 7 and 10) are derived in the same way as those of the spacing experiment, the fruits (or "bolls") on the observation rows being picked, or counted without picking, at weekly intervals, and the daily production per plant being computed as in the case of flowering.

As in the spacing experiment the curves are closely similar to the flowering-curves, with a lessened amplitude which is due to some flowers having been shed after they had opened. The abnormal mode in the early part of the flowering-curve has been much reduced, possibly in this way, though definite traces of it are still visible. In ordinary parlance it would be said that the plant, having flowered excessively, had exhausted its energies, and could not hold the abnormal number of fruits. The suggestion we would advance is that the abnormal flowering was due to abnormal pre-determining environmental conditions, and that these conditions were past and over by the time the flowers had opened, and had therefore become liable to shedding; consequently the shedding was normal, and tended to obliterate the abnormal mode.

We may again discuss the results conveniently under groupings similar to those employed in the flowering-curves. Before so doing, however, we must briefly mention an extraneous factor which will be more fully discussed under the heading of

"Technical Details." Egypt suffered in 1913 from an extremely severe attack of "boll-worms" in the cotton crop, as mentioned on p. 419. These larvæ destroy many young bolls outright, by causing them to be shed, while other bolls may come to maturity, only to reveal damaged cotton in them. The pest becomes more abundant late in the season. On inspection of the weekly bolling-curves for the nine sowings in fig. 10, the incidence of the pest is clearly visible, cutting off the tops of all the curves along a sloping line. The true form of these curves is thus obscured, but we have no reason whatever to anticipate that they should show any systematic differences from one sowing to another, other than those already indicated by the flowering-curves, as in the spacing experiment.*

The Grouped Bolling-curves (fig. 7).—Only one new feature presents itself in fig. 7, as compared with the previous curves for flowering. The rise of the late sowings above the normal maximum has been entirely obliterated. Since this was presumably due to boll-worm it has no further interest for us. Otherwise the curves, in their early portions, are the same as the flowering-curves, with a fairly constant difference due to shedding.

The Weekly Bolling-curves (fig. 10).—Since we have recognised the interference of the boll-worm with our results these curves have very little significance which has not already been dealt with under the head of the flowering-curves. If we look along the curves in the direction indicated by the marginal arrow, the erratic movements of the different curves, and their common trend, clearly indicate the operation of some such extraneous factor.

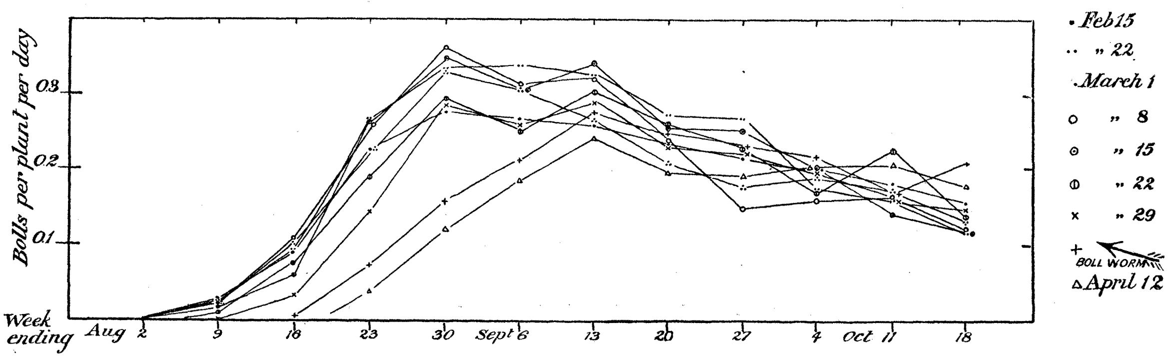


FIG. 10.—Weekly Bolling-curves.

It only remains to forecast—for any who may care to repeat the experiment—that if the boll-worm had been no more abundant than in 1912, the bolling-curves would have imitated the flowering-curves in all sowings, just as they did in the spacing experiment.

* The curves end rather abruptly, records having ceased a week earlier than in the spacing experiment in order that the land might be put under clover for the winter, and all our work be brought to an end. The pickings from these last weeks were of inferior quality, owing to the boll-worm. In any event, the bolls which ripen after the end of October are practically useless, their development being limited by falling temperature, and by senescence.

Final Yield.

A useful device in handling data obtained by our methods is to construct solid models, or even to draw contour diagrams. To do this the various flowering or bolling curves are cut out of cardboard, and set up one behind the other, with their date-ordinates in alignment. Contours can then be marked out by stretched threads.

A model made in this way does not bring out any new features, but it summarises the main experimental results, which in the case of the present experiment are the general, though slight, superiority of the sowing of March 15, the tendency to marked inferiority in sowings made before February 22, and the late development of late sowings.

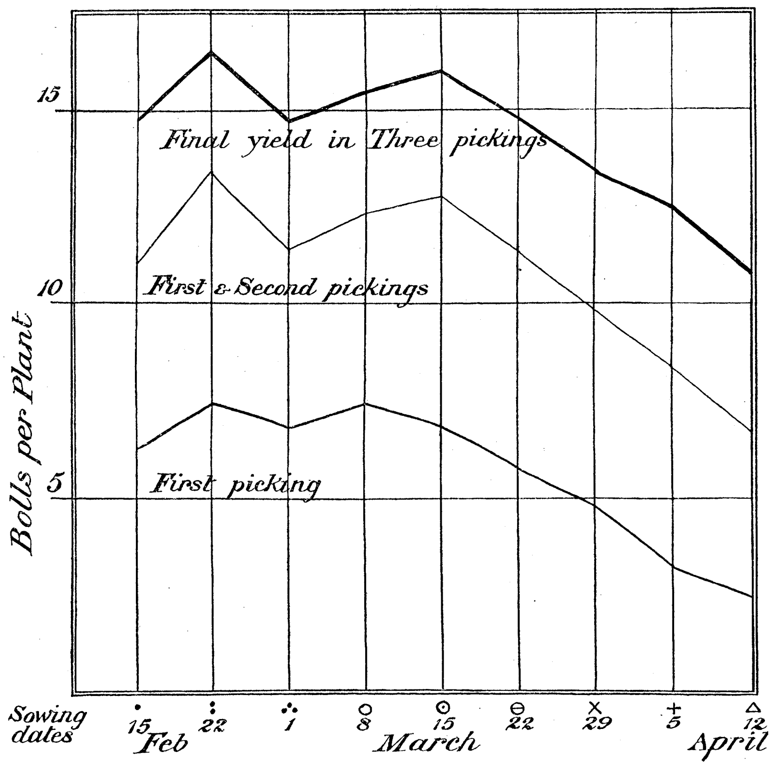


FIG. 11.—Final Yield and Conventional Pickings.

In fig. 11 we have presented the final agricultural result of the sowing-date experiment, as it would have been obtained in an ordinary agricultural trial without any of the intervening stages which we have traced.

The dates which we selected as representing the conventional pickings in 1912 were September 10 (first picking), October 1, and November 5. In practice the 1913 crop was picked rather earlier than its predecessor, owing to the large size of the first picking, which resulted from the abnormal mode in the flowering curve; we have therefore selected September 6 (first picking), September 27, and October 18, as being representative dates.

The fractional numbers of bolls produced by the average plant in each sowing on every day up to those dates are totalled to give the number of bolls picked in each of the three pickings for each sowing. This number is taken to represent the final yield, because we found in the spacing experiment that the corrections introduced by fluctuation in the average weight of the boll-contents, and in the ginning out-turn of the lint, were so small as to be negligible, for this particular site.

The three curves plotted from these data show the changes met in passing through the series of nine sowing dates, as regards the first picking, the first and second pickings together, and the final yield of all three pickings. Owing to the boll-worm effect these curves are not true general expressions, thus, the late sowings suffered more in proportion than the early ones, so that the curves fall off too steeply towards the right in the second and third pickings.

It is quite clear that the differences actually recorded between the first five sowings are so slight as to be covered by the experimental errors of their determination. This is in spite of the fact that our methods of investigation were as accurate as we could make them. We think it may be taken as demonstrated that anything less elaborate than our systematic scatter of five plots of each kind is necessarily quite useless for comparison of sowings made within this period, and that the elucidation of such fine shades of difference, even if achieved, would have very little practical significance in agriculture.

We can, however, generalise these curves from our preceding discussions. In the first place, we have seen that the flowering-curve of March 15 sowing rose a few hours later than that of its three predecessors (sowings February 22 to March 8). Therefore we know that—other things being equal—the first picking of March 15 sowing should actually be smaller than that of its predecessors, though to an almost infinitesimal extent. Similarly, we found that the earliest sowing was inferior to its successors in the rise of its flowering-curve. Thus, it is practically certain that the true form of a curve showing the size of the first picking, as in fig. 11, should rise to a maximum on the sowing of March 1 or 8. But the top of this curve would be so nearly flat that the determination of its true form could not be made by a scatter of less than 20 plots of each sowing, instead of the five which we employed.

Similar considerations apply to the later pickings. In general terms we may state the truism that, if sowing be delayed *too* late, the yield of all pickings is diminished. It is, however, evident from the flowering-curves that the yield of the late sowings should be greater in the late pickings than the corresponding yield of the early sowings; this, however, may well be a seasonal peculiarity, as already indicated, and not a general result.

One detail of interest may be noted. Taking the curves as they stand, we find that they fall along straight lines. If these lines are produced they cut the base-line, similarly produced, at three different dates. Sowings made after these dates would have produced no first, second, or third picking at all, as the case might be. Thus at Giza, in 1913, there would have been no first picking if sowings had been made after the end of April, no second picking from sowings made after the latter part of May, and had sowing been delayed until late June there would have been no picking at all. These statements are only approximations, for it is evident that they take for granted several things which we have formerly discussed, but they serve to indicate the general position.

The Custom of the Fellaheen.—The fellaheen of any one district in Egypt sow their cotton at much the same time each year, in so far as the exigencies of agricultural practice will permit. As a rule, they prefer to delay their sowing rather than to seize a favourable opportunity for early sowing. This has been ascribed to natural depravity.

In the district where our laboratory was situated the fellaheen sow about March 10. This, it will be noticed, is the date which we have just decided would have been the optimum in 1913 had our analysis been so perfect as to delineate the "flat optimum" portion of the curve correctly. But for all practical purposes the "critical" sowing date is not earlier than March 15. Sowings made a week later than this are likely to be somewhat inferior, and those made a fortnight later are certain to be distinctly inferior. By sowing rather earlier than the "critical" date the fellah is able to accomplish his re-sowing before the "critical" date is notably exceeded, while at the same time keeping his risk of re-sowing at a low level. As in the case of Spacing, he has learned by financial experience, and has selected the custom which most neatly strikes the balance between conflicting considerations.

It may be of interest to note that we had adopted a custom of our own for genetic researches long before this present experiment was conducted. We sowed as soon after March 20 as we could arrange, but never before that date. That our plants might be slightly backward was immaterial, but we could not allow our seed to fail in its field germination, as there was rarely seed to spare for re-sowing. On the other hand, when these researches were suddenly extended into a large-scale organisation for seed-propagation and supply in 1912, it became a matter of the first importance to know exactly how late we might delay our sowing to avoid loss of seed, and how early we must sow to avoid loss of crop, and consequent delay in propagation of our pure strains. This experiment, and its predecessor, were thus alike directed to placing the work of pure-strain seed-supply from the Giza station upon as exact and safe a foundatation as was possible.

Similarly, it is very clear why the fellah has turned a deaf ear to advice—not given by the authors—urging him to sow his cotton early, and risk the labour and cost of re-sowing, on account of "the advantage of getting an early crop of cotton if the plants are not killed by cold—to get the greater part picked before it can be damaged by boll-worms." The fellah was probably well aware that the argument quoted above was based on a fallacy. Early-sown cotton is not earlier in giving its yield, and the cultivator who sows more than a week before the optimum sowing date for his particular district and soil has everything to lose and nothing whatever to gain (fig. 1.)

The Nature of the Depressant Factor.

From the physiological point of view, the principal interest of this experiment attaches to the internal cause which inhibits the growth of the early sowings, so that, after a much longer existence, they have attained no greater development than their juniors, whether in respect of their height, first flower, rate of flowering, or any other feature measured.

This physiological interest increases when we consider that the operation of this factor is not confined to the very earliest sowings, but is manifested, though to a less degree, also by later sowings. It is therefore probable that we are dealing with a phenomenon which is of importance in the study of cotton-growing. It is, moreover, hardly likely that Egyptian cotton plants growing under Egyptian conditions should be the sole organisms to show this phenomenon, and we may anticipate that fuller knowledge of such a depressant factor will ultimately be of assistance in the study of growth in general.

It must, for example, be very difficult to trace the direct action of limiting factors on the growth rate, so long as these are blurred or masked by a depressant factor.

Introductory.

We propose to show in this section that the depressant factor can be traced to a cumulative toxic effect produced in the cells of the growing points by water strain, and that the environmental and structural conditions are such that the earliest sowings receive the greatest number of "doses" of this toxin. The interpretation centres round the fact that the stringency of the root's environment decreases as the soil temperature rises, this improvement in the absorptive capabilities of the root being more than sufficient to compensate for the increased stringency of the environment of the stem.

Before doing so we may briefly indicate two explanations which have formerly been offered regarding the delayed development of early sowings. The first of these is that the average of the population raised from early sowings is lowered by the inclusion of many stunted plants; while such is actually the case, it does not suffice as an explanation; the presence of exceptionally stunted plants "dilutes" the observed phenomena, but does not alter their nature, and we can see from fig. 3 that not only stunted plants, but the best plants also, show the incidence of the depressant factor.

The second explanation which has been suggested is based on the fact that early-sown seedlings are much more likely to suffer from after-effects of the attacks of the "sore-shin fungus," and this view is not easily controverted. On consideration, however, its probability is very small. Although the fungus is ubiquitous in the soil of Egyptian cotton fields, its attacks are by no means uniform in their incidence; one clump of seedlings in one hole may be completely destroyed, while the next hole escapes serious damage. It is thus quite likely that about one plant in every hundred of even the earliest sowing might escape injury. Further, the act of thinning out the seedlings to pairs of plants is in itself an act of selection, which leaves the best two plants.

Again, although the fungus in question effects most damage to the earliest sowings, it is not until mid-April sowings that the seedlings escape from it entirely, and display white roots in place of the brown scarred appearance usually seen. In order thus to account for the uniform development of the first flower shown by the first five sowings (February 15–March 22), we must assume that the amount of damage done to that one plant (in every seven hundred observed), which suffered least, was so nicely adjusted as to place it exactly in series with the corresponding plants of precedent and subsequent sowings. Such an assumption clearly strains the laws of probability too much. (For curve of First Flowers, see the inset of fig. 9.)

We therefore will now proceed to develop our interpretation of the nature of the depressant factor, by regarding it not as an accidental thing, affecting some plants severely and others lightly as the fungus does, but as a cause operative on every plant, almost uniformly. In other words, our attention must be directed to physiology, and not to pathology. For convenience, we shall restrict our discussion almost entirely to the action of the factor on a single characteristic, namely, the height of the main stem.

Effect of the Depressant Factor on Height.

In fig. 12 we have made a schematic representation of the manner in which height is affected by the depressant factor. This schema is based upon the data presented in Tables III–V, and on the discussions of the evidence obtained on pp. 425–428. It does not, however, pretend to be an exact presentation of the experimental data. Portions for which no statistical observations are available have been filled in on the basis of previous discussion.

Further, in it we have disregarded the fact that the earliest sowings become actually shorter than middle sowings, and have represented them as being all of the same height. This has been done simply for convenience in construction of the figure, as it does not affect the general argument.

On examining this schema we see that the general form of the height curve of all sowings is sigmoid, with a period of maximum elongation in the centre, where the curve is steepest. One of us has elsewhere* pointed out that the acceleration of elongation represented by the early rise of the curve can be largely accounted for by the rise in night temperature which takes place as the summer comes on; and that the falling off of the latter part of the curve may be explained as due to some internally-developed toxin, localised in the terminal bud, possibly a thermotoxin.

* W. L. B., 'The Cotton Plant in Egypt,' London, 1912.

A part of the rise in elongation-rate is also probably due to increased size of the growing-zone as the plant becomes larger.

These features of the curve are common to all sowings, and we now turn to the differences between them. At the point marked *a* the height of the second sowing becomes equal to that of the first sowing (see p. 426), and thenceforward they are represented as rising concurrently. At *b* they are joined by the third sowing, and so on to *e* and *f*, which are observed points included in the observations of height set out in Table III. At the point marked *h*, some weeks after the observations of height were discontinued, all the sowings have reached the same height.

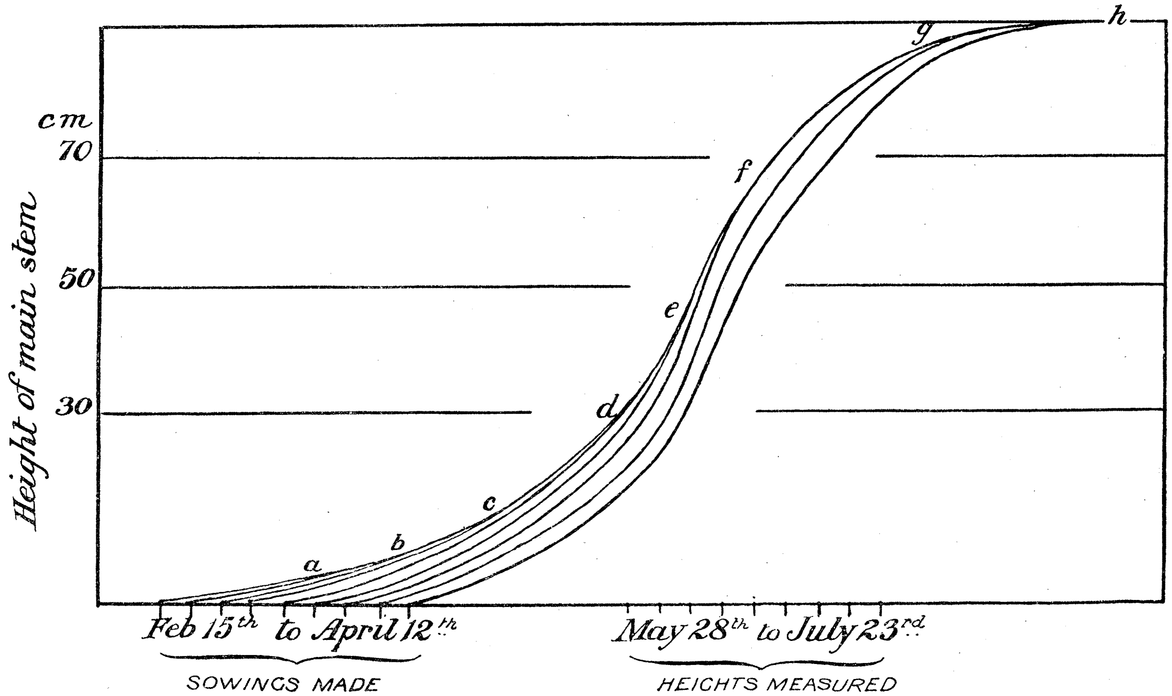


FIG. 12.—A Schema to illustrate the Development of the Main Stem in Successive Sowings.

This diagram presents the depressant factor, as being the cause which brings the height-curves together successively at *a* to *h*.

Before proceeding further we must note, however, that whereas the schema appears at first sight to indicate that this factor's action is most severe in the middle sowings, such is not really the case. At points *a*, *b*, the factor is acting on a smaller plant, with a shorter growing-zone behind its terminal bud, and the depression of the real growth-rate (see p. 425) is much greater. We can make a rough approximation again, as on p. 427, by considering it as a question of percentage elongation.

Our object, therefore, is to look for some cause which may have acted with most severity on the seedlings of the earliest sowings, with the effect of reducing their subsequent growth-rate below the rate which they might have attained under the same environmental conditions, had they been sown later.

Lastly, it is clear from the schema that the depressant factor is operative throughout the season, the severity of its incidence being great at first, then diminishing in June, and finally reasserting itself in August as the complete extinguisher of growth so far as the terminal bud is concerned.

We attribute the origin of this depressant factor to water-shortage, and have, therefore, three propositions to establish :—

(1) That early-sown seedlings suffer from internal water-strain more than later sowings.

(2) That there are causes which might normally bring about this condition of water-strain in the seedling tissues.

(3) That if any toxic substance is developed in the growing cells in consequence of such water-strain, this toxin is cumulative, and leaves an after-effect during its slow disappearance.

It will be more convenient to discuss the second of these propositions first.

The Environment of the Seedling.

Although we shall be principally concerned with only one component of the environment it is advisable to present other details for reference. This we have done in fig. 13, which indicates also the stringent conditions of the environment under which the cotton plant flourishes in Egypt. Thus, in the neighbourhood of Cairo the mean values at midsummer are: Maximum temperature, 36° C. (with rare maxima over 40° C.); evaporation, about 8 mm. of water per day; solar radiation, nearly 1000 gramme-calories per square centimetre per day.

It will be seen that the stringency of all these components is steadily increasing during the sowing season (February–April), so that we might reasonably expect water-strain to be more frequent in the later sowings, instead of the reverse relation which our hypothesis demands.

Even if we take into account the soil-temperature, which affects the absorption of water by the root system, the difficulty seems to remain undiminished. From January to February the temperature of the deep soil has fallen, while that of the surface soil has scarcely risen, so that the absorptive power of the root (as affected by temperature) would be the same, while the meteorological factors making for greater transpiration from the leaves have increased considerably.

Although the temperature of the soil must inevitably lag behind that of the air, yet certain corrections need to be made in the form of the soil-temperature curves of fig. 13 before we can accept them as representing the circumstances under which the roots of cotton are existing. These curves are based on observations made in dry desert soil at Abbassia, a suburb of Cairo. On comparing them with some records taken by the authors in connection with the preliminary sowing-date experiment in 1911 (fig. 14), it will be clear that the conditions of temperature obtaining in moist

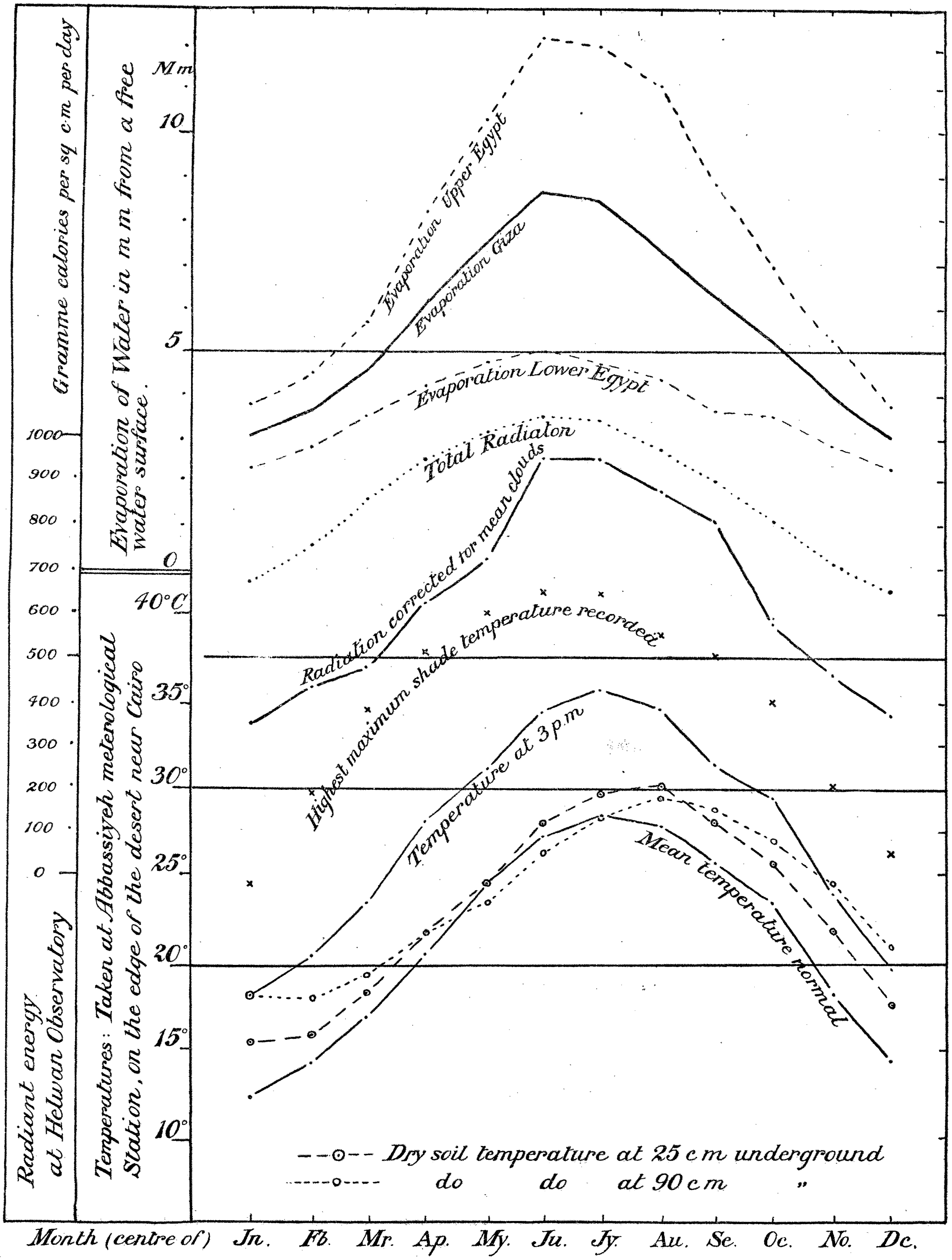


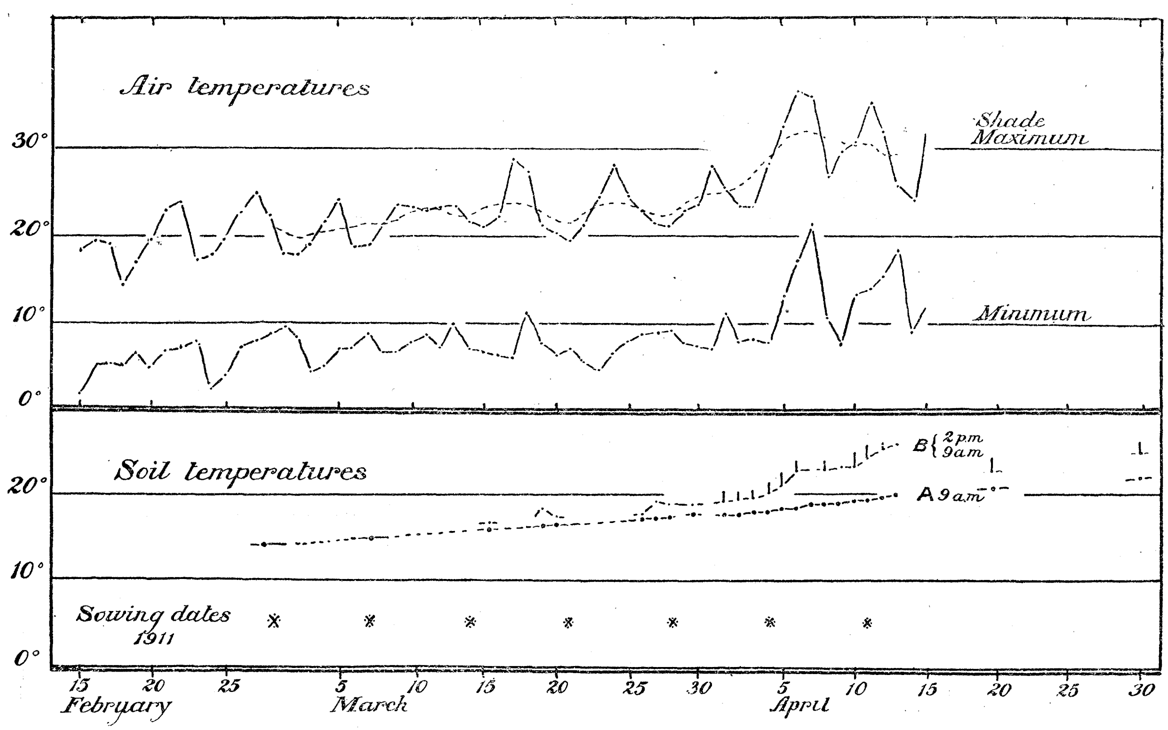
Fig. 13.—Meteorological Components. Monthly Means. Near Giza.

irrigated soil are very different from those in dry desert soil. One of us has called attention to this* in connection with thermo-electric records of the temperature of the seed-bed, also made in 1911, and the following features may be noted, since there are unfortunately no published records of soil-temperature within the crop, and we have no full series to offer :—

Wet soil is a better conductor of heat than dry, therefore changes in the temperature of the surface soil are transmitted downward more quickly in wet soil. In fig. 13 the mean temperature at 85 cm. is still higher in March than that at 25 cm., the soil being dry. In fig. 14 the soil at 30 cm. is already warmer than at 90 cm. on March 15. The habit of making the land up in ridges, and so presenting a surface at a normal to the sun's rays, undoubtedly assists this rise of temperature.

Being not only a better conductor, but also a better absorber of radiation for a few days after each irrigation, the temperature of the soil in a cotton-field more nearly follows the solar radiation. This is shown, accidentally, in fig. 14, since the mean maximum temperature (dotted line shows five-day means) was practically constant

FIG. 14.—The Environment in the Preliminary Sowing-Date Experiment, Gezira, 1911.



Sources of Data.—Air temperatures: By Survey Department, Meteorological Station at Giza; checked by thermograph among the plants.

Soil temperatures: Taken with long-stemmed soil-thermometers among the plants at 9 A.M., and additional readings at 2 P.M. Series A at 90 cm. below the furrow; Series B in centre of ridge, level with furrow.

* W. L. B., 'The Cotton Plant in Egypt,' p. 15.

from March 9 to March 30, while the deep soil temperature rose from 15° C. to 18° C. Similar effects are indicated in the surface soil, in the heart of the ridge, by the marked daily changes between 9 A.M. and 2 A.M., which are scarcely felt at 90 cm., where this change, though recognisable, was only about one-tenth of a degree, at these hours.

The temperatures which primarily concern us in discussing the early environment of seedlings are those of the upper soil, such as are indicated by the curve B in fig. 14, and it is clear that this temperature rises during the sowing-season to a greater extent than the standard meteorological records would indicate. Indeed, if we take the heart of the ridge as a convenient point of reference, we may safely assume a temperature change at Giza from 14° C. on February 15 to 23° C. on April 12, these being the dates on which our earliest and latest sowings were made in 1913.

The Transpiration of the Seedling.

The transpiring organs of the newly-established seedlings are, of course, the cotyledons. It may be of some significance in this connection to note that the chief circumstance which seems to influence the size of the expanded cotyledons in field conditions is the amount of resistance which the seedling has met with in completing its field germination; deeply-sown seeds presumably use up more of their reserves of food material from the cotyledons in lengthening and strengthening the hypocotyl. Given soil of similar texture, and similar sowing methods, the cotyledons of all sowings are of approximately the same size, so far as our observations go. This seems reasonable, because the cotyledons have grown nearly to their full dimensions by the time the seed-coat is cast off in their unfolding; up till this time they have been protected against water-loss, either by the soil or the seed-coat, so that deficiency of water is not likely to have been commonly a limiting factor in the development of their size. We may, therefore, take it as a working assumption, both on grounds of direct observation and of deduction, that the transpiring area of seedlings in all sowings is the same.

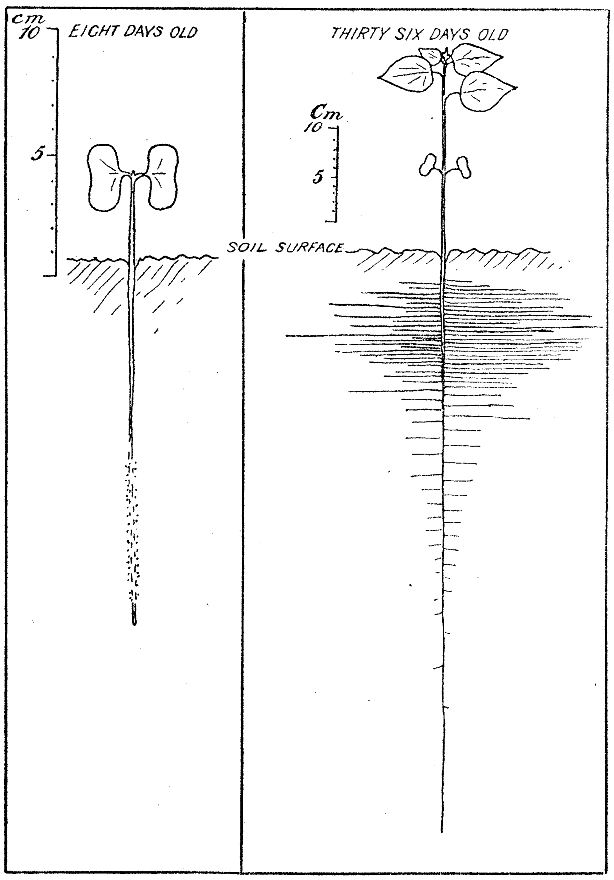
The transpiration actually effected might, however, be very different, since we have seen in fig. 13 that the evaporation component of the environment rises from 4 mm. in February to 6 mm. in April. Against this, on the other hand, we must set the regulating action of the stomata. Counts of stomata made by one of us have indicated that the cotyledons possess about 200 on the upper surface, and 275 on the lower surface, per square millimetre of epidermis. Many of these are only partly differentiated, and are probably not functional. An unknown amount of water is also lost by direct evaporation through the cuticle, before this latter is fully developed. Comparing the cotyledons with what information we possess concerning true leaves of Egyptian cotton, it is probable that the newly-established seedling is able to regulate its transpiration sufficiently to cope with the 50 per cent. increase in the February–April readings of the evaporimeter. The water loss from seedlings sown at various dates is therefore sensibly constant, given the same water supply to the cells of the cotyledons.

Our next step, therefore, is to examine the root, by which the water is supplied from the soil.

Water-absorption by the Seedling.

In fig. 15 we have depicted some examples of measurements made upon average plants from the sowing-date experiment of 1911, at ages of 8 and 36 days respectively. The plants in question were washed out with a needle-jet of water.

FIG. 15.—The Differential Development of the Absorbing and Transpiring Organs in Seedlings.



Stomata	200/276	80/150
Leaf surface	10 sq. cm.	80 sq. cm.
Absorbing root-length .	6–10 cm.	516 cm.
Soil temperature . . .	18° C.	23° C.
Evaporimeter	6 mm. per day.	$7\frac{1}{2}$ mm. per day.

Transpiration ratio . .	10 + : 100
Absorption ratio . . .	10 – : 250

The 8-day seedling had been sown on April 4. It had no lateral roots, and the tap-root was 14 cm. long. The area of the two cotyledons was approximately 10 sq. cm.

The 5-week seedling had 50 lateral roots on the uppermost 10 cm. of tap-root, the longest being 170 cm. long; on the remainder of the tap-root there were 36 other laterals, the last 17 cm. of the total 56 cm. being devoid of laterals. The leaf area was approximately 80 sq. cm.

It would seem that the absorbing system in the older seedling was much greater, but too many variables are involved for us to dogmatise on data of this kind. Beneath the figure in question are indicated some numerical relations. Thus, the evaporation from April to May rises (fig. 13) from 6 to $7\frac{1}{2}$ mm. per day, while the leaf-area has risen from 10 to 100 sq. cm. The transpiration from the two plants should therefore stand in some such ratio as 10 : 100, apart from self-regulation. To meet this increase in loss of water there has been an increase of root-system by the addition of 86 lateral roots, which would certainly seem to indicate a deficiency of root-system in the young plant, since we know that even the older plant is compelled by water-strain to close its stomata* at noon every day, cannot grow in direct sunlight through water shortage, etc.

Again, the absorbing zone of root-hairs is usually about 6 cm. long when root-hairs are developed. Thus, even if the whole tap-root of the 8-day seedling could absorb, there would only be 14 cm. of absorbing root-length as against more than 500 cm. in the 36-day plant. This would imply that absorption had increased 35-fold, although only a 10-fold increase was demanded by transpiration. But we have no justification for assuming that the amount of water supplied by a lateral root is equal to that supplied by the same number of root-hairs on the tap-root.

Still, all things considered, these and similar measurements decidedly indicate that the newly-established seedling is poorly provided with water-absorbing organs, as compared with their development at a later date. We will next see what indications are given in this respect by considering the course of the development of the root-system.

From a number of scattered observations made by one of us it appears that the first lateral root develops when the tap-root is about 15–20 cm. long, and that the development of laterals is very frequent in the surface layers of soil. Thus, in the plant depicted in fig. 16, there was a lateral to every 2 mm. of the upper tap-root. Let us now suppose that the tap-root is growing at the rate of 10 mm. per day, and consider how this will affect the size of the absorbing surface.

(*a*) After 6 days the tap-root will be 6 cm. long, entirely covered with root-hairs.

(*b*) From the 7th to the 15th day the older root-hairs are dying off, the size of the root-hair zone remaining practically constant, and the building-up of this next 80 mm. of tap-root has not increased the size of the absorbing portion of the root. (The root may of course be able to compensate for this by increased length of root-hair, but this does not affect the general argument.)

* W. L. B., "The Stomatograph," 'Roy. Soc. Proc.,' vol. 85, p. 33 (1911), and 'The Cotton Plant in Egypt.'

(*c*) On the 16th day the first lateral makes its appearance, and thenceforward new laterals appear at—let us say—every five millimetres. Thus each day's elongation of 10 mm. on the tap-root now adds two lateral roots to the absorbing system.*

Thus it is clear that whatever the rate of increase in the absorption may be during the early stages of development, this rate is enormously increased as soon as the lateral roots begin to form, and it continues to be increased as tertiary roots make their appearance.

The Effect of Temperature on Water-absorption by the Root.

The available data on this subject are rather scanty. Temperature is known to affect root-pressure; thus plants growing in flower-pots wilt when the soil is cooled to near freezing-point. VAN RYSSELBERGH has shown a logarithmic increase in the permeability of protoplasm to water from 0° C. to over 20° C., with a falling-off afterwards to practical constancy above 25° C. LEPESCHKIN has also shown a kindred relation in the case of *Pilobolus*.

For our case it is of some importance to know what the absorption would be at low temperatures—in other words, to determine the minimum temperatures at which water can be absorbed by the cotton-root—and for this we have no direct experimental evidence. There is, however, one observation which indicates that the absorption becomes slight in the neighbourhood of 10° C., namely, the behaviour of "rattoon" cotton, *i.e.*, plants left in the ground to shoot again in the following spring. Without entering into details we may say that, although such cotton flowers earlier than sown plants, through not having to build up a new main stem on which to carry the flowering branches, yet it does not start growing in the spring as soon as one would expect from the air-temperatures; if this were due to the known lag of the soil-temperature behind the air-temperature affecting the absorption of water, it would be quite explicable, and would indicate that the rise of soil-temperature from 14° to 23° C. experienced during the sowing season does not merely increase absorption in the case of cotton to the extent which VAN RYSSELBERGH's results would indicate, but to a much greater extent. The following analogy with growth may be indicated:—

We know that the growth of the tap-root also increases with temperature in such a way that, whereas the rate of elongation in a large number of observed seedlings at 19° C. was 1·1 mm. per hour and 1·25 mm. at 22° C., it had risen to 2·40 mm. at 32° C. Between these points the growth approximately doubles with an increment of 10° C. (pp. 420–422), but the growth at 10° C. is certainly not a half of what it is at

* Ultimately the root-system forms effectively an inverted cone, and changes in the growth-rate change the absorbing area as changes in the height of a cone affect its surface (excluding the base). At a later stage still the effective root-system becomes a hexagonal pyramid at the lower end of a vertical hexagonal prism (see Part I).

20° C., viz., 0·57 mm. per hour. Owing to the difficulties of obtaining a constant temperature lower than 15° C. in Egypt we have no long series of data on this point, but it may be illustrated by the fact that we regularly employed a Hearson cold incubator adjusted to 12° C. for inhibiting further development of germinated seed which was waiting to be sown, and such seed would remain in the incubator for 24 hours without appreciable growth.

In other words, the "minimum temperature" for growth of cotton is probably nearer 10° C. than zero, as is the case with another Egyptian summer crop, viz. maize, and it is not improbable that a similar relation holds good for the absorption of water by the root-hairs.

The Effect of Sowing-Date upon Water Absorption.

We have seen that the development of lateral roots does not take place until the tap-root is some 15 cm. long. The time at which this is attained varies with the soil-temperature, therefore early-sown seedlings take longer to develop the first lateral roots, since the root is growing in cooler soil.

Until the lateral roots begin to form, the plant is even more likely to suffer from water-strain than it is when they have been formed abundantly. As we know from former researches by one of us that even in the latter condition the water-equilibrium of the plant is most delicately adjusted, it follows that the seedlings must suffer more severe water-strain than older plants.

We have also seen that the relative proportions of absorbing and transpiring surfaces are much the same in seedlings of all sowings, and that the transpiration demands on the seedling are probably also constant. It remains to see how these demands are met by the seedlings sown at the various dates which we have employed.

It should be remembered that all cotton plants in Egypt, until July at least, cease growing in direct sunshine for a part of the day, owing to deficiency of water-supply and the imperative need for keeping the leaf-temperature down. We may designate this daily event as a "dose" of water-strain, in view of the next matter we shall discuss.

The seedling depicted in fig. 15 took at least nine days to develop its first lateral root in soil at 23° C., having completed its field germination on the fifth day. A sowing made on February 15 took 11 days to complete its field germination, and with its tap-root growing in soil at 15° C. it would not attain to the development of lateral roots until about the twentieth day. It would thus be exposed to nine (20 − 11) daily "doses" of water-strain, as against four doses (9 − 5) in the former case, before the lateral roots began to develop.

Roughly speaking, the duration of the exposure of the cotyledons to the air without lateral roots to augment their water-supply, is proportional to the number of days taken in completing the field germination.

In addition to this, however, we have to remember that the early sowings are necessarily absorbing water more slowly, through the coolness of the soil in which their roots are found. Therefore, at any given age, the late-sown seedlings will have the advantage in the following ways :—

1. They will have developed a larger root-system in the same number of days.
2. This root-system will be capable of absorbing water more rapidly.

Both these advantages depend on the rise of soil-temperature. It is difficult to give any exact expression for their magnitude, since we do not know the form of the absorption-temperature curve, nor of the growth-temperature curve below 18° C. It should be noted, however, that both these variables have a logarithmic relation to temperature, probably trebling from 10° C. to 20° C., and doubling from 20° C. to 30° C.

Thus, if unity represents the value of either of these functions at 10° C., the value at the time of early sowing with a soil-temperature of 14° C. will be 1·6 ; of a middle sowing with 17° C. will be 2·3 ; and of a late sowing with a soil-temperature of 21° C. will be 3·2.

Considering the two functions separately, it is clear that a late-sown root would grow to double the size which an early-sown one could have attained after the same number of days. The late-sown one would thus begin to produce laterals in half the time, and would therefore exist under conditions of severe water-strain for a shorter time.

In addition, the other function would also be affected, equal areas of root-system absorbing twice as much water in the late-sown root as in the early-sown one.

Consequently, after a certain number of days had elapsed since sowing, the late-sown root would have the advantage not only in possessing a greater area, but in absorbing twice as much water through each unit of area. Even if we neglect the effect of adding lateral roots, and consider the tap root alone, the late-sown root would be supplying four times as much water to its stem as the early-sown root could supply, and not merely twice as much.

Thus, not only does the rate of water-absorption increase with rising temperature in a logarithmic relation, but its amount depends on the size of the root-system, which is similarly related to temperature through growth, so that the significance of soil-temperature in relation to the water-supply of a seedling is enormous, a change of only a few degrees producing an augmentation of water-supply which at first sight seems too great to be accounted for.

The actual numbers given above to illustrate this augmentation depend, of course, on two assumptions : that increase in size of the absorbing organ and its absorptive capability are of equal importance, and that absorption is negligible in cotton roots below 10° C. Neither of these are justifiable in our present state of knowledge, and the numbers must be taken merely as illustrations.

Thus we have found that, contrary to expectation, early-sown seedlings, though growing in a less stringent aërial environment, may reasonably be expected to suffer from more severe water-strain, and for a larger number of days, than late-sown seedlings, on account of the greater stringency of their roots' environment.

This effect depends on the temperature of the soil, and is augmented by the necessary delay in the development of the first lateral roots.

If such water-strain produced a cumulative toxic effect, we could interpret the depressant factor. Before turning to this, however, it may be useful to cite an actual example of this water-strain.

Experimental Demonstration of Internal Water-shortage in Seedlings.

Concurrently with the 1911 preliminary experiment on the sowing-date, we obtained a number of preliminary observations on various points in the physiology of the cotton plant, to serve as guides in the further development of our researches. Subsequent events gave us no time to continue them systematically, but several useful illustrative pieces of evidence have been drawn from them. In the present connection it happens that we have preserved two growth-traces taken from the same seedling, which demonstrate this unexpected diminution of water-shortage with increased age. The following are the details respecting these traces, which are copied by pantograph in fig. 16.

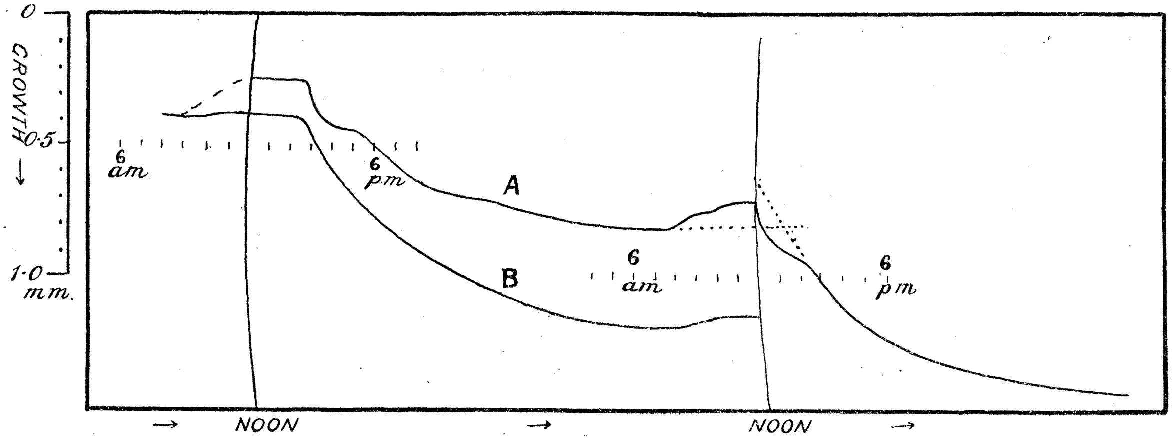
Sowing made on March 7 (see fig. 14 for environment). Field germination completed on March 16, after eight days. A clump of seven seedlings in a "hole" was chosen on March 19; this, it should be noted, was 12 days after sowing, with a ridge-soil temperature of 16–18° C, and therefore in all probability no lateral roots had been developed. None of these seedlings had developed a first internode. A capillary glass recording lever (157 + 36 mm. long) was fastened to the hypocotyl of one seedling at the insertion of the cotyledon stalks, with a light but firm tie of silk through a fine wire eyelet slipped into the end of the capillary. The trace A (fig. 16) was taken from noon on March 19 to dawn on March 21, after which the lever was removed.

On March 25 it was replaced on the same plant, which was now developing its first internode, and a similar trace was taken with the lever tied at the insertion of the first leaf (trace B).

One point needs special notice: The soil had, of course, been watered on March 7, at sowing, and it was again watered (see p. 411) on March 15. There was thus no possibility of water-shortage as regards the water in the soil, and any water-shortage shown by the seedling four days later must have been due to defective absorption as compared with its transpiration from the cotyledons.

Trace A, taken before the lateral roots had emerged presumably, will now be described. It begins at noon on the 19th, and shows no growth whatever until 2.40 P.M., when the sun had passed completely behind the trees on the west side of the site. The sunshine record for this day has also been preserved, and shows that a little sunlight struck through the trees from 3.15 to 3.40 P.M., another glimpse at 4.5, finishing with continuous weak sun through the tree-trunks from 4.20 to 5.25 P.M. It will be seen from the trace that, as soon as the sun had passed off at 2.40 P.M., the stem began to elongate rapidly, that this elongation was intermittently checked by the later sunshine, and that it did not start to grow freely until about 5.30. We shall next see that most of this elongation was not true growth, but simply recovery from water-shortage. The form of the growth-trace during the night does not now concern us. At 8.0 A.M. on the following morning, the sun came over the tops of buildings on the east side, as shown by the sunshine recorder, and the growth of the

FIG. 16.—Curves traced by a Growing Seedling, at two stages of development.



Sown . . . . March 7, 1911. A—Hypocotyl, March 19–20.
Appeared . . March 16, 1911. B—First internode, March 25–26.

seedling hypocotyl at once ceases. There then begins a contraction, amounting at its maximum to about 0·1 mm., the hypocotyl being about 50 mm. long. This contraction continues up till 12.5 P.M., when an arch of card was placed over the clump of seedlings so as to cut off direct sun for the rest of the day. The response is immediate, and it was noted at 12.20 P.M. that the pre-contraction length had been re-attained, as indicated by the horizontal dotted line. Elongation still continued, however, the trace sinking more and more slowly until 2.30 P.M., when it rapidly turns down to a maximum rate of growth at 2.50 P.M., as indicated by the sloping dotted line.

There is no doubt as to the interpretation of this "sunshine effect." Growth is checked through water supply from the root being insufficient to leave any water over after the primary demands of transpiration have been satisfied. The form of the curve after the shade was interposed at 12.5 P.M. on March 29 is rather more complicated, but its meaning seems to be clear: the primary extension of the hypocotyl up to pre-contraction length at 12.20 was due to water-absorption making up for that which had been lost through excessive transpiration—probably through the cuticle—and the subsequent slow elongation is due to the heat reflected from the soil outside the screen, maintaining the water-content as a limiting factor. When the sun went behind the trees, growth came under the control of temperature, and quickly rose to a maximum, falling off again as the temperature fell during the night.

Trace A of fig. 16 thus shows us that water-shortage was the dominant factor of the seedling environment during the day, although the soil had received an extra watering only four days previously, this seed having been sown on March 7.

We now turn to trace B in the same figure, taken from the same plant five days later, the screen having been removed on the morning of the 21st. The tissue to which the lever was tied was no stronger than before, being the actively growing first internode, yet we find that the contraction-effect is far smaller. On consulting fig. 14 we find that the temperature conditions were practically the same, and we can only conclude that the absorption of water by the root system must have been much better. Since this trace was taken when the seedling was 18 days old, we may reasonably assume that lateral roots had begun to develop, thus accounting for the improved water-supply, slightly assisted by a rise of much less than a degree in the soil temperature.

The Autotoxic Effects of Water-shortage.

However severe might be the water-strain which seedlings suffered, and however much more it affected early sowings rather than late sowings, it would not carry any weight as a depressant factor unless some after-effect were produced. Thus far we have merely indicated the mechanism which brings about the paradoxical result that seedling water-strain is worst when the evaporimeter readings are lowest.

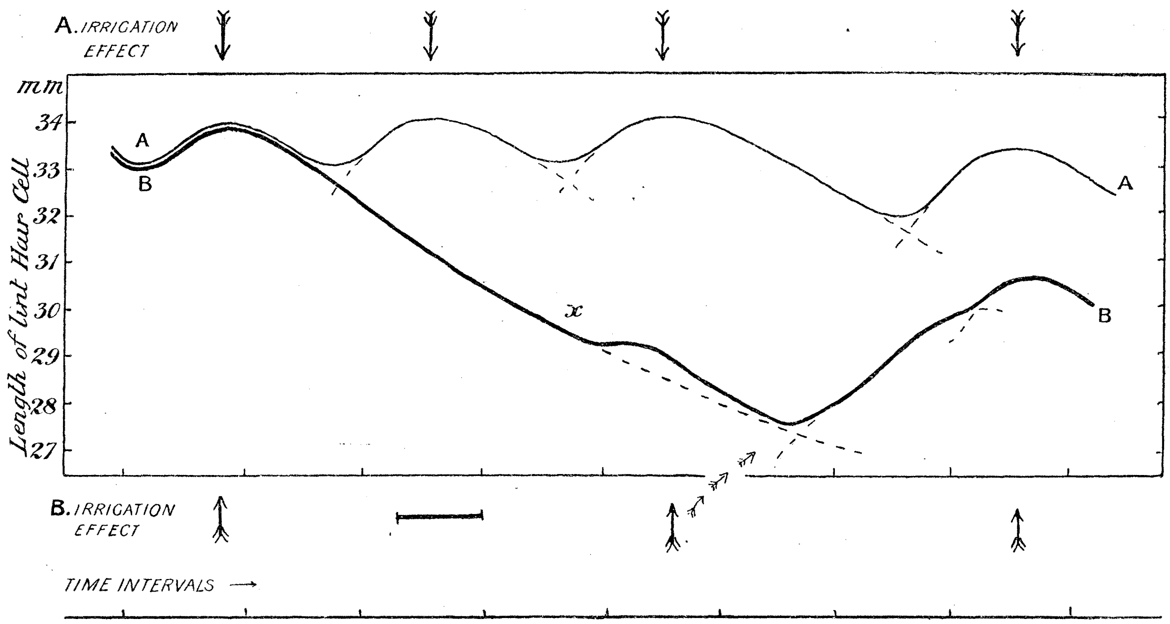
In formulating our hypothesis of the depressant factor as a toxin, produced in the growing cells of the plant as the result of water-strain, we are admittedly on uncertain ground, the only direct experimental evidence for such a view being the existence of thermotoxins in the culture media of the sore-shin fungus (p. 421). At the same time there are a number of scattered observations, not worth particularising here, which indicate the existence of such an after-effect, only explicable on some such hypothesis of autotoxy, and in addition one of us has obtained a series of data which seem to put the real existence of this after-effect beyond a doubt. These last we will now proceed to describe, in so far as they concern our present purpose, an account of them in their technical aspects having been published elsewhere.*

In the years 1912 and 1913 two series of ripe bolls were collected from plots of a pure strain of cotton (No. 77 strain) growing at Giza. The fluctuation of the length and breaking strain of the average lint-hair was thus obtained in the bolls which opened day after day for a period of some seventy days. When duly synchronised to the stage of boll-development at which each of these two cell-wall features is differentiated, the fluctuations of both are practically identical, so that we can discuss the results in terms of, *e.g.*, length of the lint alone.

* W. L. B., 'The Development and Properties of Raw Cotton,' London, 1915.

The data thus obtained have one clear advantage, in that they are data regarding a single cell, and not complex organs of the plant. We do not propose to present the actual experimental data, but to generalise them in fig. 17, which presents the curves showing the change from day to day in lint-length, as if the two plots, one normal (curve A) and the other artificially deprived of water (B), had been arranged side by side in the same season.

Inspecting curve A in fig. 17, we see that it rises to four maxima at points marked by arrows. These arrows indicate the dates on which irrigation produced its maximum effect on the lint-length.* The swing of the curves indicates, as was actually found to be the case, that the water-supply is the sole direct limiting



A. Normal irrigation. B. Water-short.

FIG. 17.—The Cumulative Depressant Effect of Water-shortage upon the Length of the Lint-hair Cell.

factor of lint-growth in the late summer. These swings can be analysed into separate curves, indicated by the dotted lines: on the rise of each curve are those bolls which were so old when the plot was irrigated that their lint had nearly ceased to grow in length, and the rise in length produced by irrigation was but slight; successively younger bolls are affected more, up to a maximum, and the effect then dies away as bolls begin to open which were so young when irrigation water was given them that their lint had scarcely begun to lengthen, and, therefore, even a doubling of its true growth-rate would not show as more than a fraction of a millimetre's increase in the length finally attained.

* It is advisable to arrange the arrows in this way, and not to place them on the actual dates when water was given, because the maximum effect is produced on bolls which are 16 days old at the time of irrigation, *i.e.*, when the lint is growing most rapidly in length.

Curve A is thus comparatively simple and straightforward, the water-supply acting directly as a limiting factor on the growth in length of the lint-hair cell.

Curve B represents the effect of depriving the plants of water, the second irrigation given to curve A having been omitted altogether, as indicated by the bar placed where the second arrow should be underneath the diagram. The portion of curve B from the point marked x to the end is based on direct observations, but the early portion is imaginary, being interpolated to show the connection between the two curves.*

It would seem that the maximum length of lint to which this pure strain (isolated in 1906) can attain under Giza conditions is 34 mm., as measured by combing on the seed. Isolated seeds may go higher than this, but a greater length than 40 mm. has only once or twice been found in the thousands of seeds which we have combed. Under conditions of ample water-supply at the conventional intervals, it oscillates between 33 and 34 mm. (curve A). On the other hand, when deprived of water, its length falls off steadily in successive bolls opening day after day to some constant minimum length (curve B). We judge that such a minimum exists, partly because of the form of the curve and partly because in all the seeds examined, often from plants severely short of water, we have rarely found one with lint-length less than 20 mm., and never less than 18 mm.

Just beyond the point marked x, however, curve B begins to rise feebly, indicating that some disturbing factor is at work, since the normal course would lie along the dotted line. This factor is clearly the irrigation-effect, acting most on the 16-day-old bolls, and indicated by the arrow below. A few days later, however, without any further water being given, the curve takes a sharp turn upwards, and apparently tries to climb up to its original level. Having climbed from 28 to 30 mm., its tendency to rise diminishes. Another irrigation-effect then comes into play, and lifts it nearly to 31 mm., only to fall again.

The question therefore arises as to why the water given at the end of the water-short period should produce this double effect, first a slight one in the expected position, and then a marked one in an unexpected position, as indicated by the three small arrows leading off from the large arrow.

The explanation we have advanced in terms of autotoxy seems to be an adequate answer. If growth under conditions of water-strain leads to the development of a toxin in the growing cells, just as growth under excessive temperatures does, then it is probable that a restoration of the water-supply would lead sooner or later to disappearance of this toxin. Its concentration would be most rapidly reduced in those organs which were youngest and smallest, and therefore contained the smallest

* The actual differences in irrigation may be of interest:—Curve B was given ordinary waterings (see p. 416) on May 30, June 19, August 2, instead of receiving water on July 10 as well; Curve A, or rather the material from which the curve is constructed, received heavy waterings on June 4 June 22, July 6, July 22, August 4, etc.

initial amounts; such reduction of concentration would be the simple result of mere increase in size, quite apart from any chemical decomposition which might also occur.

Therefore, on giving water to the plants represented in curve B, the flowers would be benefited more than the young bolls, and the buds more than the flowers. Actually it was found that the rise of the curve which indicates reduction of the toxin (on our hypothesis) begins with those buds which were not due to open as flowers till four days after the water was given.

Also it should be noticed that the first direct effect of the water (on the 16-day-old bolls) is very much reduced; the presence of the toxin blurs the straightforward action of the water as an ordinary limiting factor.

Whatever validity may ultimately be found to attach to this autotoxin hypothesis, it is clear that we are not making any unjustifiable assumption in postulating the existence of a growth-restraining internal after-effect as the result of internal water-shortage or water-strain.

Summary as to the Nature of the Depressant Factor.

We have shown that internal water-shortage leaves an after-effect on the plant which can only be removed slowly by restoration of an ample water-supply, and it is probable that this after-effect is due to the production of toxic excreta in such cells as grow under deficient water-supply. The complete disappearance of this effect, when severe, may require the lapse of several weeks, if indeed this is ever attained.

The conditions under which the seedling lives are such that the seedlings sown a month before the conventional date suffer from severe water-strain every day for at least twice as long as seedlings sown a week or so after the conventional date. They thus receive a proportionately greater number of "doses" of the toxin, and suffer accordingly by a general reduction of their subsequent growth-rate below that which they ought to attain under the control of any given set of limiting factors.

From general consideration of the circumstances it would seem quite unjustifiable to assume that there is any sharp line of demarcation beyond which cotton plants growing under Egyptian conditions can be said *not* to suffer from the depressant factor. Comparing them with plants grown under other conditions (for example, in a cool greenhouse near Cambridge by one of us), it seems very probable that the depressant factor embodies about half the total control of the growth of cotton in Egypt, and that if this were not the case the various organs of the plant would grow larger, such as the internodes of the flowering branches, and the time taken by the crop to arrive at maturity would therefore be increased, thus introducing a serious disadvantage into the cultivation of Egyptian cotton.

Until this elucidation of the depressant factor, which we have endeavoured to make, is satisfactorily established, the study of the growth of cotton—and presumably of other plants in other lands also—must labour under difficulties.

It might be added that the fall in the growth-rate of the main stem, which takes place in Egypt after midsummer, would seem to be due to the same factor, reasserting itself as the sole controller of growth (not merely as a modifying influence on the results produced by external limiting factors), when the plants have grown so large that their closely packed root-systems are inadequate to meet the loss by transpiration.

The action of the depressant factor is essentially confined to a single group of meristematic cells. Thus the growth of the main stem may be checked, but that of the younger flowering branches may continue, they having been developed from areas which did not produce the toxin, because they were not growing at the time when the toxin-provoking conditions were operative.

Technical Bearings of the Sowing-Date Experiment.

The point of obvious interest is that, as in the spacing experiment, we have again found the conventional practice of the fellaheen to be the correct one.

Our direct experimental results, namely, that early-sown plants do not flower any sooner, nor fruit any better, than normal sowings, are rather opposed to assumptions which have formerly been made. At the same time it has long been recognised that a spell of cold weather may "retard the growth" of the early sowings (*e.g.*, p. 409), but our examination of the depressant factor brings out the curious fact that this effect of cold weather is really due to the cold surface soil thus produced.

The whole story of the sowing date is thus tolerably complicated. Amongst the earliest researches effected by one of us in Egypt was an investigation into the sore-shin fungus, which showed that the effects commonly ascribed to cold were mainly due to the action of temperature on the fungus and its host conjointly. Now, at the end of our work, we have succeeded in tracing out the direct effect of temperature on the plant alone.

It is plainly a matter of indifference, as far as the best plants are concerned, whether sowings in the Giza district are made on the optimum sowing date—about March 15—or earlier. Therefore there is no justification for running the risk of failure in field-germination, with the consequent trouble and expense of re-sowing, by planting earlier. In practice it is found advisable to sow slightly before the optimum sowing date, so that any necessary re-sowing may be effected before this date is long past.

Further north than Giza the soil temperatures are lower, and also the air temperatures; the optimum sowing date should, therefore, probably be later. This conclusion is supported by the data furnished by H.H. Prince Omar Pasha Toussoun to the Cotton Commission (Egyptian Government, 1910). The converse should obtain further south.

It also follows from our analysis that the optimum sowing date might differ in two adjoining fields, if the surface soil in one were sandy, and in the other of heavier texture, since these would change their temperature at somewhat different rates.

Re-sowing.

Although the failure of the early sowings to complete their field germination successfully, as distinct from the after-effects due to the depressant factor, is mainly due to the sore-shin fungus, yet there may be failure from another cause, as was clearly shown by our earliest sowings (see Table I). In this case the failure lies not in the non-completion of field germination, but in the initiation of germination itself; many seeds and "holes" of seed failed to germinate, but were quite healthy, and came up on being watered a second time. It happened that the sowing of all five plots of the first sowing was personally superintended by the authors, so that there was no question of bad sowing or watering, and the soil tilth was excellent. The failures were quite spasmodic; of two adjacent holes one would fail while the other succeeded. The cause seems to lie in the difficulty of initiating water-absorption by the seed-coat.

The outer coat of the cotton seed is slightly waxy, probably from deposits of the same wax which has long been known on the lint-hairs. The seed, therefore, requires to be wetted thoroughly, and the trustworthy method for conducting germination tests is to immerse the seeds half-way in shallow pans of water; complete immersion in a flowing stream of aërated water is the best of all. If, therefore, the seed is planted even in fine tilth soil, much less in rough soil, and if any accident leads to breaking of the continuity of the water-films which run from the soil-particles to the seed, before the cells of the seed-coat have swollen sufficiently to destroy the wax-film, germination cannot take place.

Since the absorption of water by the walls of the dead cells of the seed-coat is a purely physical process, and its rate is directly affected by temperature, it follows that these cases of failure were due to limitation by water-supply, although the environmental factor which controlled the water-supply was the temperature.

With regard to re-sowing in general, its effects, when unavoidable, may be read off from the data and diagrams given here by remembering that all the statistics obtained and used in this account relate to plants of the original sowings. Thus the final yield of the re-sown plots of February 15 consists of the yield from 64 per cent. of plants sown on this date (Table I) plus 36 per cent. of plants re-sown three weeks later, namely on March 8. These re-sowings may be taken as equivalent to the plants of the regular sowings made on March 8. The final yield of the February 15 sowing was 14·75 bolls per plant, and that of March 8 sowing was 15·35. Thus 64 per cent. of 14·75 plus 36 per cent. of 15·35 gives 14·98 bolls per plant as the final yield of the earliest sowing, after correction for re-sowing. The alterations thus introduced are actually trivial (see Table XIV).

Such consideration of re-sowing is based on the assumption that the re-sown plants are given a fair start in life, though unless hand-watering is practised they are liable to be stunted excessively by water-shortage.

Re-sowing is commonly said to make irregular cotton in the product harvested. The studies which one of us has published elsewhere in the "Development of Raw Cotton" scarcely substantiate this view. The extraordinary identity of the daily variations of flowering in sowings of all ages (fig. 9) indicates that the properties of the lint are scarcely likely to show very conspicuous differences.

The recognition—or, rather, the confirmation—of an optimum sowing date has some economic significance. It is obviously economic waste to put land under cotton, and take the trouble to re-sow it, when, *e.g.*, an extra cut of clover might have been obtained, without losing anything on the cotton. This again is a custom of the fellah, for which he has been stigmatised as an improvident farmer.

The Exhaustion of Soil by Cotton: An Evaluation.

The following evidence drawn from two successive crops of cotton which were grown on the same soil, with intervening fallow, but no manure, shows that the consequent depreciation was scarcely recognisable, even by our methods. At the same time one must not exaggerate the evidence, since it is more than likely that the soil in question—having been but poorly cultivated for some time before we took it over—was near its lower limit of fertility, like the old-established unmanured wheat-plots at Rothamstead.

The water-table of this land is over two metres down in the summer, the soil texture is good, it can endure heavy watering without injury, and is probably capable of being worked up to give twice as heavy a yield as the five kantars which were obtained in these experiments. We had intended to keep this area as a permanent cotton plot, having laid a good foundation for the study of it in the records of these two experiments.

From the results of the two years' work we have plotted in fig. 18 two flowering-curves that ought to be justly comparable.

Both were for plants set out on spacing 2*b* (see Part I of these Analyses); the thick dotted line represents plants sown on March 21, 1912, and the thick continuous line plants sown on March 22, 1913.

It will be remembered that in Part I we pointed out a slight distortion of the flowering-curve due to slight under-irrigation in the spacing experiment. We must also take into account the later rise of the Nile in 1913 as compared with 1912, so that the latter flowering-curve is cut off sooner than the former, and more severely (p. 433). If we further correct for the abnormal rise of the early part of the 1913 curve already mentioned, we arrive at the final result that the "period of maximum rate of the flowering," when the curve remains horizontal under the control of soil-factors, is almost identical in the two years, as indicated by the level of the arrows on the left of the diagram. The actual maximum flowering rates were 0·52 flower per plant per day in 1912 as against 0·47 in 1913.

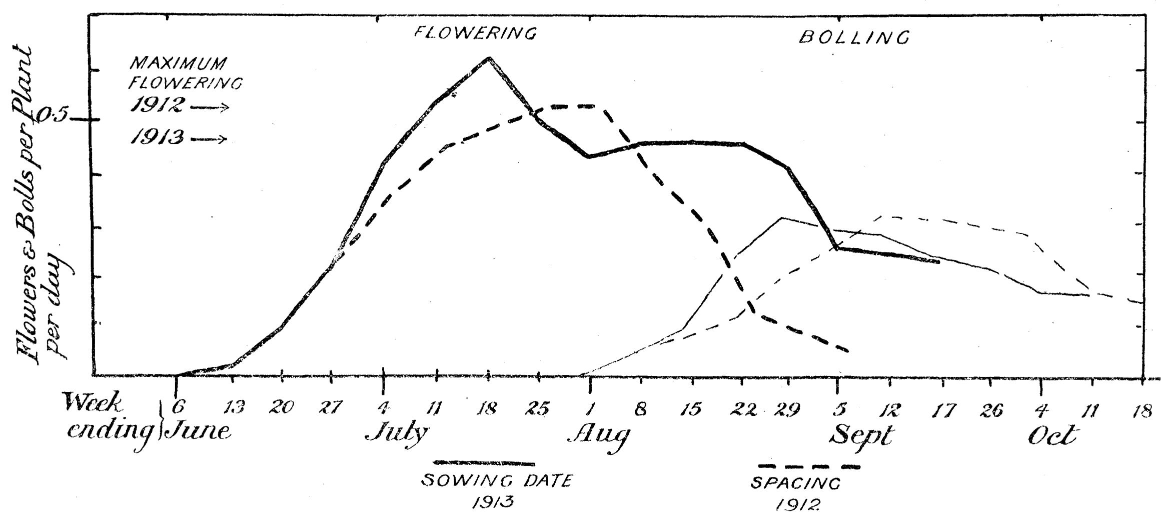


FIG. 18.—Comparison of Crops grown on the same land in two successive seasons without manure.

The result is rather unexpected. Two successive years under cotton, without manure, but with a winter fallow, has only depressed the height of the flowering-curve by 10 per cent., and its area (representing roughly the final yield) by much less.

A further analysis is worth making, because we are assuming so far that all the plants compared in the two seasons were growing on the same land, which was not the case. The sowing-date experiment occupied only the southern half of the land used for the spacing experiment in the previous year, and it might well be the case that this southern half was the more fertile. Fortunately we can pick out, from the scale plans prepared in the two years, two small areas which both bore observation rows of the same kind in both years. These were Plots 32 and 15 of 1912, and Plots (17, 18, 19) and (34, 35) of 1913, respectively. The period of "maximum flowering" in 1912 was during the weeks ending July 26 and August 2 (see Part I), while in 1913 it comprised the weeks ending August 8, 15, and 22. The reasons for these differences in the periods are indicated above. Referring to Table IX of the present communication, and to Tables III and IV of Part I, we can draw up the following statement:—

Year 1912.

Plot.	Spacing.	Holes.	Flowers in week ending—	
			July 26.	August 2.
32*a*	2*a*	84	533	491
15*a*	2*a*	64	350	346
32*b*	2*b*	86	693	706
15*b*	2*b*	74	406	375

Since we saw in the spacing experiment that *a* spacings gave about 10 per cent. less production per plant than the two plants together of the *b* spacing, we can add 10 per cent. to the above figures for *a* flowers, and consider them as having been borne on two *b* plants.

The result then is :—

600 plants produced 4122 flowers in 14 days,
or, 1 ,, ,, 0·49 ,, ,, 1 day.

The maximum flowering rate was thus 0·49 on this selected area in 1912.

Year 1913.

Plot.	Sowing Date.	Plants.	Flowers in week ending—		
			August 8.	August 15.	August 22.
17	Feb. 15 . . .	129	395	434	433
18	March 22 . . .	137	487	542	564
19	April 4 . . .	148	580	668	727
34	March 22 . . .	155	582	583	451
35	Feb. 22 . . .	145	368	341	361
Total		714	2412	2568	2536

The result then is :—

714 plants produced 7516 flowers in 21 days,
or, 1 ,, ,, 0·50 ,, ,, 1 day.

The maximum flowering rate was thus 0·50 on this same area in 1913.

The crops of the two years would thus appear to be practically identical, but it is not quite fair to include sowings of differing dates, and our correction for *a* and *b* spacings may be considered unjustified.

We will therefore reduce the areas compared, but make a more exact comparison, by taking the March 22 sowings of 1913 and the 2*b* spacing of 1912 only. From the data given above we then find :—

1912 : 312 plants produced 2180 flowers in 14 days.
1913 : 292 ,, ,, 3209 ,, 21 ,,

This gives the rates as 0·50 for 1912 and 0·52 for 1913, which is practically the same as before, and shows no evidence of soil exhaustion.

The available data can be dissected still further, however, by considering the two small areas separately, calling them A and B :—

Area A : Plot 32 of 1912, corresponding to Plot 18, 1913.
,, A : ,, 15 ,, ,, ,, 34, ,,

Again using the data given above, we find that—

In 1912 : Area A gave 0·60, while B gave only 0·38.
,, 1913 : ,, B ,, 0·55, and B gave 0·49.

Thus area B was less fertile than area A in both years, but this difference was more marked in 1912. Presumably there was some cause depressing the fertility of B in 1912, from which it escaped in the following year. On consulting the original map of the spacing experiment, on which every plant was marked, we have found that area B was on the margin of an area infested with the "negeel" grass (*Cynodon dactylon*), and that its observation rows had to be picked out so as to avoid the pest, whereas area A was well removed from any such infested patches of soil. This clears up the whole matter; area B is untrustworthy as regards its flowering rate, which should apparently have been 0·54 in 1912.

Area A, on the other hand, is exactly comparable in the two years, and its maximum has fallen off from 0·60 to 0·55 flower p.p.p.d., or 9 per cent., which is the same as the fall shown by the average of the whole area employed in fig. 18. It should, of course, be remembered that the error of comparison on area A by itself is affected by the small number of plants observed, but the probable error from this cause would probably not be more than ±4 per cent., according to other indications.

In any case, the evaluation which we have here performed is sufficient to demonstrate the utility of our methods.

The Effect of Boll-worms: an Evaluation.

As previously mentioned (p. 419), our land at Giza suffered most severely from the attacks of boll-boring larvæ in 1913, the year in question being the worst on record for Egypt in this respect up till that time. Our wide-sown propagation plots, where the principal crop is obtained late in the season, suffered terribly, reducing our seed-production far below the estimated amounts.

The effect on field crop is most clearly shown by the bolling-curves of the sowing-date experiment, where can be traced the absence of all those bolls which failed to ripen as the result of boll-worm attack (p. 437). They do not, on the other hand, point out those damaged bolls which succeeded in opening despite the damage done to them. This could only be obtained by instituting regular observations for the purpose, such as we had hoped to carry out in connection with our ordinary routine.

The data do, however, indicate that our ideas as to the amount of destruction by such pests are likely to err on the pessimistic side (fig. 18).

On examining the bolling-curves for 1912 and 1913, corresponding to the flowering-curves already discussed, it will be seen that the slight water-shortage mentioned as an accidental feature of the spacing experiment in Part I of these "Analyses" had not only checked the flowering slightly, but had also provoked extra shedding. The indication of this lies in the fact that the 1912 bolling-curve comes further away from the 1913 one, and at an earlier stage, than do the corresponding flowering-curves. Beyond this stage, however, the same differences exist as between the flowering-curves, viz., very slight inferiority on the part of 1913. Then a new phenomenon is observed; the 1913 curve does not remain steadily at a maximum after the manner of the 1912 (and other) curves, but falls steadily downwards from the true maximum on September 9.

Since this fall is not shown by the flowering-curve, it must have been due to some cause acting after the flower opened, causing shedding. There can hardly be any doubt as to the nature of this cause, namely, the attacks of boll-worms; the larvæ frequently provoke shedding of the young bolls which they occupy, or may prevent them from ripening properly.

The remarkable feature of this fig. 18 (see also fig. 10) is the low value which it assigns to the amount of direct crop-loss from boll-worm, in an exceptionally bad site and an exceptionally bad year. Even if we assume that the maximum rate of boll-production would have been sustained at so high a level as 0·30 bolls per plant per day from August 27 to October 9, if the boll-worm had been entirely absent, still the area of the bolling-curve (in other words, the total yield) would only have been one-quarter more than was actually the case. Thus this attack of boll-worm in this site and year did not diminish the total crop by more than 20 per cent. of the ideally possible number of bolls.

A loss of 20 per cent. may appear amply sufficient, especially as it does not take account of the number of bolls which succeed in opening, though their contents are partially spoiled, but it sounds a small amount beside the estimates which are frequently made. The reason is, of course, that once the boll-worm has been recognised as abundant, all sins of cultivation and accident are promptly attributed to it. In the evaluation we have made there are no recognisable accidents left unaccounted for.

In discussing the loss in certain districts during another fairly bad boll-worm year (1905) Mr. F. C. WILLCOCKS assesses it at a maximum of 25 per cent. of the total crop, but this authority's caution has not always been imitated. One of us has elsewhere expressed his opinion that the obvious nature of the damage effected by insect pests has caused a disproportionate amount of attention to be given them, as compared with that devoted to the plants on which they act, and the present result—which had not then been noticed—goes far to substantiate this criticism.

It will be evident that our investigation is not destined to introduce into agriculture any novelties in the spacing or date of sowing of Egyptian cotton. On the contrary, it establishes on firm scientific basis that the custom of the fellah is the best under Egyptian circumstances.

GENERAL CONCLUSIONS.

The experiment here described dealt with the yield obtained by sowing Egyptian cotton at different times, both before and after the sowing date conventionally employed.

Forty-five plots were sown, each with an observed group of about 150 plants demarcated in it as an "observation row." The same piece of land was used as for the spacing experiment of 1912, already described in Part I. This land was situate at Giza, Egypt, adjoining the Botanical Laboratory (Cotton Experiment Station) of the Egyptian Department of Agriculture. The supply of irrigation water to each plot was varied according to the requirements of each sowing, and was also varied around the mean estimated requirement from one plot to another of the same sowing. Nine sowing dates were employed, at weekly intervals from February 15 to April 11, five plots being sown each week.

Statistical records were obtained for the field germination, weekly height of the main stem, daily flowering, and weekly ripening of the bolls, or fruits.

The results may be summarised as follows :—

A. *Elimination of Accidents of Season and Soil.*

In our analysis of the components which make up the yield we have evaluated certain effects which were not due to the sowing date, but to extraneous and accidental causes, such as the soil and insect pests. Thus we have incidentally obtained statistical statements of these effects.

B. *Analysis of Effects Due to Sowing Date Alone.*

1. Examination of the results shows the existence of an optimum date for sowing. This date accords nearly with the conventional practice of the native cultivators of the district.

2. This date would appear to be a constant one, from year to year, or practically

so. Sowings made before this date do not gain the corresponding advantage which might be expected, and may be inferior.

3. To explain this result we must assume that some depressant factor is brought to bear on the early seedlings, which has less effect on later sowings.

4. This depressant factor must be primarily an internal one, induced within the plants. Its probable nature and causation are discussed in a separate section of this communication, and summarised on p. 458.

5. Secondarily, the origin of this depressant factor can be attributed to the temperature of the soil, which is the only factor of the environment whose seasonal fluctuations are practically uniform from year to year.

APPENDIX.

Tables of Statistical Data (I–XIV).

Table I.—*Field Germination.*

The following counts were made on April 15–20, supplemented by some earlier notes. They include the number of holes sown in each plot (not merely in the observation rows), the number of these which failed to produce at least one plant from the 12–15 seeds sown in each hole, and the number and percentage (see black squares in fig. 1) of the remaining holes, where germination had been accomplished satisfactorily.

Additional data present the number of holes which germinated successfully on the second watering, having failed initially (p. 460).

The data for the five plots of each sowing are grouped together.

Table I.

Sowing.	Holes sown.	Holes failed.	Holes successful.	Percentage successful.	Successful at second watering.	
					Number.	Per cent.
February 15	808	291	517	64	126	15½
,, 22	821	119	702	85	55	6½
March 1	820	52	768	93½	27	3½
,, 8	809	5	804	99½	—	—
,, 15	860	8	852	99	—	—
,, 22	837	25	812	97	—	—
,, 29	815	11	804	98½	—	—
April 5	820	8	812	99	—	—
,, 12	826	15	811	98 ?	—	—

Note.—A fortnight later many of the plants in the last sowing were "drying off," thus reducing the successful germination to about 93 per cent. (p. 421).

TABLE II.—*The Observation Rows.*

The group of plants observed in each plot was situated on the five central ridges of the plot. The plants were usually in pairs (two plants to the hole), but occasionally only one had survived. Though the error thus introduced was negligible, the actual counts are given below, as the numbers of single and double plants in each sowing, the plots being grouped according to their date of sowing.

It should be noted that the actual sowing was made against gauges laid along the ridges, so that no plant was ultimately more than a centimetre or two out of its correct spacing, viz., 45 cm. apart.

TABLE II.

Sowing.	Plot Nos.	Pairs.	Singles.	Holes.	Plants.
Feb. 15	14, 17, 24, 33, 46	269	56	325	594
„ 22	8, 22, 31, 35, 43	295	55	350	645
March 1	10, 16, 27, 39, 42	336	45	381	717
„ 8	4, 20, 30, 41, 49	330	57	387	717
„ 15	5, 18, 26, 34, 37	363	50	413	776
„ 22	9, 11, 23, 40, 48	352	46	398	750
„ 29	12, 15, 28, 36, 45	344	41	385	729
April 5	19, 21, 29, 32, 44	316	62	378	694
„ 12	13, 25, 38, 47, 50	351	37	388	739

TABLES III–V.—*Observed Height of Main Stem.*

Measurements of about sixteen plants in each plot were made weekly to the nearest centimetre, on the dates given in the Table. The figures given below for each date of sowing thus represent the mean of about eighty plants, expressed in centimetres (see also p. 413). See also schema in fig. 12.

TABLE III.

Sowing.	Height.								
	May.	June.				July.			
	28.	4.	11.	17.	25.	2.	9.	16.	23.
Feb. 15	27·36	30·90	41·01	54·10	61·80	68·64	72·33	78·36	82·77
„ 22	29·35	36·37	47·21	61·65	69·47	77·16	80·20	84·51	87·68
March 1	29·69	36·63	48·64	61·69	67·52	74·44	79·48	84·35	88·08
„ 8	29·13	36·70	48·00	60·54	66·96	73·63	78·06	81·86	84·64
„ 15	31·24	38·86	49·98	63·88	70·68	76·99	81·44	87·90	90·52
„ 22	28·31	34·98	45·30	57·89	67·07	71·19	75·79	81·26	85·36
„ 29	25·61	31·90	44·10	58·28	67·73	73·98	78·46	83·53	87·70
April 5	21·21	26·50	36·75	52·21	61·08	68·99	75·65	80·56	84·02
„ 12	17·93	23·34	31·91	44·38	53·58	61·79	68·96	75·08	80·82

The data in Table II may be grouped into Early, Middle, and Late sowings, three each, as follows.

TABLE IV.

Early	28·13	34·63	45·62	59·15	66·26	73·41	77·34	83·07	86·18
Middle	29·56	36·85	47·76	60·77	68·24	73·94	78·43	83·67	86·84
Late	21·58	27·25	37·59	51·62	60·80	68·25	74·36	79·72	84·18

Over 6,000 measurements of individual plants for their height are summarised in Table IV. The method employed in the measurements was crude (p. 425), and a detailed statement would be of little value. One week's data are figured in the text (fig. 3), and the statistical constants for the first three dates of measurement have been worked out, with the following results (Table V).

It should be noticed that any one sowing has almost the same probable error per cent. in each week, showing that the deviations are real for the particular groups of 80 plants observed, and that the crudity of the method has been practically eliminated by the large number measured. On the other hand, the groups might not have been fair samples of their respective plots, though we have no reason to think this to be the case.

The sudden fall in probable error per cent. from March 8 to 15 is noteworthy, and also the increased irregularity of the last sowing, which should be compared with the note in Table I, and with p. 424.

TABLE V.

Sowing.	Height on May 28.			Height on June 4.			Height on June 11.		
	Mean.	S.D.	P.E.	Mean.	S.D.	P.E.	Mean.	S.D.	P.E.
			p.c.			p.c.			p.c.
Feb. 15	27·36	7·44	18·21	30·90	9·31	20·19	41·01	11·07	18·00
,, 22	29·35	8·94	20·30	36·37	11·15	20·54	47·21	12·68	17·88
March 1	29·69	8·26	18·64	36·63	10·82	19·79	48·64	13·34	18·28
,, 8	29·13	8·87	20·40	36·70	11·42	20·84	48·00	14·34	19·90
,, 15	31·24	7·43	15·93	38·86	9·25	15·93	19·98	11·15	14·87
,, 22	28·31	6·48	15·33	34·98	8·81	16·87	45·30	10·75	15·83
,, 29	25·61	6·29	16·45	31·90	8·82	18·52	44·10	10·98	16·59
April 5	21·21	4·47	14·12	26·50	5·88	14·87	36·75	7·72	14·01
,, 12	17·93	5·13	19·07	23·34	6·49	18·67	31·91	9·37	19·56

TABLES VI–VIII.—*Computed Elongation of Main Stem.*

Computed from the height data in Table III. The difference between the height in consecutive weeks is divided by the number of days intervening, and gives the average elongation rate in millimetres per plant per day for the week ending on the given date. Plotted in fig. 4.

TABLE VI.

Sowing.	Growth (in mm.p.p.p.d.) in week ending on—							
	June.				July.			
	4.	11.	17.	25.	2.	9.	16.	23.
Feb. 15	7·8	14·5	16·4	12·8	9·8	5·3	8·6	6·3
„ 22	10·0	15·5	18·1	13·0	11·0	4·3	6·1	4·5
March 1	10·0	17·2	16·3	9·7	9·9	7·2	6·9	5·3
„ 8	10·8	16·2	15·7	10·7	9·5	6·3	5·4	3·9
„ 15	10·9	15·9	17·4	11·3	9·0	6·3	9·2	3·7
„ 22	9·5	14·7	15·7	15·3	5·9	6·6	7·8	5·8
„ 29	9·0	17·5	17·7	15·7	8·9	6·4	7·2	5·9
April 5	7·6	14·6	19·3	14·8	11·3	9·5	7·0	4·9
„ 12	7·7	12·2	15·6	15·3	11·7	10·2	8·7	8·2

These figures may be grouped as in Table IV (plotted in fig. 5) as follows :—

TABLE VII.

Early	9·3	15·7	16·9	11·8	10·2	5·6	7·2	5·4
Middle	10·4	15·6	16·3	12·4	8·1	6·4	7·5	4·5
Late	8·1	14·8	17·5	15·3	10·6	8·7	7·6	6·3

An approximation to the real growth-rate (see p. 425) may be obtained by taking the grouped figures from Tables IV and VII, and computing from them the percentage increments of height.

The results (plotted in fig. 6) are as follows :—

TABLE VIII.

Sowing.	Percentage increment in week ending on—							
	June.				July.			
	4.	11.	17.	25.	2.	9.	16.	23.
Early	3·30	4·54	3·70	1·99	1·54	0·76	0·93	0·65
Middle	3·51	4·35	3·41	2·04	1·19	0·87	0·96	0·54
Late	3·76	5·42	4·66	2·96	1·74	1·27	1·04	0·79

TABLES IX–XI.—*Observed and Computed Flowering Data.*

The following Table gives the number of flowers opening on each plot during each week *ending* on the given dates.

TABLE IX.

Plot.	Number of plants.	Number of Flowers Opening in Week ending upon— June. 6.	June. 13.	June. 20.	June. 27.	July. 4.	July. 11.	July. 18.	July. 25.	August. 1.	August. 8.	August. 15.	August. 22.	August. 29.	September. 5.	September. 12.	September. 19.	September. 26.	October. 3.	October. 10.	October. 17.
Sowing of February 15. (•)																					
14	111	—	9	65	137	301	455	498	326	292	306	352	395	370	243	255	207	178	186	164	146
17	129	—	13	81	181	412	496	562	416	293	395	434	433	385	271	255	198	172	191	130	121
24	152	2	14	116	262	427	484	474	397	476	587	645	603	502	311	266	240	226	200	116	130
33	61	—	1	14	51	74	133	216	192	150	198	238	230	227	150	124	104	70	70	75	70
46	141	2	14	87	168	339	437	514	453	475	515	527	413	267	143	92	84	66	64	61	58
All	594	4	51	363	799	1553	2005	2264	1784	1686	2001	2196	2074	1751	1118	992	833	714	711	546	525
P.p.p.d.		0·001	0·012	0·087	0·192	0·374	0·482	0·545	0·429	0·406	0·482	0·528	0·500	0·421	0·269	0·239	0·200	0·171	0·171	0·131	0·126
Sowing of February 22. (••)																					
8	148	1	47	176	348	656	695	866	688	530	593	531	507	473	383	334	318	264	270	250	215
22	142	—	9	88	204	428	518	607	472	322	375	448	458	488	373	329	303	250	235	174	150
31	103	—	1	34	94	239	319	339	273	232	278	261	357	320	235	193	182	135	137	114	105
35	145	—	22	87	181	385	474	639	458	353	368	341	361	303	196	132	118	108	118	124	130
43	106	1	25	121	238	423	578	744	605	362	283	277	218	232	164	139	103	124	114	85	84
All	645	2	104	506	1065	2131	2584	3195	2496	1799	1897	1858	1901	1816	1351	1127	1024	881	874	747	684
P.p.p.d.		0·000	0·023	0·112	0·236	0·472	0·572	0·707	0·553	0·398	0·420	0·412	0·421	0·403	0·299	0·250	0·227	0·195	0·194	0·165	0·151
Sowing of March 1. (•••)																					
10	156	—	8	56	145	305	527	556	508	449	471	513	601	556	349	336	284	277	281	227	214
16	139	—	7	151	262	535	569	509	414	363	439	432	413	346	227	230	166	124	136	89	91
27	130	2	15	84	167	411	457	425	516	434	502	493	386	298	222	179	180	126	154	115	78
39	159	4	21	167	319	558	710	864	603	418	427	387	445	419	279	250	159	90	126	98	82
42	133	—	—	74	202	419	512	419	354	371	423	444	545	471	365	321	274	185	183	149	135
All	717	6	51	532	1095	2228	2775	2773	2295	2035	2262	2269	2390	2090	1442	1316	1063	802	880	678	600
P.p.p.d.		0·001	0·010	0·106	0·218	0·444	0·553	0·553	0·457	0·406	0·451	0·452	0·476	0·417	0·287	0·262	0·212	0·160	0·175	0·135	0·119

TABLE IX—(*continued*).

Plot.	Number of plants.	Number of Flowers Opening in Week ending upon—																	
		June.				July.				August.					September.				October.
		6.	13.	20.	27.	4.	11.	18.	25.	1.	8.	15.	22.	29.	5.	12.	19.	26.	3.	10.	17.
								Sowing of March 8. (○)													
4	150	—	2	25	69	193	275	459	598	634	726	618	556	438	334	281	242	180	178	145	137
20	143	—	7	114	282	575	709	763	505	348	328	326	319	364	266	285	261	231	255	226	182
30	138	—	8	83	198	437	562	625	415	294	313	381	501	447	264	258	240	194	218	175	160
41	129	—	13	94	231	434	589	723	546	389	362	393	345	273	184	197	164	124	134	105	89
49	157	—	14	160	368	627	782	876	679	418	243	180	193	177	130	123	89	95	114	77	59
All	717	—	44	476	1148	2266	2977	3446	2743	2083	1972	1898	1914	1699	1178	1144	996	824	899	728	627
P.p.p.d.		—	0·009	0·095	0·229	0·452	0·594	0·686	0·547	0·415	0·393	0·378	0·381	0·339	0·235	0·228	0·198	0·164	0·179	0·145	0·129
								Sowing of March 15. (⊙)													
5	161	—	10	97	225	500	469	658	689	653	687	631	460	342	268	216	161	138	119	105	95
18	137	—	5	51	147	325	453	566	500	430	487	542	564	483	347	284	268	207	185	154	137
26	167	—	3	77	210	434	565	561	305	285	319	411	611	563	365	294	252	231	228	170	152
34	155	—	5	75	208	492	685	824	699	568	582	583	451	354	205	178	82	74	96	113	78
37	156	—	16	112	265	622	731	856	683	580	553	525	431	323	201	173	158	103	121	113	89
All	776	—	39	412	1055	2373	2903	3465	2876	2516	2628	2692	2517	2065	1386	1139	921	753	749	655	551
P.p.p.d.		—	0·007	0·076	0·194	0·437	0·534	0·638	0·530	0·463	0·484	0·496	0·463	0·380	0·255	0·210	0·169	0·138	0·138	0·120	0·101
								Sowing of March 22. (⦶)													
9	146	—	3	51	169	444	560	611	528	464	599	634	616	552	429	404	313	201	241	205	190
11	142	—	9	71	194	396	406	478	490	535	490	439	368	289	204	189	138	96	98	77	89
23	145	—	1	30	114	313	453	535	418	383	548	646	783	685	529	475	428	360	333	246	206
40	157	—	2	56	179	332	363	397	454	505	611	665	592	467	287	249	151	100	114	98	87
48	160	—	4	82	196	437	569	753	701	489	349	281	234	243	149	115	91	90	85	72	77
All	750	—	19	290	852	1922	2351	2774	2591	2376	2597	2666	2593	2236	1598	1432	1121	847	871	698	649
P.p.p.d.		—	0·004	0·055	0·162	0·366	0·448	0·528	0·494	0·453	0·495	0·508	0·494	0·426	0·304	0·273	0·213	0·161	0·166	0·133	0·123

Sowing of March 29. (×)																					
12	138	—	—	16	80	328	423	447	424	520	613	623	652	555	407	352	315	219	223	158	142
15	145	—	—	9	75	227	435	508	337	357	436	482	487	426	276	216	183	156	139	136	113
28	146	—	—	3	32	204	270	371	393	470	533	598	591	540	398	329	209	170	163	126	96
36	154	—	—	22	132	427	521	610	446	419	469	592	673	474	358	254	176	183	156	154	119
45	146	—	—	21	119	343	629	835	767	637	504	436	395	318	203	171	128	122	171	162	181
All	729	—	—	71	438	1529	2278	2771	2367	2403	2555	2731	2798	2313	1642	1322	1011	850	852	736	651
P.p.p.d.		—	—	0·014	0·086	0·300	0·446	0·543	0·464	0 471	0·501	0·535	0·548	0·453	0·322	0·259	0·198	0·166	0·167	0·144	0·127
Sowing of April 5. (+)																					
19	148	—	—	—	7	103	265	313	287	367	580	668	727	573	415	345	241	176	143	111	96
21	121	—	—	—	25	180	281	312	338	479	573	592	586	567	376	334	259	214	184	149	112
29	143	—	—	—	13	130	234	307	415	370	389	487	590	553	331	243	174	120	133	93	78
32	150	—	—	1	20	183	312	432	398	344	393	445	561	544	335	276	188	144	112	97	75
44	132	—	—	1	17	153	327	527	626	602	581	612	533	473	269	215	150	99	95	90	93
All	694	—	—	2	82	749	1419	1891	2064	2162	2516	2804	2997	2710	1726	1413	1012	753	667	540	454
P.p.p.d.		—	—	0·000	0·017	0·154	0·292	0·389	0·425	0·445	0·518	0·578	0·617	0·558	0·355	0·291	0·208	0·155	0·137	0·111	0·093
Sowing of April 12. (Δ)																					
13	111	—	—	—	—	26	152	249	351	432	638	709	714	643	478	332	234	188	136	106	86
25	147	—	—	—	1	81	188	230	233	358	602	704	807	753	478	368	220	166	128	96	73
38	166	—	—	—	4	112	306	445	375	449	603	657	848	695	565	440	334	234	173	108	76
47	160	—	—	—	7	159	339	477	485	447	426	407	373	349	224	176	125	95	84	73	47
50	155	—	—	—	4	60	233	420	467	408	445	484	427	427	244	163	105	89	112	84	80
All	739	—	—	—	16	438	1218	1821	1911	2094	2714	2961	3169	2867	1989	1479	1018	772	633	467	362
P.p.p.d.		—	—	—	0·003	0·085	0·236	0·352	0·370	0·405	0·525	0·572	0·612	0·554	0·385	0·286	0·197	0·149	0·122	0·090	0·070

The plots are grouped according to their sowing dates, and the symbol used for each in the diagrams is given in brackets. Data plotted in fig. 8, etc.

For each group of five plots of any one sowing the total flowers per week is given, as obtained by totalling the (unpublished) daily observations. This figure is divided by the total number of plants observed, and by seven (days in the week) to give the number of flowers per plant per day, abbreviated to "p.p.p.d."

The data are directly comparable with those presented in Tables I–XX in Part I of these "Analyses."

TABLES X and XI.—*First Flower, and Daily Flowering.*

The number of flowering observations taken, plot by plot daily, and embodied in Table IX, amounts to more than 6000 numbers, and the counting of about a quarter of a million flowers. It is doubtful whether the detailed presentation of these figures would serve any useful purpose. We have therefore confined ourselves to the following abstracts :—

(1) Daily means for each sowing, p.p.p.d., presented only in graphic form in fig. 9.
(2) Date of appearance of the first 50 flowers or so in each plot, given in non-tabular statement as Table X.
(3) The daily mean for all sowings grouped from February 22 to March 15, presented in Table XI.

The date of the first flower is an extremely delicate test, so that we have thought it advisable to present the available data in condensed form for the use of other investigators (Table X). The mean first flowers are plotted in fig. 9, inset.

The plots are grouped by their date of sowing. After each plot is given a series of numbers in ordinary type, each being followed by an italic number. The numbers in ordinary type indicate the dates in the month of June upon which flowers were open. The italic numbers indicate how many flowers were open on each date specified. Thus in the first plot of the Table, plot 14, the number 11.*2* signifies that two flowers were open on June 11, being the first flowers to open on this plot.

The record is thus presented until about fifty flowers had opened on each plot.

The variations in mean daily rate of flowering in all the sowings made from February 22 to March 15, and irrigated in a number of different ways (see Chart of Irrigations, p. 417), should be very nearly a correct expression of these variations for the district surrounding the observed plots.

Table XI gives these mean daily rates of flowering p.p.p.d., obtained by totalling the flowers open each day on these 20 plots, and dividing these totals by the number of observed plants, viz., *2855*.

In order to economise space the figures are given in serial groups of seven days. Thus the first line gives the daily rates from May 31 to June 6, inclusive.

The fourth decimal place is only given in the first two lines, being scarcely significant.

Table X.

Sowing of February 15.

Plot 14: 11.*2*; 12.*1*; 13.*6*; 14.*5*; 15.*5*; 16.*12*; 17.*14*; 18.*8*; 19.*15*; 20.*6*.
Plot 17: 7.*1*; 8.*1*; 10.*2*; 12.*3*; 13.*6*; 14.*7*; 15.*11*: 16.*13*.
Plot 24: 4.*1*; 6.*1*; 7.*1*; 9.*2*; 10.*2*; 11.*1*; 12.*2*; 13.*6*; 14.*13*; 15.*6*; 16.*14*; 17.*19*.
Plot 33: 13.*1*; 14.*1*; 16.*1*; 17.*3*; 19.*4*; 20.*5*; 21.*3*; 22.*2*; 23.*4*; 24.*3*; 25.*8*; 26.*7*; 27.*24*.
Plot 46: 3.*1*; 6.*1*; 8.*1*; 10.*2*; 12.*6*; 13.*5*; 14.*6*; 15.*1*; 16.*15*; 17.*8*; 18.*13*.

Sowing of February 22.

Plot 8: 6.*1*; 7.*1*; 9.*4*; 10.*5*; 11.*10*; 12.*8*; 13.*19*; 14.*17*.
Plot 22: 9.*1*; 11.*1*; 12.*2*; 13.*5*; 14.*7*; 15.*6*; 16.*13*; 17.*14*; 18.*10*; 19.*21*.
Plot 31: 13.*1*; 14.*3*; 15.*2*; 16.*4*; 17.*4*; 18.*5*; 19.*7*; 20.*9*; 21.*5*; 22.*9*; 23.*20*.
Plot 35: 8.*3*; 10.*2*; 11.*5*; 12.*3*; 13.*9*; 14.*9*; 15.*13*; 16.*11*; 17.*9*; 18.*12*.
Plot 43: 3.*1*; 8.*4*; 9.*2*; 10.*2*; 11.*2*; 12.*4*; 13.*11*; 14.*6*; 15.*14*; 16.*20*; 17.*17*.

Sowing of March 1.

Plot 10: 11.*3*; 12.*3*; 13.*2*; 14.*4*; 15.*8*; 16.*7*; 17.*8*; 18.*9*; 19.*11*; 20.*9*.
Plot 16: 10.*1*; 12.*2*; 13.4; 14.*16*; 15.*11*; 16.*23*; 17.*20*.
Plot 27: 6.*2*; 9.*3*; 10.*2*; 11.*1*; 12.*2*; 13.7; 14.7; 15.*8*; 16.*15*; 17.*9*; 18.*12*; 19.*14*.
Plot 39: 3.*1*; 4.*1*; 5.*1*; 6.*1*; 8.*1*; 10.*5*; 11.*1*; 12.*3*; 13.*11*; 14.*16*; 15.*14*; 16.*28*; 17.*24*.
Plot 42: 14.*3*; 15.*5*; 16.*3*; 17.*12*; 18.*9*; 19.*17*; 20.*25*.

Sowing of March 8.

Plot 4: 12.*1*; 13.*1*; 14.*2*; 15.*1*; 16.*4*; 17.*4*; 18.*1*; 19.*5*; 20.*8*; 21.*8*; 22.*5*; 23.*6*; 24.*9*.
Plot 20: 12.*3*; 13.*4*; 14.7; 15.*8*; 16.*14*; 17.*14*; 18.*20*.
Plot 30: 8.*1*; 10.*2*; 13.*5*; 14.*10*; 15.*8*; 16.*11*; 17.*10*; 18.*11*.
Plot 41: 10.*1*; 11.*3*; 12.*1*; 13.8; 14.9; 15.*10*; 16.*11*; 17.*17*; 18.*18*; 19.*16*.
Plot 49: 10.*1*; 11.*1*; 12.*2*; 13.*10*; 14.*11*; 15.*14*; 16.*25*.

Sowing of March 15.

Plot 5: 8.*1*; 10.*1*; 11.*1*; 12.*3*; 13.*4*; 14.7; 15.*13*; 16.*15*; 17.*9*; 18.*15*; 19.*16*.
Plot 18: 11.*1*; 13.*4*; 14.*4*; 15.*2*; 16.7; 17.7; 18.*9*; 19.*11*; 20.*11*; 21.*13*.
Plot 26: 13.*3*; 14.*3*; 15.*5*; 16.*11*; 17.*10*; 18.*13*; 19.*19*.
Plot 34: 11.*2*; 12.*1*; 13.*2*; 14.*5*; 15.*2*; 16.*10*; 17.*14*; 18.*18*.
Plot 37: 9.*2*; 10.*1*; 11.*1*; 12.*3*; 13.*9*; 14.*12*; 15.7; 16.*11*; 17.*19*; 18.*20*; 19.*24*.

Sowing of March 22.

Plot 9: 12.*1*; 13.*2*; 14.*10*; 15.*4*; 16.*1*; 17.7; 18.7; 19.*8*; 20.*14*; 21.*10*.
Plot 11: 11.*1*; 12.*3*; 13.*5*; 14.*4*; 15.7; 16.*6*; 17.*14*; 18.*20*; 19.*22*; 20.*10*.
Plot 23: 13.*1*; 14.*2*; 15.*2*; 16.*4*; 17.*3*; 18.*4*; 19.*8*; 20·7; 21·*9*; 22.7; 23.*13*.
Plot 40: 12.*1*; 13.*1*; 14.*4*; 15.*4*; 16.*6*; 17.*8*; 18.*10*; 19.*14*; 20.*10*.
Plot 48: 8.*1*; 12.*1*; 13.*2*; 14·3; 15.*1*; 16.*9*; 17.*22*; 18.*10*; 19.*13*.

Sowing of March 29.

Plot 12: 16.*2*; 18.*2*; 19.7; 20.*5*; 21.7; 22.*5*; 23.*9*; 24.*8*; 25.*13*; 26.*14*.
Plot 15: 15.*1*; 16.*1*; 17.*1*; 18.*1*; 19.*2*; 20.*3*; 21.7; 22.*2*; 23.*12*; 24.*11*; 25.*10*; 26.*11*.
Plot 28: 14.*1*; 19.*1*; 20.*1*; 21.*1*; 22.*1*; 23.*3*; 24.*2*; 25.7; 26.*5*; 27.*13*.
Plot 36: 15.*1*; 16.*2*; 17.*4*; 18.*4*; 19.*5*; 20.*6*; 21.7; 22.9; 23.*14*; 24.*15*; 25.*24*.
Plot 45: 14.*2*; 15.*1*; 16.*2*; 17.*1*; 18.*3*; 19.*6*; 20.*6*; 21.*8*; 22.*9*; 23.*21*; 24.*14*; 25.*21*.

TABLE X—*continued.*

Sowing of April 5.

Plot 19: 23.*1*; 24.*1*; 25.*1*; 26.*1*; 27.*3*; 28.*5*; 29.*10*; 30.*11*.
Plot 21: 21.*2*; 24.*2*; 25.*4*; 26.7; 27.*10*; 28.*12*; 29.*12*.
Plot 29: 21.*1*; 23.*1*; 25.*1*; 26.*4*; 27.*6*; 28.*12*; 29.*7*; 30.*19*.
Plot 32: 20.*1*; 22.*1*; 24.*1*; 25.*7*; 26.*4*; 27.*7*; 28.*7*; 29.*8*; 30.*27*.
Plot 44: 20.*1*; 21.*1*; 23.*2*; 24.*3*; 25.*1*; 26.*3*; 27.*7*; 28.*9*; 29.*10*; 30.*16*.

Sowing of April 12.

Plot 13: 29.*1*; 30.*1*; (July) 1.*2*; 2.*4*; 3.*9*; 4.*9*; 5.*21*; 6.*13*.
Plot 25: 26.*1*; 28.*3*; 29.*5*; 30.*2*; (July) 1.*10*; 2.*15*; 3.*21*.
Plot 38: 24.*1*; 26.*2*; 27.*1*; 28.*3*; 29.*5*; 30.*8*; (July) 1.*16*; 2.*28*; 3.*32*.
Plot 47: 22.*2*; 25.*1*; 26.*1*; 27.*3*; 28.*8*; 29.*10*; 30.*18*; (July) 1.*24*; 2.*33*.
Plot 50: 24.1; 27.*3*; 30.*7*; (July) 1.*9*; 2.*5*; 3.*19*; 4.*20*.

TABLE XI.

	Daily rate of flowering. P.p.p.d.						
Day	1.	2.	3.	4.	5.	6.	7.
Week ending—							
June 6	0·0000	0·0000	0·0000	0·0007	0·0003	0·0003	0·0010
,, 13	0·0003	0·0030	0·0040	0·0080	0·0110	0·0140	0·0420
,, 20	0·055	0·056	0·095	0·090	0·102	0·132	0·145
,, 27	0·134	0·154	0·219	0·176	0·255	0·271	0·319
July 4	0·348	0·361	0·371	0·415	0·543	0·543	0·571
,, 11	0·475	0·485	0·600	0·550	0·431	0·648	0·749
,, 18	0·721	0·778	0·592	0·539	0·718	0·626	0·538
,, 25	0·543	0·545	0·554	0·528	0·530	0·521	0·425
Aug. 1	0·511	0·424	0·308	0·466	0·367	0·426	0·456
,, 8	0·435	0·434	0·384	0·402	0·414	0·537	0·463
,, 15	0·464	0·374	0·442	0·370	0·408	0·457	0·538
,, 22	0·378	0·560	0·407	0·423	0·506	0·470	0·312
,, 29	0·495	0·369	0·441	0·305	0·380	0·363	0·333
Sept. 5	0·307	0·296	0·269	0·294	0·246	0·228	0·236
,, 12	0·251	0·226	0·219	0·285	0·225	0·235	0·214
,, 19	0·230	0·204	0·203	0·223	0·156	0·219	0·167
,, 26	0·141	0·207	0·164	0·128	0·160	0·174	0·166
Oct. 3	0·161	0·172	0·191	0·155	0·191	0·150	0·171
,, 10	0·132	0·141	0·155	0·142	0·125	0·118	0·171
,, 17	0·097	0·137	0·132	0·161	0·109	0·109	0·115

TABLE XII.—*Observed and Computed Bolling Data.*

This Table shows the number of plants in each plot, the number of bolls ripening on each plot in each week, the total number in each week, and the rates per plant per day. This rate p.p.p.d. is thus tabulated for the week *ending* on the date given.

The plots are grouped in fives according to the dates of sowing.

Data plotted in fig. 10, etc.

TABLE XII.

Plot.	Number of plants.	Number of Bolls Ripened in Week ending upon—											
		August.					September.				October.		
		2.	9.	16.	23.	30.	6.	13.	20.	27.	4.	11.	18.
		Sowing of February 15.											
14	111	4	31	45	171	240	160	201	177	146	115	152	64
17	129	7	32	72	236	253	270	305	204	204	232	110	171
24	152	3	21	105	279	249	209	151	218	208	286	226	92
33	61	1	3	10	50	90	140	106	89	171	52	70	98
46	141	—	19	150	211	309	306	302	266	150	138	198	210
All	594	15	106	382	947	1141	1085	1065	954	879	823	756	635
P.p.p.d. .		0·003	0·025	0·092	0·228	0·275	0·261	0·256	0·229	0·211	0·198	0·182	0·153
		Sowing of February 22.											
8	148	13	50	146	335	433	307	360	235	346	272	242	115
22	143	—	7	50	216	306	306	338	322	427	219	174	70
31	103	1	7	10	131	143	189	164	134	134	109	88	89
35	145	4	13	124	255	230	281	262	273	163	121	83	121
43	106	—	16	100	249	377	430	330	252	118	77	126	117
All	645	18	93	430	1186	1489	1513	1454	1216	1188	798	713	512
P.p.p.d. .		0·004	0·021	0·095	0·263	0·330	0·335	0·322	0·269	0·263	0·176	0·158	0·113
		Sowing of March 1.											
10	156	3	26	51	150	242	294	243	206	211	187	226	89
16	139	5	37	161	367	336	249	224	196	200	186	98	155
27	130	2	3	67	145	265	176	224	192	187	301	119	122
39	159	—	16	129	278	463	518	474	295	188	138	281	93
42	133	—	8	82	206	313	300	147	149	116	117	142	180
All	717	10	90	490	1146	1619	1537	1312	1038	902	929	866	639
P.p.p.d. .		0·002	0·018	0·098	0·228	0·323	0·306	0·262	0·207	0·179	0·185	0·172	0·127
		Sowing of March 8.											
4	150	—	10	40	122	188	192	231	209	224	204	227	90
20	143	—	15	127	279	392	334	278	159	148	243	142	76
30	138	2	10	44	249	250	253	279	176	162	159	100	134
41	129	1	19	121	262	406	359	335	314	121	144	285	124
49	157	8	40	214	371	550	418	482	299	88	66	69	162
All	717	10	94	546	1283	1786	1556	1605	1157	743	816	823	586
P.p.p.d. .		0·002	0·019	0·109	0·256	0·356	0·310	0·320	0·230	0·148	0·163	0·164	0·117

TABLE XII—*continued.*

Plot.	Number of plants.	Number of Bolls Ripened in Week ending upon—											
		August.					September.				October.		
		2.	9.	16.	23.	30.	6.	13.	20.	27.	4.	11.	18.
		Sowing of March 15.											
5	161	3	35	92	300	325	267	312	271	247	230	239	72
18	137	1	5	22	188	326	264	338	199	312	221	121	85
26	167	1	10	41	277	315	227	274	171	150	236	154	178
34	155	—	1	45	292	333	434	481	381	293	213	145	171
37	156	—	16	135	332	566	468	432	379	357	187	107	130
All	776	5	67	335	1389	1865	1660	1837	1401	1359	1087	766	636
P.p.p.d. .		0·001	0·012	0·062	0·255	0·344	0·306	0·338	0·258	0·250	0·200	0·141	0·117
		Sowing of March 22.											
9	146	—	11	43	210	319	259	277	231	269	215	201	131
11	142	1	16	82	255	338	182	309	271	266	206	208	165
23	145	—	2	32	86	261	263	286	369	249	204	252	110
40	157	1	15	124	226	237	222	193	126	251	191	414	79
48	160	—	4	109	212	385	387	520	335	146	85	114	90
All	750	2	48	390	989	1540	1313	1585	1332	1181	901	1189	675
P.p.p.d. .		0·000	0·009	0·074	0·188	0·293	0·250	0·302	0·254	0·225	0·172	0·226	0·129
		Sowing of March 29.											
12	138	—	2	37	126	353	152	217	194	312	210	215	176
15	145	—	—	22	121	218	204	260	221	162	161	183	119
28	146	—	2	11	110	164	158	241	197	206	279	182	184
36	154	—	—	36	167	383	402	381	261	264	214	100	209
45	146	—	2	45	202	340	386	372	290	165	136	124	45
All	729	—	6	151	726	1458	1302	1471	1163	1109	1000	804	733
P.p.p.d. .		—	0·001	0·029	0·142	0·286	0·255	0·288	0·228	0·217	0·196	0·157	0·143
		Sowing of April 5.											
19	148	—	—	2	43	132	167	222	168	185	308	164	104
21	121	—	—	6	87	171	167	237	244	213	199	119	302
29	143	—	—	8	84	139	139	266	277	214	167	135	243
37	150	—	—	3	65	150	239	267	132	246	163	188	209
44	132	—	—	7	63	160	303	313	375	235	205	214	140
All	694	—	—	26	342	752	1015	1309	1196	1093	1042	820	998
P.p.p.d. .		—	—	0·005	0·070	0·155	0·209	0·270	0·246	0·225	0·215	0·169	0·205

TABLE XII.—*continued.*

Plot.	Number of plants.	Number of Bolls Ripened in Week ending upon—											
		August.					September.				October.		
		2.	9.	16.	23.	30.	6.	13.	20.	27.	4.	11.	18.
		Sowing of April 12.											
13	111	—	—	—	6	71	106	164	100	310	301	179	199
25	147	—	—	—	54	87	114	115	144	212	315	261	88
38	166	—	—	—	32	121	252	276	216	224	194	211	167
47	160	—	—	9	64	202	260	342	303	110	108	233	202
50	155	—	—	2	23	140	216	342	249	140	122	161	253
All	739	—	—	11	179	621	948	1239	1012	996	1040	1045	909
P.p.p.d. .		—	—	0·002	0·035	0·120	0·183	0·240	0·196	0·192	0·201	0·202	0·176

TABLES XIII and XIV.—*The Conventional Pickings and Final Yield.*

These are computed from the data in Table XII, the number of bolls for all plots of a given sowing being added together, up to the dates selected (see p. 438), and divided by the number of plants.

The pickings are thus expressed as the number of bolls per plant (see Part I).

The approximate dates on which five bolls per plant had been ripened are also given. Data plotted in figs. 1 and 12.

TABLE XIII.

Sowing.	Pickings.			Total.	Five bolls ripe.
	First.	Second.	Third.		
Feb. 15 . .	6·17	4·87	3·72	14·75	Sept. 2
,, 22 . .	7·32	5·97	3·14	16·43	Aug. 30
March 1 . .	6·82	4·53	3·39	14·72	,, 31
,, 8 . .	7·36	4·89	3·11	15·35	,, 30
,, 15 . .	6·85	5·93	3·21	16·00	,, 31
,, 22 . .	5·70	5·46	3·69	14·88	Sept. 3
,, 29 . .	4·85	5·00	3·38	13·20	,, 9
April 5 . .	3·07	5·18	4·12	12·39	,, 13
,, 12 . .	2·38	4·39	4·05	10·80	,, 18

Correction for Re-sowing.

All plots were re-sown three weeks after their original sowing to the extent indicated in Table I. The calculated effect of this is as follows (see p. 414).

TABLE XIV.

Sowing.	Pickings.						Corrected total. (Original figure in brackets.)
	First.		Second.		Third.		
	Original.	Re-sown.	Original.	Re-sown.	Original.	Re-sown.	
Feb. 15 . .	39·5	26·5	31·2	17·6	23·8	11·2	14·98 (14·75)
,, 22 . .	6·22	1·03	5·07	0·89	2·67	0·48	16·36 (16·43)
March 1 . .	6·37	0·43	4·24	0·41	3·17	0·28	14·90 (14·72)

Remainder practically identical with figures in previous Table, the amount of re-sowing being less than 3 per cent.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES