PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Analyses of Agricultural Yield. Part III. The Influence of Natural Environmental Factors upon the Yield of Egyptian Cotton

W. Lawrence Balls

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V. *Analyses of Agricultural Yield.* Part III.—*The Influence of Natural Environmental Factors upon the Yield of Egyptian Cotton.*

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INTRODUCTION: THE FACTORS AT WORK.

The aim of the present communication is to study the operation of various environmental factors in their effects on the yield-curve of Egyptian cotton, as shown in the existing data for analysed yield obtained by the author's methods.

Of such factors we have especially examined the spatial one, and the sowing-date, in Parts I and II, together with the action of a boll-destroying insect. To these factors the present account adds more particular discussion of the effects of soil-fertility (165, 187, 205), of soil-texture, as shown in the effects of a "hard-pan" (165, 184), of soil-depth (193), and shortage of soil-water (167, 169, 199); of the effects of lixiviation of the upper soil by over-watering, and its converse (205); of the effects of weather (174, etc., 185, 188), and of climate (187), the latter being shown by way of soil temperature; of defoliation by leaf-eating insects (174), and finally, of the effects of root-asphyxiation induced by a rise of the water-table (165–175, 191–197, 200, 204, and 207).

The data available comprise not only those collected by the author and Mr. HOLTON at Giza, from 1909 to 1913, but also the results obtained by other workers in five other sites. It will be convenient to make a list of these at once, since the names will recur frequently throughout the communication. It should be understood that although, in most cases, some experimental treatment was being given, yet the data represent the behaviour of a true field crop in every case cited, the general cultivation of the observed plots being conventional.

Data obtained at Gīza, near Cairo.

Terraces.—The Terrace Experiment, 1909, 1910, and 1911.

Spacing; Sowing Date.—The Spacing and Sowing-date Experiments, 1912 and 1913.

Data obtained near Gīza.

Talbīa.—The Irrigation Experiment by the Survey Department at Talbīa, 1912.

Data obtained in other Parts of Egypt.

Gemmáiza.—The "Strip Experiment" on the Water-table by the Survey Department at Gemmáiza in the Middle Delta, 1911.

Sálaka, Mit Khaláf.—The Irrigation Experiments by the Survey Department at Sálaka, and at Mit Khaláf, in the Middle Delta, 1913.

Neguīla.—The Variety Trials conducted by HADDAD BEY for the author at Neguīla, in the extreme North-Western Delta, 1913.

In addition to these we shall make use of some miscellaneous data obtained by the author at Gīza and at *Korashīa* (near Gemmáiza), during the work of propagating pure-strain seed into bulk for distribution.

The study of these data can be confined in the main to the curves which show the daily rate of flowering, since we have seen in the two preceding Parts that flowering is the main determinant of yield, but in order to avoid misapprehension we shall briefly discuss the accidental deformations of the bolling-curve from that form which the flowering-curve would lead us to anticipate.

When studying the flowering-curve we shall deal with its three main periods, with the existence of which we have become familiar in Parts I and II—namely, the period of rise, followed by the period during which the curve remains horizontal at a maximum, and the concluding period of curtailment. The ideal form is clearly visible in curves which have been smoothed, either by taking weekly averages, or by the more precise method of computing successive five-day means. Being thus familiarised with the form of the curve under conditions of cultivation which were as favourable as was practicable, we shall be able in the present communication to take into account a greater variety of cultural conditions, producing various deformations of the curve from this ideal form.

But in Part II we also noted that the flowering-curve displayed remarkable and sudden fluctuations from day to day, and that these daily fluctuations were not accidental. In this Part we shall discuss the causes of these sudden movements, so far as the available evidence will permit. By comparison of this evidence we shall find definite indications that these fluctuations are not mere local manifestations, but that they are shown in varying degree simultaneously by all the cotton plants throughout the Delta of Egypt, thus indicating that our results have some general significance in relation to the cotton crop of Egypt as a whole, and are not merely isolated and particular in their interest.

To obtain such general significance it behoves us to take into careful consideration all factors of the environment in each of our available experimental sets of data, even though some may appear trivial, since these data have been obtained in a few sites only, and do not of necessity represent fairly the crop of the whole country; the geographical position of a plot, its date of sowing, spatial allowance, dates of irrigation, etc., may all be important, but in order to avoid encumbrance with these details, most of them have been confined to the Appendix. Of course, the ideal method would have been to obtain data from a number of permanent Observation Stations, so scattered over the country as to provide a fair sample of the whole, and preferably subjected to the ordinary cultivation and irrigation *régime* of the site and season. It should also be remembered that for our present critical purpose no data of non-analysed yield are of any use.

It might be thought that such an analysis as we propose to make would be hampered by "seasonal factors," so it is perhaps worth while at the outset to call the reader's attention to the fact that there is no seasonal factor left, as such, on the completion of our analysis. Certain peculiarities of any one season may leave an impress on the crop; of such are a late or early flood, or a hot day in the spring, but these are not "seasonal" in any vague sense.

It remains to outline the method of treatment given to the data in this presentment. The logical method would be to take factor by factor and discuss the operation of each one separately. Reference to the Appendix will show that such treatment would be much too lengthy. The converse method has therefore been adopted, by classifying the data and making a factorial analysis of them; thus we have dealt with the various causes which may influence the rise of the flowering-curve by bringing together all our data on this matter, and then showing how the date and rate of the rise have been controlled by soil-temperature, soil-fertility, sowing-date, water supply, and so forth.

As a preliminary to this classification of the data for discussion we have made an initial presentment of it in historical sequence and graphic form (figs. 3–7) with full descriptive legends on the page opposite to each figure. This arrangement is the most compact and easy of reference possible with such a mass of data, and we would call the reader's attention to the fact that these legends, though printed in small type, are an essential part of this communication, and are not merely repetitions of statements made elsewhere in the text.

Data Available for Analysis.

It is not necessary to deal separately with the methods employed in procuring the data, as they were simply variations on those described in the two preceding Parts. It is fortunate that the flowering records were obtained daily in 1909, though their significance was not then fully understood, so that in the two following years the flowers were only counted once a week. The Survey Department made flower-counts on alternate days only. Bolling data were obtained weekly in almost every case, and daily counts were initiated in 1913. Growth-curves for the main stem were taken daily in the Khedivial Agricultural Society's garden at Gezira (Cairo), in 1911, and in field crop at Giza in 1912 and 1913.

The principal data are those obtained at Giza, on two sites separated by an interval of only 200 metres. The first of these was "The Terraces," described below, and used during 1909, 1910, and 1911. The other was the land employed for the experiments described in the two preceding Parts.

Some 2 kilom. away from the Giza sites, on the road to the Pyramids, the Survey Department conducted the Talbia Experiment in 1912, concurrently with the Spacing Experiment.

At various sites in the Middle Delta, only a few kilometres apart, were obtained the data from Gemmaiza (1911), Korashia propagation plots, Salaka, and Mit Khalaf (1913), the two last and the first also being Survey Department experiments.

Lastly we have the set of data due to the voluntary assistance of GABRIEL HADDAD BEY, in 1915, from his farm at Neguila. This site is in the extreme north-west of the Delta, not far from the Mediterranean, in a cooler climate, on light sandy soil, and in all respects a marked contrast to Giza. The data are therefore particularly useful.

The Terraces at Giza merit separate description before we proceed to examine in detail the actual data obtained.

Description of the Terraces at Giza.

The design and construction of the Terraces was due to the author's former colleague, Mr. F. HUGHES, and the Khedivial Agricultural Society. The object of the experiment was to ascertain whether, as the present author had reason to believe, the autumnal rise of the water-table injured the cotton plant very seriously. By excavating some land into a series of terraces, and growing crops on these terraces, Mr. HUGHES hoped to show that the crop on the lowest terrace would suffer most, since its roots would be immersed and asphyxiated sooner and more extensively than those of the crops on the higher terraces, while the uppermost terrace would be affected last and least.

The experiment was in part a failure, since the non-analysed plot yields obtained by Mr. HUGHES were disturbed by certain extraneous causes, while the analysed data which the author obtained from observation rows on each terrace could not be fully interpreted at the time. This interpretation has now been made possible by subsequent research, with most useful results, since they not only provide the demonstration of water-table effect anticipated by Mr. HUGHES, but other information also.

The original Terrace site was a piece of land 42 metres long and 10 metres wide. Past the north end of this flowed a field water-channel, usually carrying water to adjacent land, and to the Terraces when necessary. This site was excavated to form the Terraces at the end of 1908.

An area of 25×10 metres at the north end was demarcated as Terrace I, its surface-level being unaltered. The remaining portion was excavated to form three more Terraces (II, III, and IV) in steps of 40 cm., each one forming a plot 8×10 metres. Terrace IV was thus the lowest, and its surface was 120 cm. below that of Terrace I.

The treatment given to the soil should be noticed carefully. In order to provide a good seed-bed the top $\frac{1}{2}$ metre of soil was removed from the whole area before excavation began. On Terrace I it was simply replaced; in other words, this terrace was merely hoed to a depth of $\frac{1}{2}$ metre. On the remaining terraces it was carried away to the side of the plot, and not replaced until 40, 80, or 120 cm. of soil had been excavated, thus forming the arrangement shown in figs. 1 and 2. It is clear that the stratum of soil at a depth of $\frac{1}{2}$ metre below the finished surface in each of the terraces must have been consolidated to some extent by the naked feet of the labourers; the hardness of the "pan" thus formed would have been closely similar in II, III, and IV, but much less in I, where the $\frac{1}{2}$-metre stratum could not have been trodden upon to the same extent. We shall see that the existence of this "hard-pan" played an important part in modifying the form of the yield-curve.

The soil having settled in place during the winter, it was well manured for the 1909 crop. No further manure was applied, so that a soil-exhaustion effect might be expected in 1910 and 1911.

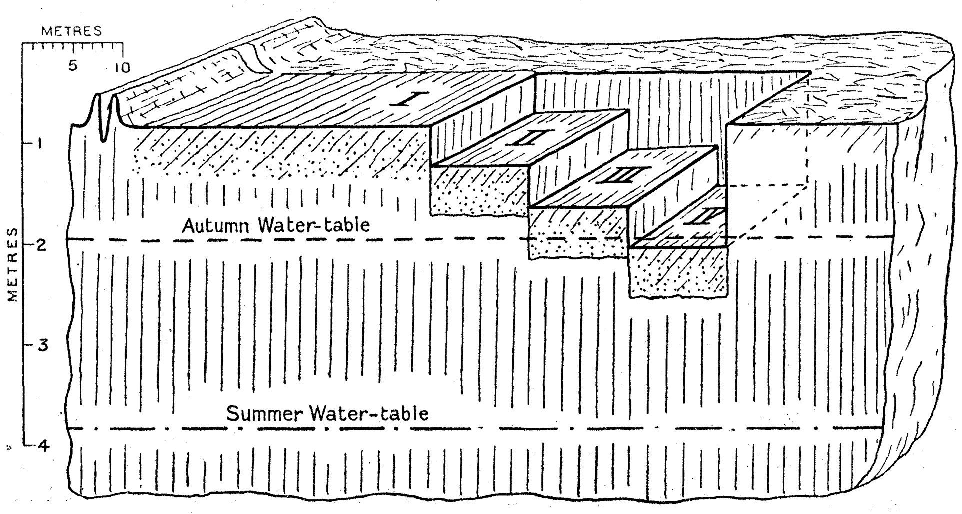

FIG. 1.—The Terraces: Giza, 1909–1911. Diagrammatic view-section.

The dates of irrigation are given in the Appendix, but it should be noticed that the first few ridges at the north end, adjacent to the irrigation channel, would tend to obtain more water than the rest, and actually obtained water by seepage when none had been given deliberately to the rest of the plot. The existence of this seepage was a fortunate accident, which greatly increases the utility of the data obtained in 1911.

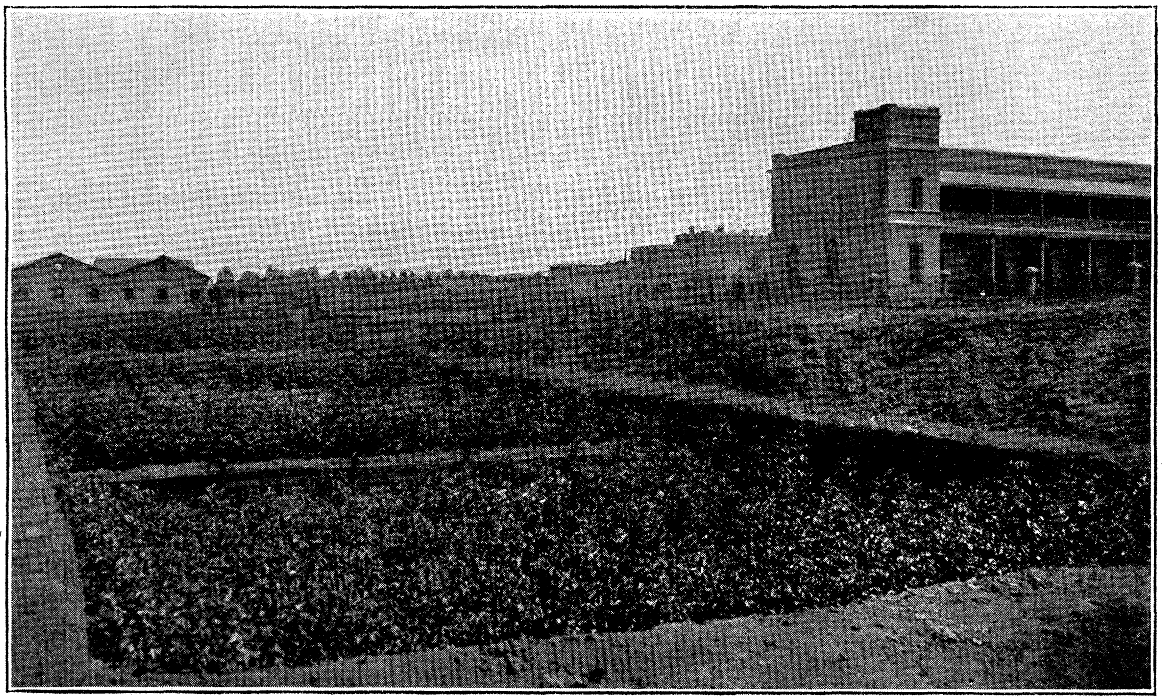

FIG. 2.—The Terraces: Giza, 1909–1911.

Photographed in June, looking north, over Terrace IV towards Terrace I.

The land in the immediate vicinity was left fallow. Outside this, again, lay the author's experimental plot for investigations in Genetics.

Another difficulty which hampered interpretation of the results at the time lay in the erratic behaviour of the tube-wells which had been sunk in Terraces I and IV to measure the movements of the water-table. Both were untrustworthy; one was bedded in a layer of impervious clay, while the other tapped a stratum of sand which was not in direct connection with the surface soil wherein the roots were growing. Certain supplementary observations were therefore made in 2-metre bore-holes, but our knowledge of the movements of the water-table on the Giza site was not then so complete as it is now.

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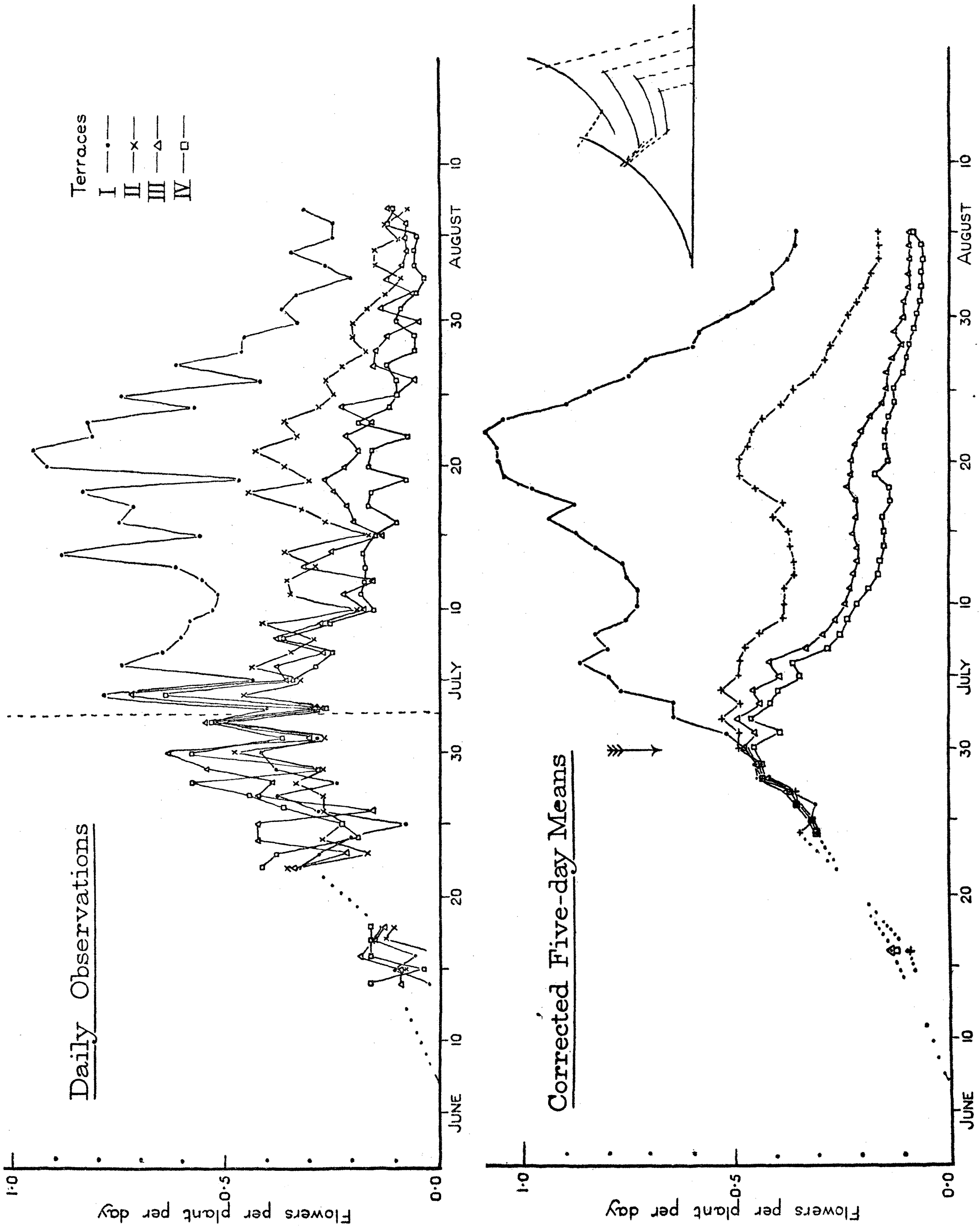

FIG. 3.—Season of 1909. Site: The Terraces at Giza. Flowering Curves.

FIG. 3.—SEASON OF 1909.

These data have been discussed elsewhere in the form of weekly totals, and with an imperfect realisation of the water-table conditions. ('The Cotton Plant in Egypt,' p. 73.) Obtained on the Terraces at Giza (p. 161), from observation rows demarcated in the plots prepared by Mr. F. HUGHES.

Sown in the middle of March. Irrigated normally. The observation rows at first consisted of only one 10-metre ridge containing about 20 holes in each terrace. On July 2 the size of the observation rows was trebled by including adjacent ridges, because the daily fluctuations in flowering were clearly erratic, the significance of this not being then understood.

Records of flowering begun on June 14. Data for June 19–21 have been lost. Photographed (fig. 2) on July 10. Flowering observations continued daily until December 1. Bolls counted weekly. Shedding of leaves noted as being abundant in lower terraces on July 31; at this date the plants were smaller in the lower terraces. Final yield about 400 lb. of lint per acre on Terrace I, and 200 lb. on Terrace IV.

The rapid curtailment of flowering at the end of July was at the time imagined to be normal. This detail shows how little understanding we had gained by non-analytical observation of the crop. The daily observations appeared confusing, and were treated at the time with corresponding diffidence.

The erratic data obtained from the single-ridge observation rows before July 2 (dotted vertical line) become much smoother when the effective size of the rows is increased by computing successive five-day means (lower diagram). They are then parallel in all four terraces, and this we know now to be the rule for young plants, even under less uniform conditions than those which Mr. HUGHES had been at such pains to ensure. A further correction is needed, for the early flowering rates in III and IV are clearly higher than in I or II; this discrepancy has since been traced (with the help of the Spacing Experiment and by a field note recording inferior germination in the lower terraces through over-watering down-hill) to the "per plant" method of computation. We were not then aware that a pair of plants in one hole produced little more than a single plant, so the number of pairs and singles was not recorded. After July 2 the total numbers of plants observed were: I, 118; II, 120; III, 100; IV, 109; since all ridges were equal in length these numbers themselves indicate a deficit of paired plants in III and IV. Altering the numbers of plants accordingly, and re-computing, the data plot out as "Corrected Five-day Means" in the lower half of the figure.

These are clearly reliable. All terraces are identical till the end of June. Then, very suddenly, their curves separate (arrow), rising to independent maxima, which are reached first in IV and last in I. From this maximum each falls away, to rise again to a second maximum about July 20. Curtailment follows, and it affects Terrace I the last, while in IV the second maximum is only indicated by a check in the fall of the curve.

The following explanation of the movements may be given. Until the roots were 50 cm. long they occupied similar soil in all four Terraces, and all the plants grew alike. On reaching the "hard-pan" (p. 162) the root-function experienced a check, due perhaps directly to the consolidated state of the soil-particles or to accumulation of salt during the exposure of this stratum to evaporation, or perhaps to a "floating" water-table. Whatever may have been the proximate cause, it produced effects similar to those of water-shortage, and least severe in I, where the soil had been least trodden upon. In II, III, and IV the effects were identical, and the apparent differences between these three are due to the next factor which operated.

Escaping from the trodden stratum the roots resumed their normal function, and the flowering-curves begin accordingly to resume their rise, but the angle of inclination of this rise varies with the fertility of the soil in which the new roots are growing. The compounding of these rising curves with the falling ones due to the previous check gives rise to the ostensible differences between the first maxima.

It would seem that the true maximum has been attained, and that the curves have remained horizontal for a day or two (*e.g.* at 0·8 flower p.p.p.d. in I, "Daily observations") when the curves are suddenly curtailed. For the present it suffices to note that this coincides with the rise of the water-table as shown in surface borings, and is due to the root-asphyxiation thus produced. It is therefore shown last in I, and sooner by lower terraces. The demonstration of this effect was the prime object of the experiment; at the time, we imagined that we had failed.

The marginal sketch of intersecting curves illustrates the operation of these various factors. First comes the uniform rise of flowering common to all four terraces; this is cut at two different intensities by the effect of the trodden soil; these two are counteracted by the resumption of flowering in soils of four different degrees of fertility, and these four are finally intersected successively by the root-asphyxiation effect.

It remains to add that the root-depth on July 1 is more than the 50 cm. which our interpretation seems to indicate. This apparent discrepancy is due to the fact that flowering is pre-determined, and will be duly discussed later.

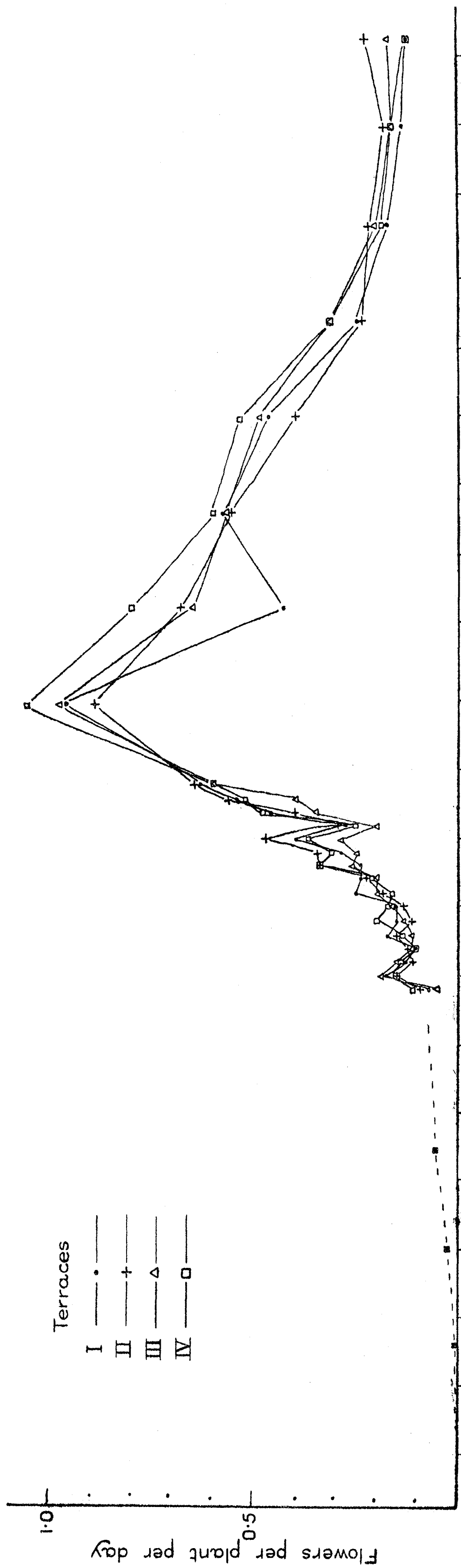

FIG. 4.—Season of 1910. Site: The Terraces at Giza. Flowering Curves.

FIG. 4.—SEASON OF 1910.

The Terraces were not studied so carefully during 1910 and 1911, because the 1909 results had seemed to be almost negative.

The chief features of 1910 on the Terraces are: no further manuring, and deprivation of water during June. The curves show soil-exhaustion, delayed maturity of the crop through water-shortage, and the complete disappearance of any hard-pan effect.

Sowing made on March 20. Irrigated May 5 and May 29; then an *interval of* 37 *days* to July 5; July 30, August 29, and September 24. No manuring, but winter fallow. First flower on June 7 as in previous year. Flowered feebly at first, and the crop seemed to be late. Scattered flowering observations till July 9, then daily till July 24, thence weekly till October. No bolling recorded. Weekly collection made of all shed buds, flowers, and bolls. ('The Cotton Plant in Egypt,' p. 68.) Pickings made on September 16, October 1 and October 28, showed the yield of all four terraces to be practically identical, totalling about 430 lb. of lint per acre, but IV was slightly the best. Weekly records of height were also taken.

Observation rows comprised the whole Terrace of II, III, and IV, together with the southern one-third of Terrace I.

The flowering-curves as shown begin at the usual time but fail to rise normally, and, effectively, the rise has not started until July 15, a month late. The parallelism of the four terraces is fairly good, *e.g.*, July 10 and 21. The delay of the rise was ascribed at the time to "a late season"; in reality it was caused by water-shortage during June, and the recovery after watering on July 5 is due to removal of the Depressant Factor (Part II) and to Pre-determination. The sharp peak on July 30 has no particular significance; probably it was merely a day on which flowering was exceptionally rapid.

The true maximum height of the flowering-curve lies near 0·6 flower p.p.p.d., which is lower than in the previous season, and this is due to soil-exhaustion. It might be noted that the maxima in the Spacing and Sowing-date experiments were lower than this figure.

From August 20 to 27 there is a distinct curtailment, without recovery, similar to the root-asphyxiation effect of the previous year, but much later in the season, which agrees with the later rise of the water-table in 1910.

Soil-differences between the four terraces are quite obliterated. (The higher final yield in IV can be traced to a smaller amount of shedding, due to its low-lying situation, which obtained more water for it.) The soil had presumably become less heterogeneous: the penetration of the roots in 1909 had broken up the trodden "pan," and the movements of soil-water—by evaporation, transpiration, irrigation, and by immersion of the sub-soil in the water-table—had eliminated the differences in the distribution of nutrient salts which were found at different depths in 1909.

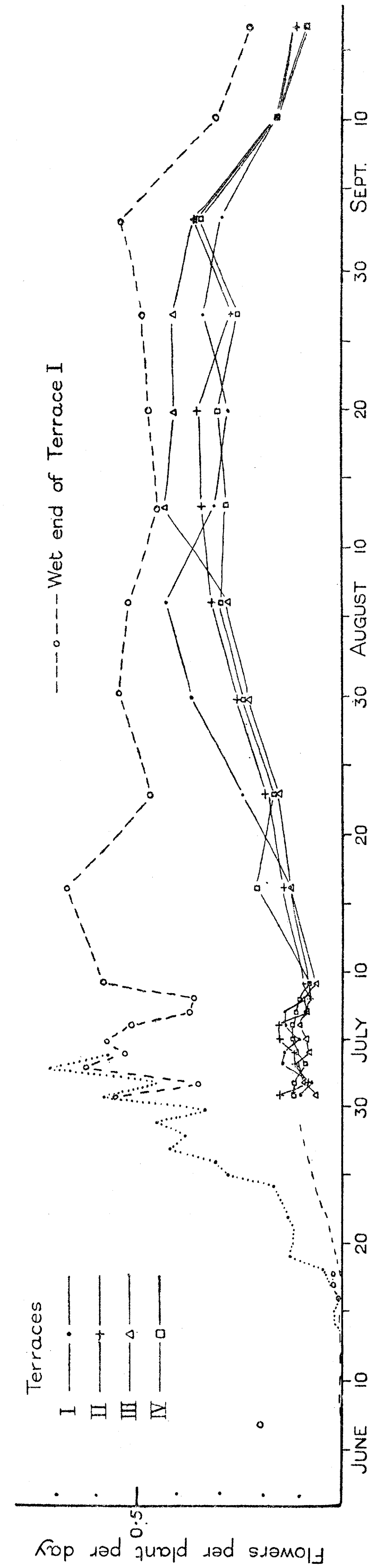

FIG. 5.—Season of 1911. Site: The Terraces at Giza. Flowering Curves.

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FIG. 5.—SEASON OF 1911.

The Terraces were employed for testing varieties, together with Pure Strain No. 77. Each of the 60 ridges was separately sown, and the data from each were kept separate. Thus the behaviour of the whole plot can be analysed ridge by ridge, as well as by terraces. Ridge No. 1 was next to the irrigation channel on Terrace I; ridges 30–39 on II; 40–49 on III; and 50–60 on IV. Comparing this with 1910, ridges 20–29 corresponded with the area taken to represent Terrace I in that year; this same area is therefore used again in the present figure, but an additional curve is plotted which represents the flowering of ridges 1–5.

The chief features of the season are: the third year's cultivation without manuring or other crops, and extreme water-shortage over most of the area of the Terraces.

Sowing was delayed until April 3, after winter fallow. Field germination complete on April 10, the soil being rather caked in III and IV through the difficulty of restricting the supply of water down-hill. Irrigated May 4 (similar to 1910), and then a 54 *day interval without watering* until June 27. Another long interval till August 3, then August 22, and September 12. The water-table was very late, and very slow in rising, and the curtailment of flowering is proportionately delayed.

Flowering began on June 16, the sowing having been late. Flowers were recorded before this date on "Hind weed" plants, but not on any Egyptian plants. The first flower on the adjoining Genetics plot for any Egyptian plants was on June 14. Daily observations of flowering were taken from July 1–9, with intermittent observations previously, and weekly ones afterwards. Bolling-curves were taken.

Each ridge constituted a separate observation row.

The curves I–IV show a slow and late rise. Their similarity is poor, indicating soil-differences between various terraces, such as would naturally result under deficient water-supply. The maximum is lower than in 1910. All the curves come together in the curtailment period (September 3–10) presumably under the influence of the water-table. They are not instructive until we compare them with ridges 1–5, where the plants were obtaining additional water by seepage from the irrigation channel. We there obtain a curve which is obviously true, and had already risen to the maximum (at 0·5 flower p.p.p.d.) when the flowering record first began, and which maintained this height until the curtailment period.

To complete the curve the dotted line showing its rise has been interpolated. This is computed from the total flowering of all the Egyptian plants on the Genetics plot close by, which was wide-sown, but watered normally; we know from the Spacing Experiment that this interpolation is legitimate, since the early part of the flowering-curve is the same in both wide-sown and field-sown populations. From the composite curve thus completed we can see the effect of water-shortage in May and June on the other curves. This is an important point in comparison with the negative results of the Survey experiments on water supply.

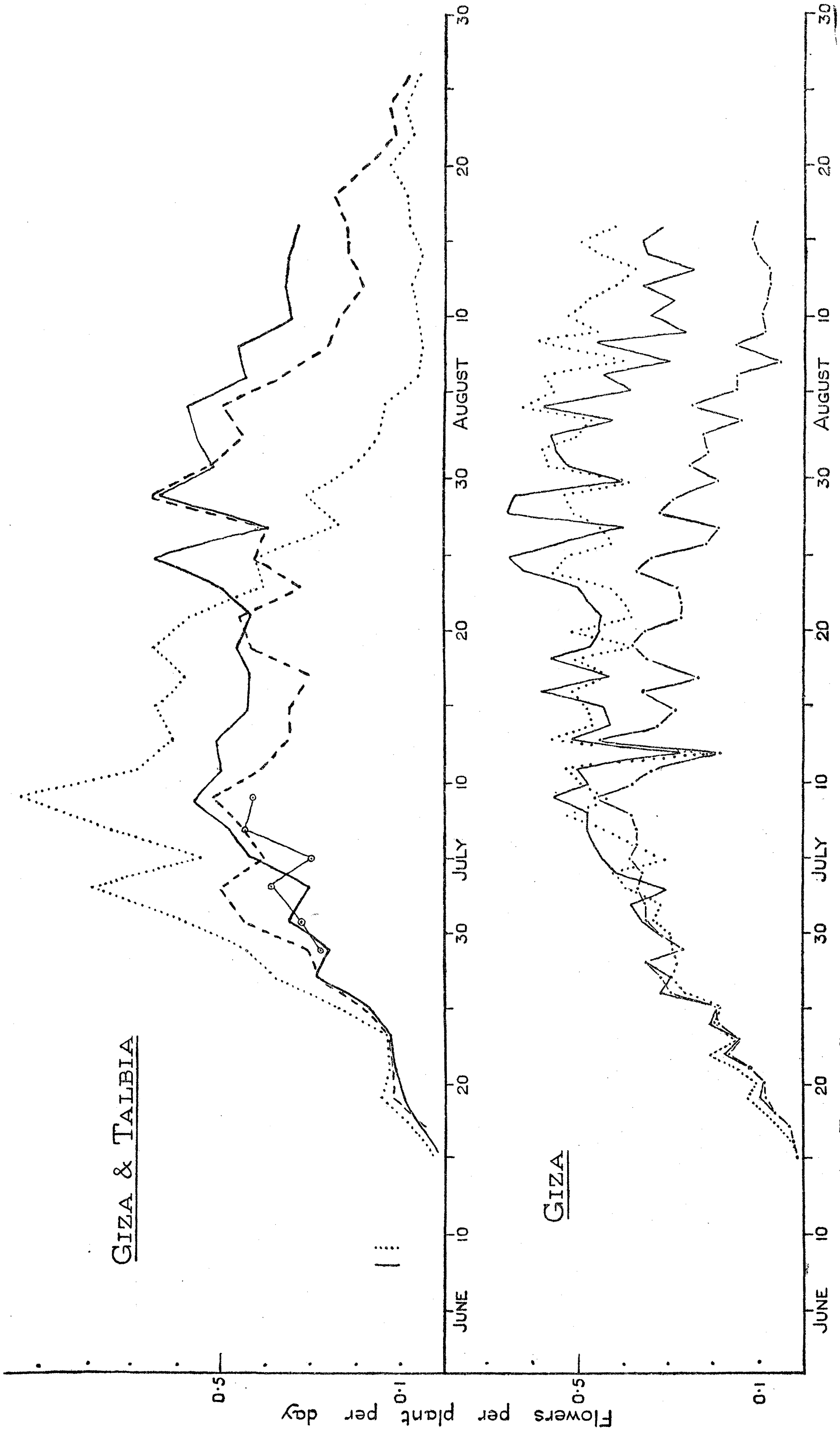

Fig. 6.—Season of 1912. Sites in Giza district. Flowering Curves from Giza and Talbia.

Above—
- ——— Giza, Spacing 2*b*.
- – – – Talbia Wet (2064m³ water, May–Sept.)
- ········ Talbia Dry (931m³ ,, ,,)
- ⊙——⊙ Giza (Field Sowings).

} Alternate Days.

Below—
- —·— Spacing 1*b*; 75 cm. × 30 cm.
- ——— Spacing 2*b*; 75 cm. × 45 cm.
- ········ Field Sowings; 75 cm. × 35 cm.

} Daily Observations at Giza.

FIG. 6.—SEASON OF 1912.

Much of the interpretation given to the preceding data was not possible until 1913. In 1911 there had been observation rows at Gemmaiza, but they were too defective to be instructive (p. 193). With the 1912 season the Giza data gave a hint as to their general significance, by comparison with the Survey Department's experiment at Talbia, near by.

In this figure the *daily* flowering of Spacing **2b** (not published in Part I) is compared with that of **1b**, with an adjacent "field sowing plot" of strains and varieties which were being tested, and with the "wet" and "dry" groups of plots at Talbia. The latter observations were taken on alternate days only, and the data for Spacing **2b** are therefore also plotted for the same days only, in the upper half of the figure.

There is a close general resemblance between the three Giza curves, although GFS was under a slightly different irrigation *régime* from the others. G **2b** and G **1b** are almost exactly similar in their daily fluctuations, the only exceptions being July 3, 19, and 20. When compared with GFS we note two discordant periods, July 3–7 and July 19–21, which—it will be noted—include the dates already mentioned.

Similarly, although the TW plots were given nearly twice as much measured water as the TD plots, the daily fluctuations are the same. Moreover, on comparing these with G **2b** there are marked resemblances, the only discordance being within the same two periods already noted. Stranger still, in one of these they resemble GFS instead of G **2b**; six dates of the former are plotted for comparison. Thus we may conclude that the cause inducing these daily fluctuations in flowering is climatic, and is not to be sought in the soil, as a general rule.

With respect to the general form of these curves, the rise is practically the same in all until June 23. After this the TD curve rises most rapidly, and to the highest maximum; this maximum, however, it is not able to sustain, but it falls away, crossing the TW curve. The ostensible cause of this peculiar result was water-shortage in the dry plots, but in this communication the author advances the view that the effect of differential water in this Talbia experiment (and at Salaka and Mit Khalaf in 1913) was *not* a primary water-effect, but that the water altered the concentration of available salts in the various levels of the soil, so that these Survey experiments were actually dealing with available manurial food-supply, probably of nitrates. Thus the slower rise of TW and the Giza curves was due to lixiviation of the upper soil, whereas in TD the nutrient salts in the upper soil had been concentrated by evaporation.

The maximum height of the curves is greatest in TD, but it was not sustained, because the concentration of nutrient salts in the upper soil implies their exhaustion when this stratum has been ransacked by the roots. This curve is nearly akin to Terrace IV of 1909. The maximum in TD, on the other hand, is sustained until curtailment, as also are those of G **2b** and GFS. The maximum of the close spacing (G **1b**) is not sustained, since, as we saw in Part I, the dense crowding of the roots involves risk of water-strain effects, as shown in the single-plot curves (Part I, fig. 3, 1*a*) and it is curtailed prematurely, partly from this cause and partly from bud-shedding. The curve for GFS is interesting, because the spatial allowance was only a little more than for G **1b**, and much less than for G **2b**, yet it keeps up to its maximum throughout; small differences in the soil and the irrigation probably account for this, and it may be mentioned that this plot was subsequently unable to sustain its maximum bolling-rate, and suffered severely from shedding, showing that it was planted too closely.

Distinct from this premature curtailment in TD and G **1b**, we find the usual curtailment period in TW and G **2b**, clearly due to the rise of the water-table in the latter case. The published account of the Talbia experiment concludes in error that no such effect was shown, owing to a false premise.

It should be noted that the first flower opened at Talbia on June 8, and at Giza on June 9, as against June 7 at Giza in previous years, being a trivial difference. The height of the maximum is not comparable with those of previous years, as the Terrace site had been abandoned when the Agricultural Department's laboratory was built some 200 metres away. It is obvious, however, that Talbia and Giza were closely similar in this respect under similar waterings, and analyses of soil composition in the former experiment have been published, showing it to be rather poor land, though the soil was deep, as at Giza.

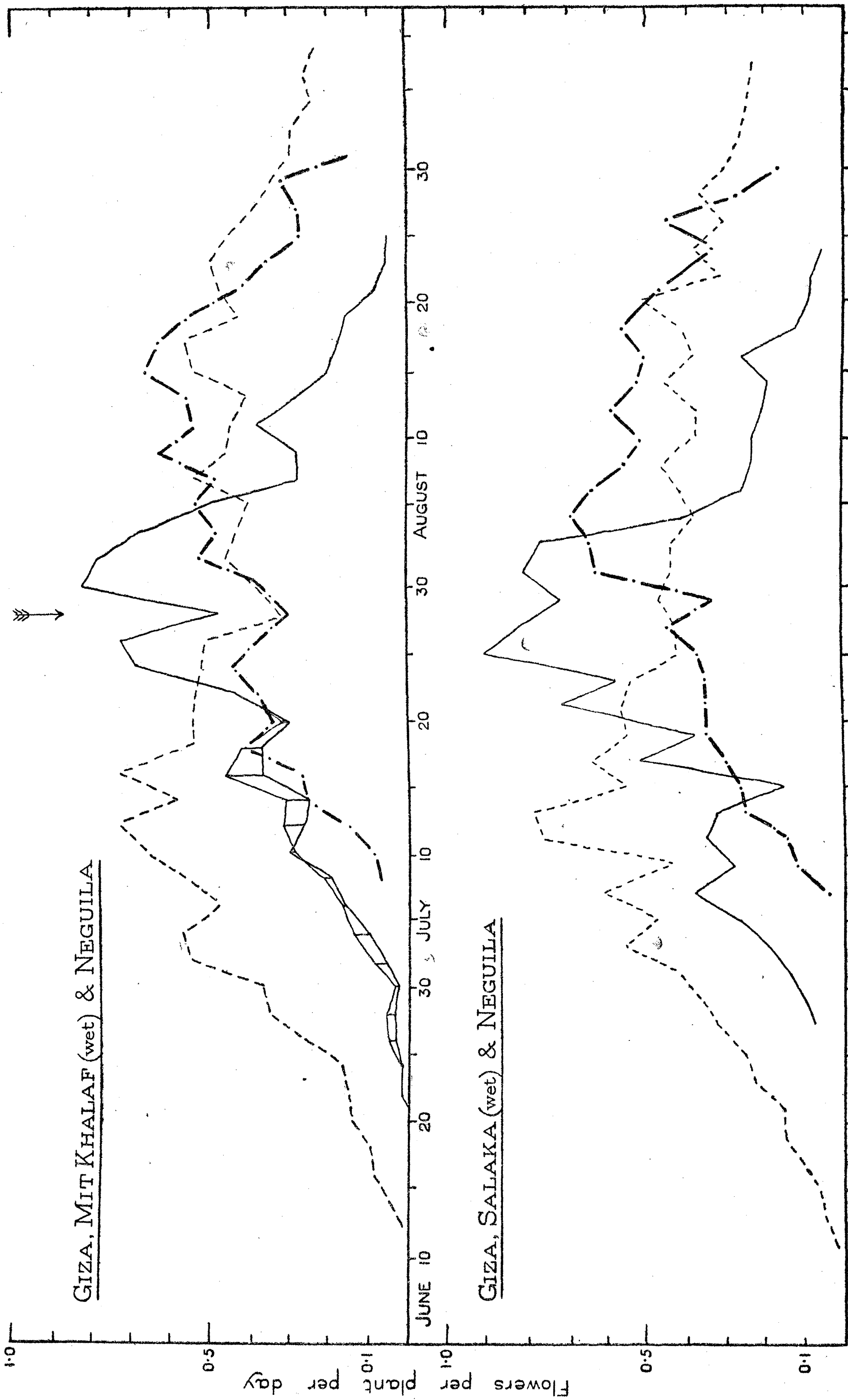

FIG. 7.—Season of 1913. Sites in Southern, Middle, and Northern Delta.

Flowering Curves, showing resemblances and contrasts from very different districts of Egypt.

- - - - - - Southern Delta. ———— Middle Delta. —·—·— Northern Delta.

(Giza : Sowing Date Experiment.) (Survey Department Watering Experiments.) (Negula : pure strain trials.)

Only those dates are plotted which coincide with the alternate days of observation in the Survey Department Experiments.

FIG. 7.—SEASON OF 1913.

The mean daily flowering for Giza in 1913 was computed in Part II (Table XI). From this computation the Giza curves in the present figure are plotted, taking alternate days to accord with those on which observations were taken in the Survey Department experiments at Salaka and Mit Khalaf respectively. The daily data from Neguila are treated similarly. The Survey data are valuable as coming from a district intermediate in latitude between Giza and Neguila; they were directed to study of differential watering as at Talbia, and at Mit Khalaf they gave the same result, though in less marked form, while at Salaka all waterings gave the same curve. The mean of all plots is plotted in both cases.

The necessity for daily observations is clearly shown, since both the Giza curves are plotted from the same data, and yet look quite dissimilar, as also do those for Neguila, in the details of their fluctuation.

Further, even allowing for this, it would seem that the Salaka curve is deformed in early July, as if the roots had been checked, while Mit Khalaf indicates a similar phenomenon. This was probably due to water-shortage in May before the experiment proper began.

Considering the disabilities which attach to the two-day observations, there is a suggestive resemblance between the movements of the various curves. In the upper half of the figure we find that Giza and Mit Khalaf are similar until July 17, while later on they again agree, and with Neguila also, on July 28. Similarly, in the lower diagram we find similar agreement between Giza and Salaka until July 19, and between all three sites on July 29. After the end of July the various curves appear to be independent. This indicates a possibility of estimating the date and size of the first picking all over Egypt from observations made in a single site.

Taking next the major features of the curves, it is clear that the rise of the curve is affected by the latitude of the site, and the evidence in Part II leads us to consider this factor as operating by way of soil-temperature. Neguila is in the north, nearer Alexandria and the sea, and its curve rises a month later than that at Giza, while the two mid-Delta sites give an intermediate rise.

The maximum attained was much the same at Giza and at Neguila, the soil at the latter place being rather poor, very light land, with low water-retentiveness, and needing frequent irrigation, while that at Giza had borne cotton for two years in succession. (Part II, p. 461.) The sites at Salaka and Mit Khalaf, on the other hand, were chosen as being good typical land, and in spite of the check shown in the early part of both curves, which lost an appreciable amount of final yield, they both rose to a higher maximum than the author's sites.

The curtailment of these curves shows several interesting features which would have been incomprehensible in 1912. On comparing the two mid-Delta curves it will be seen that they are both curtailed simultaneously, and from the suddenness with which this happens we may hazard a conjecture that it was due to the behaviour of the water-table in their district, as affected by the *régime* of the irrigation canals. This we are the more entitled to do because the relatively feeble curtailment at Giza can be traced definitely to such a cause.

The Pre-determination of Daily Fluctuations in Flowering and Other Observed Phenomena.

Our discussion of this subject must be somewhat tentative, since the author did not arrive at the conception of Pre-determination until the end of 1912, and the pressure of work on seed supply of pure strains prevented any experimental investigation in 1913, though some data were collected from a field crop, concurrently with the Sowing-date Experiment.

The term Pre-determination implies that the ultimate manifestation of a fluctuating characteristic is not necessarily the result of circumstances which were contemporary with that manifestation, but may often be due to circumstances which acted weeks or even months before.

In one sense such pre-determination is an obvious necessity in plant life. A spring frost kills the apple blossoms and pre-determines a bad crop; hyacinth bulbs raised in Holland construct the primordia of the flowering-spikes with more flowers than those raised in England, and thus pre-determine better results for the grower who uses Dutch bulbs. In the present section the author's purpose is to show that this conception may be extended to much more delicate fluctuations, even to such an extreme fluctuant as the daily flowering-rate of a cotton field. Further, that this conception makes it possible to interpret certain complex phenomena in plant life in a reasonable manner, usually in terms of limiting factors.

The subject of daily flowering-rate gains interest from the data already given in figs. 6 and 7, which indicate that these fluctuations may be common to the whole of Egypt on some days of the season. The crop may thus be regarded as a meteorological recorder with a long latent period, during which it automatically develops the integrated result of its daily experiences.

A simple illustration, drawn from the single-plant records of the author's experiments in Genetics, will serve to introduce the subject.

Pre-determination of Flowering in Spite of Defoliation.

A photograph published* elsewhere shows a pure-strain cotton plant badly damaged by the leaf-eating larvæ of *Prodenia littoralis*. Four wide-sown companion plants of the same strain were unattacked. All the events in this episode can be exactly dated, though their significance was not grasped at the time.

The egg-masses were laid in the night of June 21, 1909. Growth of the main stem ceased by July 2, the terminal bud having been destroyed. The photograph cited was taken on July 10. Flowering continued unaffected, just as on normal plants, until *July* 23. It then slowed down, but did not stop entirely until July 30. Only two flowers opened during August, but during the next two months

* 'The Development and Properties of Raw Cotton,' Plate VIII.

flowering was not merely resumed, but was abnormally rapid. This does not particularly concern us, the principal interest resting in the fact that this extremely unhealthy plant flowered normally for nearly a month, though of course it failed to retain any of the flowers as ripe bolls.

The details are given in Table IX. The explanation seems simple. The act of defoliation reduces the water strain, and the expansion of pre-formed organs can proceed; but it also reduces the photo-synthetic area, and so restricts the growth of new primordia. Consequently, those flower-buds and internodes of flowering branches which were fully differentiated as the "scaffolding" of the plant continue to develop, and the flowers open in due course. These being all opened, flowering must stop until new leaves and new scaffolding shall be built up, and a fresh series of flowers produced.

The Development of Branches.

Since the rate of flowering is intimately connected with the development of the "scaffolding" of flowering branches, we propose to examine this development in some detail, taking first a simple case in which the growth of young flowering branches in the early summer is compared with the growth-curve of the main stem, and then following the details of the growth of a single plant in all its branches.

On the physiology plots adjacent to the Spacing Experinent in 1912 a group of ten plants was measured daily at 9 A.M. with dividers, in order to determine the rates of elongation of the main stem. The points defining this elongation were successive marks on the stem at intervals of 100 mm., and the axil of the youngest visible leaf. The curve showing the mean daily elongation of these ten plants is plotted in fig. 8 as a thick line. We may postpone any detailed discussion as to the action of the environment in determining the form of this curve, and note only the following points:—That the daily fluctuations in elongation-rate are mainly determined until late June by the night temperature, *i.e.* the 24-hour minimum, but that a very hot day depresses the rate in the following night. Days on which the rate should thus have been depressed by a preceding hot afternoon are marked in fig. 8 by means of black triangles. The arrows signify dates of irrigation.

This ten-plant curve for the main stem may be used as a standard of reference. On comparing it with the short curve marked X there are clearly similarities. This latter curve shows the mean elongation-rate of all the first flowering branches developing on these ten plants, one on each; upon these ten branches the ten first-flowers should be borne. The close similarity of the curves shows that both the main stem and the flowering branches were reacting in the same way to environmental factors at this season. The record unfortunately ceases on May 31, but on this morning we find that the mean elongation of the flowering branches had been greater than that of the main stem, their curve crossing that of the latter for the first time. From subsequent data it will be seen that this could not be due to a "grand period" in the growth. Thus the flowering branches are beginning to display some individuality, and it is very significant that this display takes place during the reaction to irrigation on a very hot day (see arrow and triangle below). On the author's interpretation this is due to a larger dose of thermic toxin being developed in the older terminal bud of the main stem than in the younger buds of the flowering

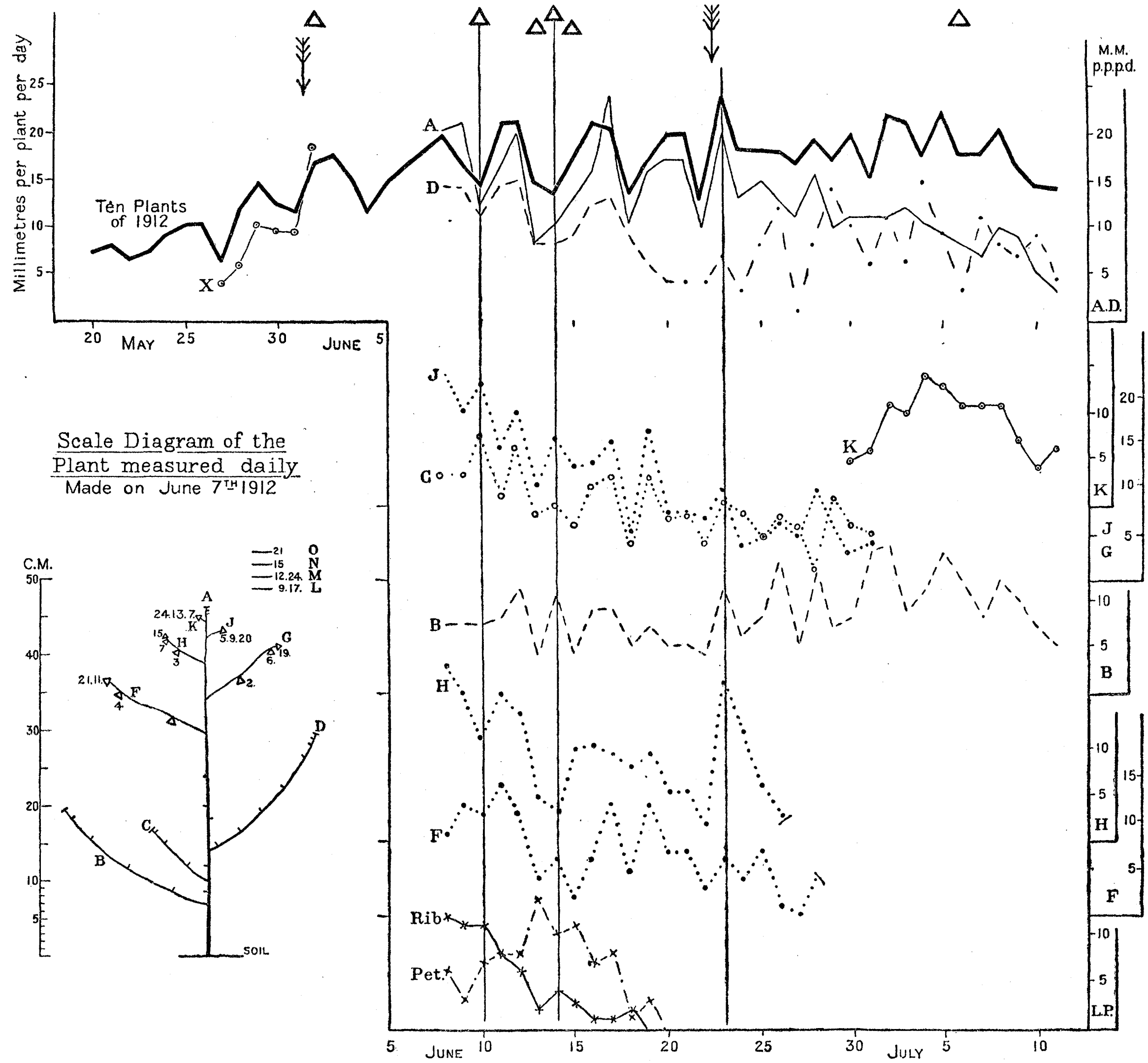

FIG. 8.—Growth of Branches.

Letters denote various branches whose subsequent daily elongation is recorded on the right. Numbers represent order of opening of the flowers. Flower-buds shown as triangles. Other nodes by dashes on stem. Days of opening of flowers shown on fig. 9.

△ Dangerous Maximum Temperature on previous afternoon.
Watered.
Flowering Branches (sympodia).
Vegetative Branches (monopodia).
Leaf, midrib and petiole.
Terminal Bud.
For comparison: mean of Ten Plants, 1912.

branch as a result of exposure to the high temperature. Consequently the main stem is less able to respond by growth to the warm night which followed. Other investigators have attributed similar phenomena to abstraction of available water from the old buds by the young ones.

The development of such individuality amongst the branches is found to be quite general when we next proceed to examine the development of a single individual plant in detail.

On the left-hand side of fig. 8 is a scale-diagram of a plant which was adjacent to these ten plants, as it appeared when measured on June 7. The remaining curves of this figure represent the daily elongation of various branches of this plant, as determined by measurements made each morning from June 7 to July 11. The scale-diagram shows three basal monopodia, B, C, and D, borne on the main stem A; above these are sympodia bearing flowers (indicated as triangles) and lettered F, G, H, and J. The subsequent development of five more sympodia above these is also indicated. Alongside each sympodium are numbers which indicate the order in which its flowers opened, out of the 24 flowers which appeared between June 22 and July 14.

In fig. 9 these flowers are plotted as a flowering-curve, the reference letter of each sympodium and the order of each flower on its own sympodium being written in upon the curve. The first flower on any sympodium is especially marked by the use of capital letters.

Returning to fig. 8, and examining the various curves separately, the following features may be noticed. The elongation-rates of the terminal bud (curve A) at first follow those of the ten plants, and only display marked individuality in July; but before this it is noticeable that curve A lags behind that of the ten plants on June 11 and 17, as if the preceding hot afternoons had injured it more than the average amount of injury, and had thus left an after-effect which needed another night to effect equivalent removal.

The curve for D, the principal monopodium, is more closely similar in this last respect to that of the ten plants than to that of its own main stem. After June 18, however, it becomes independent of them both. The other large monopodium (B), on the other hand. scarcely behaves like any of the previously mentioned curves, even at the beginning, and it seems to represent a transitional stage to the sympodia G and J, preceded in this transition by H, and followed by F. The curve for H at first resembles A.

These sympodia G and J are closely similar to one another in their growth, and are both quite unlike either the ten plants, or their own main stem. They are suggestively like the young flowering branches, plotted as curve X and already mentioned, in that the effect of a hot day is to increase their rate of elongation (on June 10), instead of depressing it; presumably they also had not yet passed into a state of senescence through accumulation of toxins.

Lastly, we have measurements of the young sympodium K, and these measurements were begun as soon as it was long enough to handle, so that it is comparable in age with those measured earlier in the season as X. Yet it shows no similarity whatever to the ten plants, as X had done; this is presumably due to toxin accumulation in the latter, which we saw beginning at the end of the X-curve. It might be noted, as an indication for further research, that even the petiole and mid-rib of the same leaf are independent.

Out of these complex details we can draw certain conclusions of more general nature. The chief of these is that the average elongation-rates of the various branches from day to day are closely correlated with those of the main stem during May. In June there begins to be individuality: first of the terminal buds as distinct from the branches, then of one terminal bud or branch from another. On the author's interpretation, the cause of this is to be sought in the development of internal toxins, which act as depressant factors. A record of the elongation-rates of the main stem, which are themselves controlled by meteorological conditions principally, will therefore serve as an index to the rate at which the scaffolding of flowering branches is being built up, though during the early part of the season *only*.

There is also undoubtedly an average rate of elongation of flowering branches, even in the latter part of the season; but it is not so easy to determine, because the "average individuality" of the flowering branches would have to be ascertained. We may, however, anticipate that the flowering-curve itself would constitute such a determination, at least to some extent.

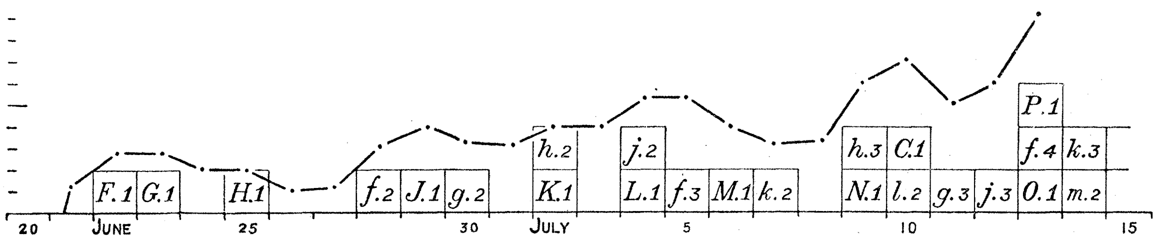

FIG. 9.—Flowering Curve of the Single Plant shown on Fig. 8.

Letters denote branches. Numbers denote succession of flowers on any branch.

We have next to consider what relation these early rates of elongation of the main stem bear to the early part of the flowering-curve. To effect this properly we need a second scale-diagram of the plant shown in fig. 8, made from measurements at the end of the observations. Such a diagram was actually prepared, but has been lost, and in its absence a general discussion must suffice.

If the internodes of the main stem were all of the same length, and if the first internode of each flowering branch always took the same number of days from its first appearance to develop up to the opening of its first flower, then it would follow of necessity that the time-intervals elapsing between the opening of successive first flowers on successive sympodia (passing up the main stem) would be inversely proportional to the rate at which nodes were formed by the main stem.

In other words, under these postulates the rates of flowering would be directly proportional to the elongation-rates of the main stem, *but* only after a lapse of time equal in duration to that required for the first internode of a flowering branch to develop. Thus, the growth of the main stem would pre-determine the flowering, and this actually appears to be the case in the Egyptian cotton crop, though in a less simple form, since various secondary considerations are involved.

For example :—The presence of a node (and therefore of a potential sequence of flowers) at any given point on the stem does not merely depend on the rate of stem elongation, but it also depends on the differentiation of primordia in the terminal bud. Further, since differentiation precedes extension, the latter must be to some extent pre-determined by the former, as in the example of a hyacinth bulb. In this connection it might also be noticed that the fluctuations in the rate of differentiation are probably the same as the fluctuations in rate of extension, at any given time.

Also, in the case of cotton, the time-interval relation is complicated as soon as the second flower on each sympodium appears, owing to the fact that this second flower follows the first one much more quickly than the first flower follows the first appearance of the branch which bears it. In other words, the second (and later) internodes of the sympodium develop more quickly than the first one, being much shorter. We can ascertain what the actual intervals were in the case of the plant which we have examined, by consulting fig. 9 : on the branch F, from first flower to second took 6 days, from second to third took 7 days, and from third to fourth took 8 days ; similarly for branch G the intervals were 7 and 11 ; for H, 7 and 7 ; for J, 5 and 8 ; for K, 5 and 7. The average of these intervals is 7 days.

On the other hand, the first internode takes about four weeks to develop. Thus the branch K was just appearing on June 7, but its first flower opened on July 2, after 25 days ; similarly, we can deduce that J made its first appearance on June 4 or 5, and its first flower opened on June 29. Other observations show that these figures are approximately correct, so that in the Giza district the first internode of the early sympodia occupies from 25 to 30 days in its development to open its first flower. Thus, the "lag" of flowering fluctuation with respect to elongation fluctuation should be about four weeks, so far as the first flowers on each branch are concerned.

Before proceeding to examine the available evidence which indicates that this interpretation is substantially correct, it will be well to examine the manner in which a flowering-curve is actually built up, flower by flower.

Construction of the Flowering-curve.

Returning to fig. 9 for purposes of illustration, it will be seen that the foundation of the curve is laid down by the first flowers of each successive sympodium ; the ideal curve begins with the first flower of the lowest sympodium, and for the first few days the curve for the "average plant" by which we study a crop consists entirely of such first flowers.

About the seventh day after the commencement of the curve, the second flowers on successive sympodia begin to make their appearance, and thereafter the third, fourth, and even later flowers of each sympodium.

Since the time of appearance of the early flowers is conditioned primarily by the antecedent growth-rates of the main stem, and since the degree of development of adjacent plants necessarily is not uniform at the epoch of such conditioning growth-rates, it therefore follows that the modes of which the flowering-curve consists do not necessarily correspond to the flowering of successive sympodia (as they do at the beginning of fig. 9). On the contrary, these modes—which we may conceive as existing ideally—are usually obliterated by the modes which are due to variations in the preceding growth-rate.

On the modes thus constructed there is superimposed the accumulation of second and later flowers on each branch. The earlier of these will necessarily have their time-distribution affected by the time-distribution of their first-flower predecessors, but any fluctuation in the length of the seven-day period of development of the second sympodial internodes will tend to obscure this, and in the later flowers it will suffice to obliterate the relation entirely. The later fluctuations of the flowering-curve should therefore be less violent, and should be traceable to less remote causation, than in the early part of the curve; pre-determination should take place at a seven-day interval, rather than at a four-week interval. This, however, we shall not attempt to trace at present.

Pre-determination of the Early Part of the Flowering-curve by the Growth-curve.

Two plant-development curves are plotted in fig. 10; one shows the daily elongation of the main stem in the ten plants of 1912, of which we have already made use in fig. 8; the other shows the daily flowering of spacing 2*b* of the Spacing Experiment (ordinary field-crop). To simplify the presentment we shall omit discussion regarding the causation of the fluctuations in the growth-curve, and simply take the data as they stand.

The two curves are plotted with a "shift," the same ordinates representing 29 days earlier for the growth-curve than for the flowering-curve. The exact length of this interval is chosen arbitrarily, being that which gives the best "fit" of the two curves thus superimposed, but we have already seen that the history of the plant's development indicates the interval to be of this order.

In the figure thus plotted there are definite indications that these two curves owe their fluctuations to a common cause. The effect of the watering given on June 23 may be noted as an example: by mid-June the rate of elongation of the main stem is, as we have already seen, becoming subject to a depressant factor which can

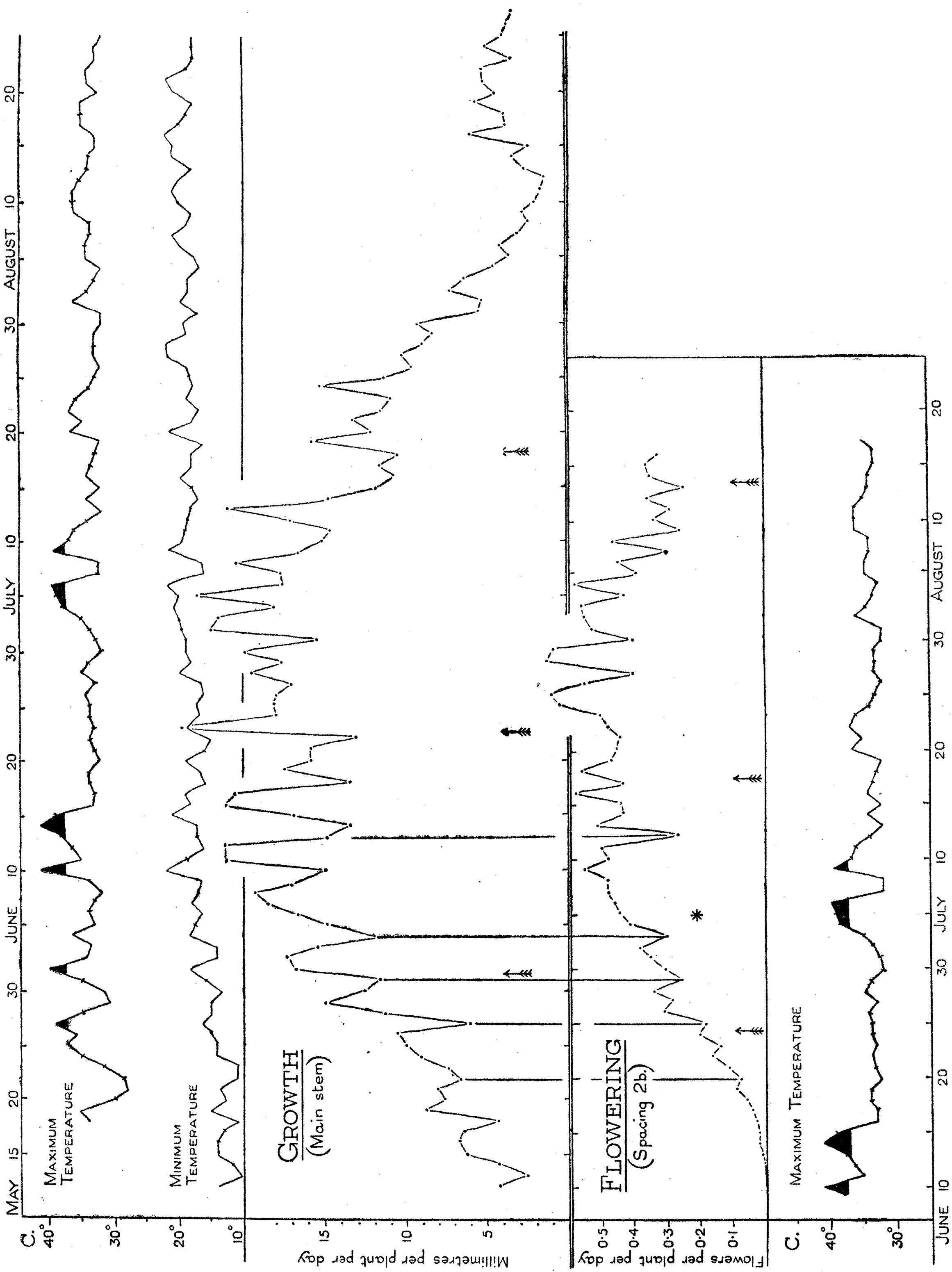

FIG. 10.—Pre-determination of Flowering. Season of 1912.

Growth:—Daily elongation of main stem measured on Ten Plants in Physiology Plots of the Spacing Experiment at 9 A.M. Max. and Min. shade temperatures of previous 24 hours in meteorological screen half a mile away (Survey Dept.) plotted above.

Flowering:—Daily observations from Spacing 2*b*, with Max. temperature on previous day. Shifted 29 days.

be partly removed by watering. (This removal is more clearly shown later in the season on July 18.) Consequently, after this watering the growth-curve rises sharply, and this rise re-appears in the flowering-curve at the equivalent later date. Yet the watering given on July 18, which was only four days before this equivalent date, produced no effect at all on the flowering-curve. The remote cause was powerful, while the near and obvious cause was impotent.

The later portions of these curves show no correspondence, for reasons which we have already discussed. In general, these data are distinctly suggestive, but they need amplification. This the author attempted in the following year by demarcating a plot of 200 plants contiguous with the Sowing-date Experiment, and observing them carefully. The height of one plant in each hole, or 100 plants in all, was measured daily to the nearest half centimetre by a Plant Observer, the end of the measuring scale being rested on a notched peg embedded permanently in the ground near each plant; errors due to sampling were thus entirely eliminated, while the errors of the individual measurements smooth out in the calculated mean.

The flowers were counted daily on both the plants in each of the hundred holes in the usual way. The data are plotted in fig. 11, with a "shift" of 27 days.

The choice of this shift is again quite arbitrary, but there are two reasons which make it very probable that the time-interval need not have been the same as in 1912. In the first place the variety Assili was used in 1912, while Domains Afifi was employed in 1913, and these two varieties are actually known to differ slightly in the time-interval which covers another period of development, to wit, the maturation of the boll. In the second place there were no very hot days in the spring of 1913 to encourage excessive development of internal thermic toxins.

Unavoidable circumstances prevented the growth records from being commenced until June 1. The temperature records before this date have therefore been interpolated to indicate what the form of the growth-curve would most probably have been, since it follows the night-temperature curve closely during the early part of the season. The flowering for all normal sowings from the adjoining land (Part II, Table XI) is also plotted, in order to show that the fluctuations of flowering in this plot were typical. If we admit the validity of the interpolated preliminary portion of the growth-curve, there is an extraordinarily close resemblance between the growth-curve and the flowering-curve, which resemblance continues till the end of June.

This long-continued resemblance is not unexpected, for, as we mentioned in Part II, there were no very hot days in the early summer of 1913 to encourage (p. 175) the development of individuality in the older buds, so that the various branches might be expected to follow the terminal bud in their rates of elongation until a later date than usual. Even if we neglect the interpolated portion of the growth-curve, the resemblance is still striking, but the number of pairs of points is insufficient to make a statistical presentment of the correlation of deviations advisable.

Our conclusion, therefore, is that the principal cause of the daily fluctuations in rate of flowering during the early part of the curve is to be traced to fluctuation in the rate of elongation of the main stem, about four weeks previously. The data at our disposal are not sufficient to permit an attempt at analysis of the later fluctuations,

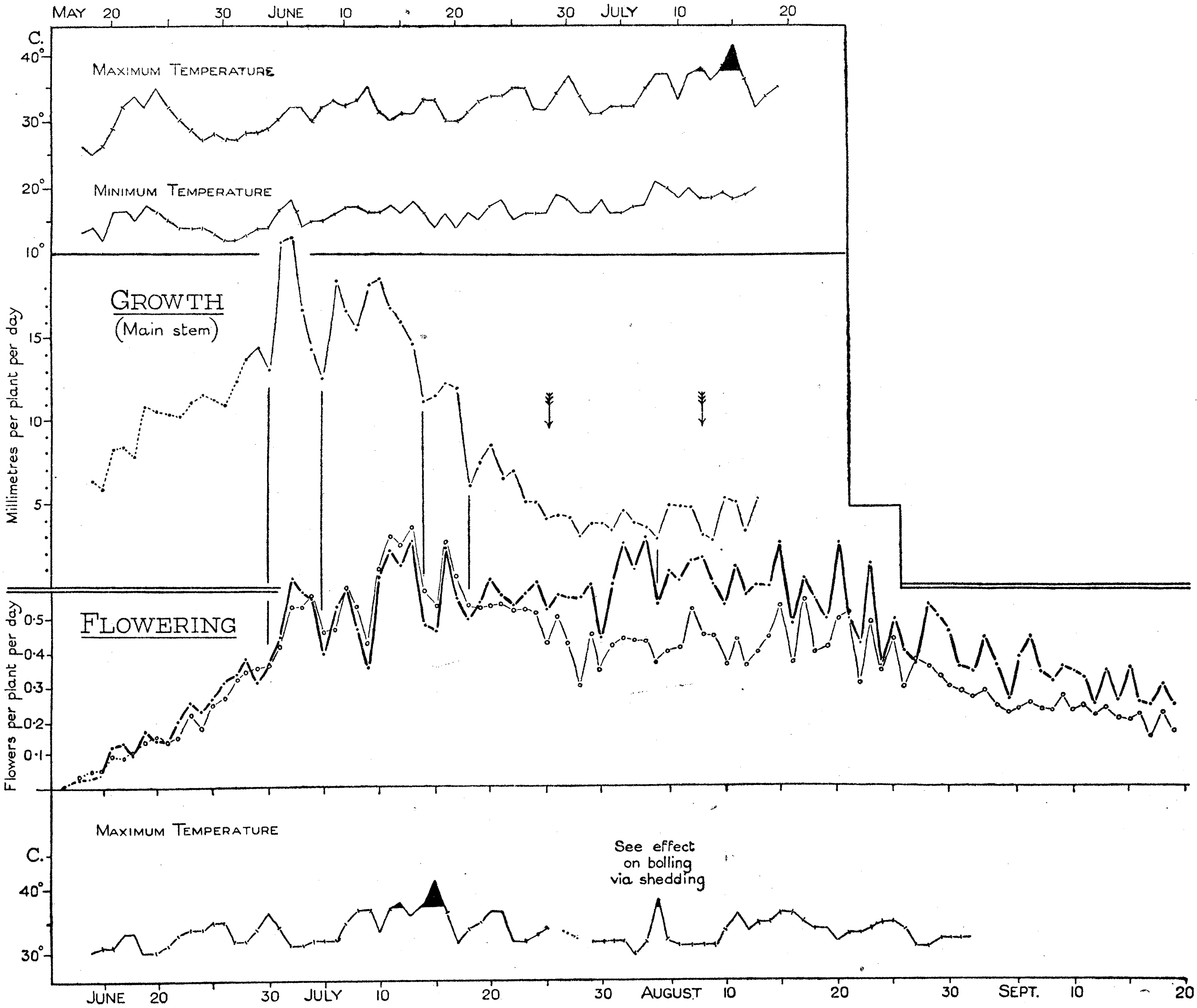

FIG. 11.—Pre-determination of Flowering. Season of 1913.

Growth :—Daily elongation of main stem measured on 100 Plants in Physiology Plots of the Sowing Date Experiment at 9 A.M. Max. and Min. shade temperatures of previous 24 hours in meteorological screen half a mile away (Survey Dept.) plotted above.

Flowering :—Daily observations from same group of plants (thick line) and mean of sowings, Feb. 22 to March 15 (thin line and circles). Maximum temperature on previous day. (For their Bolling-curve, see fig. 17.) Shifted 27 days.

but it is probable that they will be found to result from the integration of this long-period pre-determination with a shorter one, while bud-shedding may sometimes introduce minor complications.

Some Other Instances of Pre-determination.

We noticed in the Spacing Experiment that the effect of the rising water-table on wide-sown plants was quite as marked as on field-sown plants, but with the difference that in the former case the effect was delayed for a month. This was due to the fact that the differentiation of buds was checked, but all those buds already differentiated were able to open after due lapse of time, as in the case of the defoliated plant (p. 174).

In the 1909 Terraces the check due to the trodden "pan" at a depth of 50 cm. is shown by the flowering-curve on July 1 (fig. 3), although our available evidence regarding the development of the root-system would indicate that such a depth must have been reached by the root much sooner than this date. This apparent discrepancy becomes strong evidence in favour of our interpretation concerning the "pan" effect, when the additional four weeks is allowed for the check to become manifest.

The rise of the flowering-curve in 1910 (fig. 4), after water-shortage had been removed by irrigation on July 5, is a mixed effect, in part pre-determined, and in part immediate. The direct effect is to check bud-shedding, and to restore the normal condition of diurnal water-strain, so that by July 17 the curves begin to show their normal simultaneous fluctuations, which had been pre-determined in mid-June before the plots had become water-short. Further, we find later on that whereas the four terraces are closely similar on July 30 and on August 13, they deviate widely from one another on the date intermediate between these two, viz. August 6. It is very probable that this deviation is really the pre-determined effect of the water-shortage which had terminated a month before, since a condition of water-shortage practically necessitates soil-differences from plot to plot.

In the 1911 Terraces this effect is even more marked, and is combined with a very heavy dose of the Depressant Factor which water-strain and water-shortage induce. (Part II.) The curves take a long while to recover from the drought which ended on June 27; they show no sign of rising even so late as July 9 (fig. 5).

In the Survey Department experiments of 1913 we find a most interesting case of experimental error due to pre-determination (fig. 7). We have already noted that these curves from Salaka and Mit Khalaf do not rise as smoothly as a normal curve should do; both show a distinct check in their rise. At Mit Khalaf this check is manifest between July 10 and 20; at Salaka it is slightly earlier, or at least the recovery takes place sooner. If these checks had been pre-determined by, *e.g.* water-shortage, they would indicate that the water-short condition had come to an end not later than June 22 at Mit Khalaf, and rather sooner at Salaka. Consulting the published details we find that the differential watering and official supervision of the Mit Khalaf experiment began on June 21, up to which date all the plots had received the same treatment, and similarly at Salaka (though the actual date is not given). It seems more than likely that this watering in June was delayed a few days too long, while preparations were being made for the experiment. The paradoxical result follows that, although these experiments show that "the differences between the results from the various grades of watering are quite insignificant," yet a very marked watering effect runs through the whole experiment, pre-determined before ever the experimental treatment began.*

A further feature of interest in these experiments is the accentuation of this water-shortage effect at Salaka on July 15, by its coincidence with a check in flowering which is sharply shown at Giza, and is indicated at Neguila also by a check in the rise of the Neguila curve (fig. 7). An effect which is thus shown in three sites, extending across a hundred miles of latitude, and which is moreover quite independent of any peculiarities in the irrigation *régime* at each site, can only be due to a meteorological cause. The most obvious of such causes is the hot day immediately preceding (July 14), when the highest temperature of the year was reached at Giza (42° C.); such a day might cause bud-shedding throughout Egypt, especially in the south, and so cause a deficiency of flowers on July 15. But this explanation is not valid; we have already seen that this drop in the rate of flowering was caused by a drop in the growth-rate during the night of June 16–17 on the Giza site, which in its turn was caused by low temperature during that night; if therefore, the coolness of this night was a general effect, shown all over Egypt, we are entitled to suppose that it was the real cause of the diminished flowering shown by all our three sites on July 15. Other coincidences of movement shown in fig. 7 were also presumably determined in the same way. We thus arrive at the remarkable conclusion that by measuring the growth-rates of a few plants on a single site it may be possible to predict, with very fair accuracy, the daily variations in flowering which the whole cotton crop of Egypt will show in a month's time.

Instances of pre-determination might be multiplied almost indefinitely, but the examples quoted, and the last of these in particular, will suffice to illustrate the matter. Any English garden provides innumerable instances; the author has noted casually some excellent examples in the development of another malvaceous plant, the hollyhock, and statistical evidence has been obtained from the tomato. It is obvious that once we admit the necessity for due synchronisation of the operative cause with the visible effect, many obscure peculiarities become quite rational and comprehensible, and not alone in the Egyptian cotton crop, being then traceable directly to physico-chemical reaction between the inherited constitution of the plant and the surrounding environment.

One such obscurity might be mentioned more particularly, especially since it obtruded itself on the author's notice persistently during his earlier researches on the genetics of cotton, in connection with the breeding of early-maturing strains; it is commonly believed, and borne out by practical experience, that the so-called

* KEELING, B. F. E., 'Cairo Scientific Journal,' 1915.

"cardinal temperatures" for flower-formation are different from those for simple growth of the vegetative organs. To the author's mind the existence of any such fundamental change in the cells as this, has always seemed to be unlikely; whereas, if we recognise that the act of flowering must always be pre-determined to some extent, the difficulty disappears, because it is highly unlikely that the climatic conditions should be exactly the same at the time of actual flowering as they were when the flower-formation was pre-determined.

NOTE.—The author is indebted to Mr. H. E. HURST for an unpublished contribution to the elucidation of the above subject, which, though negative, was none the less valuable. In an attempt to explain the fluctuations shown by the Talbia flowering-curves in 1912 ('Survey Dept. Paper,' No. 31, Cairo, 1913), Mr. HURST determined the correlation of their deviations with all the recorded meteorological components, both for the same day, and for two or three of the preceding days. The elaborate investigation thus undertaken gave no real result whatever, confirming the present author's own similar examination of data, and so, by establishing definitely the insignificant influence of the environmental conditions which precede flowering immediately, directed the author's attention to more remote causation.

The Control of the Flowering-curve by Environmental Factors.

Having established the general principle of Pre-determination, and having thus interpreted the significance of daily fluctuations in the rate of flowering, during the previous chapter, we now turn to consider the more conspicuous alterations of the general form of the flowering-curve which may be produced by various environmental factors. In so doing we may bear in mind that we are dealing with the principal determinant of the final yield. The most convenient arrangement will be to take the three main portions of the curve separately.

The Rise of the Flowering-curve.

In Part I of these Analyses we found that the initial rise was not affected by the spatial allowance, which indicated that in normal cultivation it is pre-determined by climatic factors, and not by edaphic ones. In Part II we found that the rise was unaffected by variations in the date of sowing, so long as the optimum sowing-date was not exceeded, and we traced this phenomenon to an inhibition of the growth of the early sowings by excessive production of the internal Depressant Factor, itself controlled effectively by the soil temperature. In our summary of the seasonal data (figs. 3–7), above, we have seen that the date of appearance of the first flower is practically the same each year; and we will next consider fig. 12, in which are plotted together all the available curves from plots sown normally in various sites and seasons, to show their rise only.

Since the depth of available soil, and its chemical composition also, was much the same at Talbia as at Giza, and since the two sites were only a few kilometres apart, the marked similarity of the curves T. '12 D, T. '12 W, and G. '12 2*b*, is not surprising. But, on the other hand, judging by popular opinion, one would have expected to find G. '13 very different, because the crop of Egypt in this year was unusually "early," whereas the G. '13 curve is substantially the same as its predecessors at the beginning.

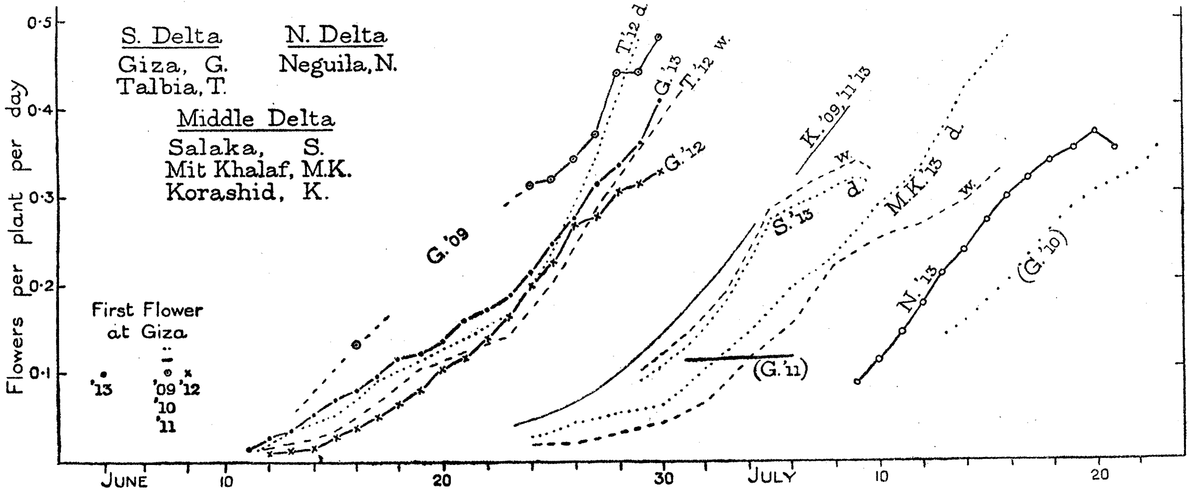

Fig. 12.—The Rise of the Flowering Curve in various Sites and Seasons. Collated in form of 5-day means.

Turning next to G. '09, we find that although the first flower appeared at the usual time, the curve rose more rapidly. This might have been due to the season, but it is much more likely that it was due to the excellent condition of the well-manured upper soil, which had been carefully attended to in the making of the terraces.

The curves from the wet and dry plots at Talbia (T. '12 W and D) also develop differences in this respect towards the end of June, when the effect of the differential watering which was begun on May 27–29 had made itself felt through pre-determination, and we have reason to believe that this is in reality a soil-fertility effect.

Our first conclusion is, therefore, that the rate of rise of the flowering-curve may be influenced by soil fertility, but that the actual commencement of the season's flowering is determined by the soil-temperature, and is therefore sensibly constant from year to year in any given locality.

We next consider the effect of changing the locality (Giza and Talbia having been close together), and it is obvious that as we pass northwards, where the soil-temperature on any given date in the spring is lower, the curve begins later. The three middle-Delta sites are closely grouped together, about ten days later than the Giza curves, in spite of the deformation of the S. and MK. curves by preliminary water-shortage (p. 184). The curve for Korashia is roughly indicated on the basis of miscellaneous observations made during several years by M. Audebeau and by the author.

Passing still further north to Neguila, only 20 miles or so from the Mediterranean, the curve rises later still.

Our second conclusion is thus merely an amplification of the Sowing-date results :

that the rise of the flowering-curve, beginning with the date of the first flower, depends on the soil-temperature, which in Egypt is roughly synonymous with the latitude, though the subsequent rate of the rise may be affected by soil-fertility.

These conclusions agree with practical experience up to a certain point, but they offer no explanation of a fact which is common knowledge—to wit, that the Egyptian crops of some seasons are early, while others are late. It is not likely that there should be any very striking difference in soil-fertility over all Egypt between one season and the next, even in the event of an outbreak of cattle-plague. There must consequently be some other operative cause, and this is very clearly indicated by our data as being the available soil-water. We saw in figs. 4 and 5 that the Terraces at Giza were "late" in 1910, and later still in 1911, except at the wet end, and we have discussed the determination of this delay by water-shortage on p. 184. It only remains to notice how perfectly such delay may simulate real "lateness," by comparing, in fig. 12, the two curves G. '10 and N. '13. A portion of G. '11 is plotted for comparison, before its feeble rise has begun at all.

The idea of Pre-determination is very useful here. If the crop has been sown and cultivated in a normal manner, and yet is, on the average, a "late" one, the fact shows that the cause was most probably a deficient water supply during May, a time to which less importance in this respect is commonly attributed than to June, since it is in the latter month that the effects pre-determined by deficient water supply in May are visible.

It is here that we obtain the first indication of a real major seasonal effect. Thus far we have spoken of the water supply as if an actual deficiency of irrigation water were involved, as it was in the curve G. '10, G. '11, and MK. '13. But there may very well be an effective shortage of water even when the irrigation supply is normal, if the weather conditions are unusually stringent; and in point of fact it is during the months of May and early June that the abnormally hot days frequently mentioned in this communication are likely to occur. The auto-toxic effects of such days, whether caused directly by water-strain or by thermic effects, are mitigated or even abolished if the soil is sufficiently wet, but it is difficult to ensure this in May, when the plants are small, since the soil is not sufficiently shaded, and the roots have not reached to any great depth.* On the whole, however, our analysis indicates that the irrigation system of Egypt has perhaps been trading on rather too narrow a margin in this matter of the early summer supply of water, because during the five seasons covered by our data there is no sign of any delay in any of our sites under normal cultivation, whereas for the country at large there were two very early seasons and one late one within this period.

* W. L. B., "Movements of Soil Water in an Egyptian Cotton Field," 'Journal of Agricultural Science,' 1912.

The Maximum Height of the Flowering-curve.

We saw that the volume of soil available for the root system determined the height at which the curve ceased to rise, through the flowering-rate becoming constant (Part I). The results of the Spacing Experiment were applied in 1913 to the propagation of pure-strain seed for supply in bulk, on two areas of 20 and 40 acres respectively at Giza and at Korashia; the Giza land was close to the laboratory, hastily taken over from market-garden cultivation, and in places very rich, though foul with weeds and pernicious insects; the Korashia site was typical good mid-Delta land. Some records of the flowering on these plots were obtained in order to serve as guides in this novel system of cultivation; extracts from them are plotted in fig. 13.

The highest flowering-maximum obtained in the Spacing Experiment (from spacing $10a$) is indicated in fig. 13 by an arrow, and the whole flowering-curve for

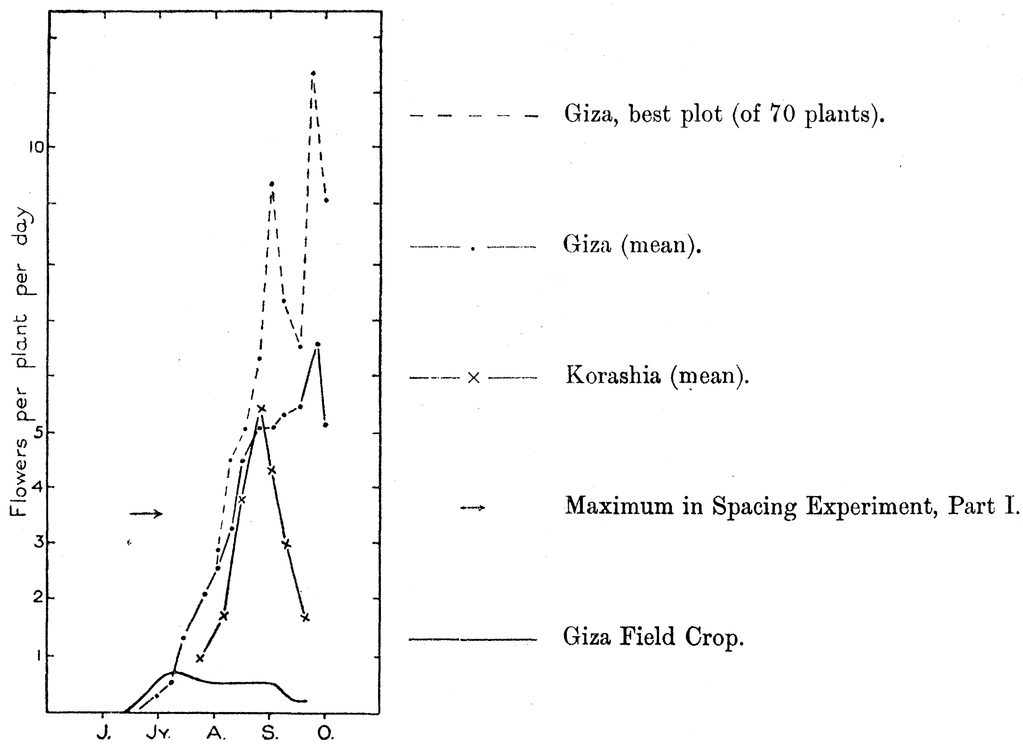

FIG. 13.—Flowering Curves from Pure Strain Wide-sown Propagation Plots, 1913.

field crop in 1913 at Giza (Part II, Table XI, and fig. 7 above) is reproduced to scale for comparison. The curves from the propagation plots can thus be easily compared with these standard results. On the Giza propagation plots the spacing was considerably wider than that of $10a$ in the Spacing Experiment, and the maximum rises more than proportionately higher; taking out separately the data for the 116 plots which comprised the Giza area, we find that the most productive plot gave a curve which attained to a maximum of nearly 10 flowers p.p.p.d., as the average of 70 plants. The maximum at Giza was sustained for some time, but at Korashia the curve begins to fall again as soon as the maximum has been attained; this fall was due to secondary causes which we need not discuss. The feature of interest is that the employment of richer land than that used for the Spacing Experiment has greatly increased the height of the maximum.

We saw that two successive years under cotton had not lowered the height of the maximum to any marked extent, in fig. 18 of Part II, and we noted that this might well have been due to the fact that we were using land which had been "let down" already to somewhere near its natural minimum fertility. This latter deduction is supported by the close resemblance between the maximum at Talbia and at Giza (fig. 6), the former also having been poor land, as shown by the published account of its manurial composition. On comparing these low maxima with the value of 0·8 attained in Terrace I during 1909 (fig. 3), where the soil had been freshly manured with care, and with the subsequent lowering of the maximum on the Terraces in 1910 and 1911, even after the water-shortage effects have been eliminated, this conclusion is further supported.

On the whole, it seems to be established as clearly as is possible in the absence of any direct manurial experiments with analysed data, that the effect of a deficiency in the manurial constituents of the soil is not merely to slow down the rise of the curve, but also to lower its maximum.

We shall meet later with an indication that the shallowness of available soil above the water-table has a similar effect (fig. 15), which is quite probable, since limitation of soil-depth is somewhat similar to the limitation in lateral dimensions which we studied in the Spacing Experiment. It should be noted, nevertheless, that there is a distinction between the effects of soil-volume and of soil-composition. The former does not affect the rising curve until root-interference stops the rise, whereas the latter affects both the rise and the maximum.

The Abnormal Maximum of 1913.—The occurrence of an abnormal mode was noted in Part II, producing a false and temporary maximum. This mode was centred about July 12. In fig. 7 we can see traces of this mode extending to the northern districts. The cause must be sought in the growth-curve of the Hundred Plants shown in fig. 11, where the growth is seen to be extremely rapid in early June. Since the author has only two other detailed seasonal records of growth it is difficult to affirm that the 1913 growth-curve was abnormal, but it is certainly so as compared with 1911 and 1912. It will also be noted that the growth-curve falls away very rapidly in 1913—a month sooner than usual; in other words, the plants remained short, and this not only at Giza, but all over Egypt. This point will be mentioned again.

Meanwhile, the very rapid elongation of the main stem had pre-determined rapid flowering (p. 182), and it was not until the effect of this had died away that the curve returned to its normal position.

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The Curtailment of the Flowering-curve.

A number of causes which may effect this curtailment of the curve have already been mentioned, such as planting too closely, exhaustion of soil, shortage of water, and, in rare cases, the autumnal fall of temperature.

In the greater part of the data at present available, however, the cause is simply root-asphyxiation by the rise of the water-table to the lower roots. The prejudicial effect of a high water-table had already been demonstrated by AUDEBEAU and GIBSON, when the present author pointed out that if a rising water-table was also injurious, the two together would account for all the known features of the yield deterioration which the Egyptian cotton crop was showing. It was, however, by no means easy to carry conviction in this matter. The fact that fields could be found in which the plants were loaded with ripe bolls, although the water-table had risen above the soil-surface, so that these laden plants were standing in a lake, was considered strong evidence that a rising water-table might be highly beneficial.

The Terraces Experiment was planned by Mr. HUGHES in order to obtain data on this subject, but the plot yields were not conclusive, on account of soil-disturbance, and our knowledge of daily flowering was not then sufficient to enable the author to interpret the data obtained in the observation rows. Moreover, the water-table conditions were not truly represented by the tube-wells. The only available data from 1909 for the level of the water-table in the soil surrounding the roots themselves are the five points plotted in the lower half of fig. 14, from which it is clear that the water-table had risen much sooner than the well-levels (figured on p. 73 of 'The Cotton Plant in Egypt') had indicated. Further, it was noted on August 8, 1909, that the surface of the lowest terrace was under water, while from other circumstances we know that the rise to this level could not have taken place before the end of July.

If we now examine, in fig. 14, the flowering-curves for I, II, and III, smoothed to five-day means as in the lower half of fig. 3, the effect of the rise is obvious. These curves have here been re-computed so as to bring them all together on July 11–12, irrespectively of differences between the plots; from the coincidence thus adjusted they separate on their renewed rise, until on July 19 the curve III falls slightly instead of rising with the others, whose movements it had previously followed exactly. On July 21, two days later, the curve II falls also, instead of rising along with curve I; lastly, after two days more, on July 23, curve I falls, and does not recover. These dates are marked on the curves by arrows. There can be no shadow of doubt that this timing of the beginning of curtailment, from which there is no subsequent recovery, must be due to the immersion in succession of the roots on the three terraces, the lowest being first affected. We know the approximate depth of the root system at this time, and on the assumption that this depth was normal and equivalent in all the terraces, a curve has been plotted below to show the rise of the water-table as

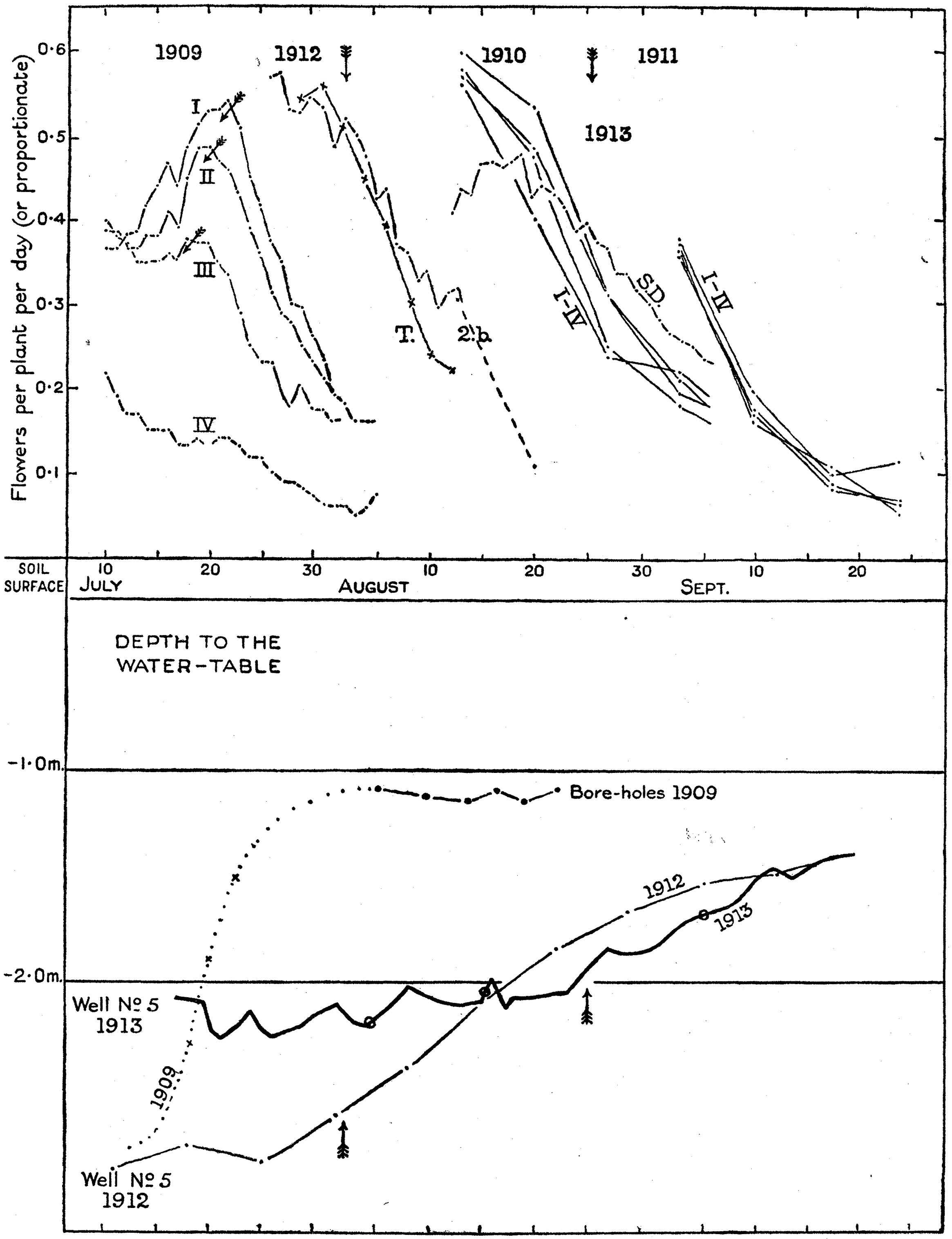

FIG. 14.—The Curtailment of the Flowering Curve at Giza, etc., in various Seasons. Collated as 5-day means.

I, II, III, IV = Terraces. T. = Talbia, 1912.
S.D. = Sowing Date, Giza, 1913. 2b = Spacing 2b, Giza, 1912.

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deduced from the probable date of first contact with the roots; this curve rises rather more steeply than is actually likely to have been the case, presumably because the roots in II, III, and IV had not penetrated to the normal depth, owing to the check caused by the pan (figs. 1 and 3). Terrace IV has not been included in this re-computation, because it was already flowering so feebly that no further misfortunes could have injured it.

The flowering data from the 1909 Terraces thus provided a conclusive proof as to the deadly action of a rising water-table, when viewed in the light of our present knowledge concerning the fluctuations of the flowering-curve. No further evidence of a differential effect as between the four terraces can be drawn from the two subsequent seasons, because the flowers were not counted daily.

In the year 1911 an investigation was performed by the Survey Department,* under the designation of "The Gemmaiza Strip Experiment," which practically settled the whole question so far as the soil-depth factor was concerned, but remained slightly uncertain as to the effect of the rise of the water-table. The present author's methods were tentatively employed, by establishing a set of observation rows, and his assistance was given in the discussion of the results. Unfortunately, the data from the observation rows were scanty, as judged by our present standards, since they were not begun until flowering was well advanced, and were only taken once a week; their worst fault, however, was that the ridges on either side of the observation rows were uprooted to form a pathway, and thus the spatial allowance was completely changed. The author is indebted to the Survey Department for permission to use the unpublished data thus obtained, and in view of the crucial nature of the experiment in question, it seems well worth while to remove the only ambiguity shown by its results (Table IV).

The strip of land employed was chosen because its water-table sloped from a depth of about 60 cm. at one end to 250 cm. at the other. At the shallow end the water-table fluctuated with each watering throughout the season, while at the deep end it began to rise in early August, and rose to within 180 cm. of the surface. Intermediate positions behaved accordingly. The published account states that "the yield of cotton and the productiveness of the plant generally . . . . increase as the depth below the ground of the water-level, as shown by bores, increases." The correlation between total yield and depth to water was +0·88, while that between "ratio of third picking to second picking" and "mean rise of water August to September" was −0·85. This latter method of utilising the available data was suggested by the present author, and it clearly indicated the prejudicial effect of the rise. But, in the observation rows, as distinct from the plots, there was "practically no detectable effect due to the rise of water in the autumn."

This failure to drive home the final conclusion as to the effect of a rising water-table was very unfortunate It was simply due to defective methods, and we are

* H. T. FERRAR and H. C. HURST, 'Survey Dept. Paper,' No. 24.

now able to apply corrections to the data in the light of the Spacing Experiment. In fig. 15 (centre) some of the weekly flowering data are plotted; the figures are

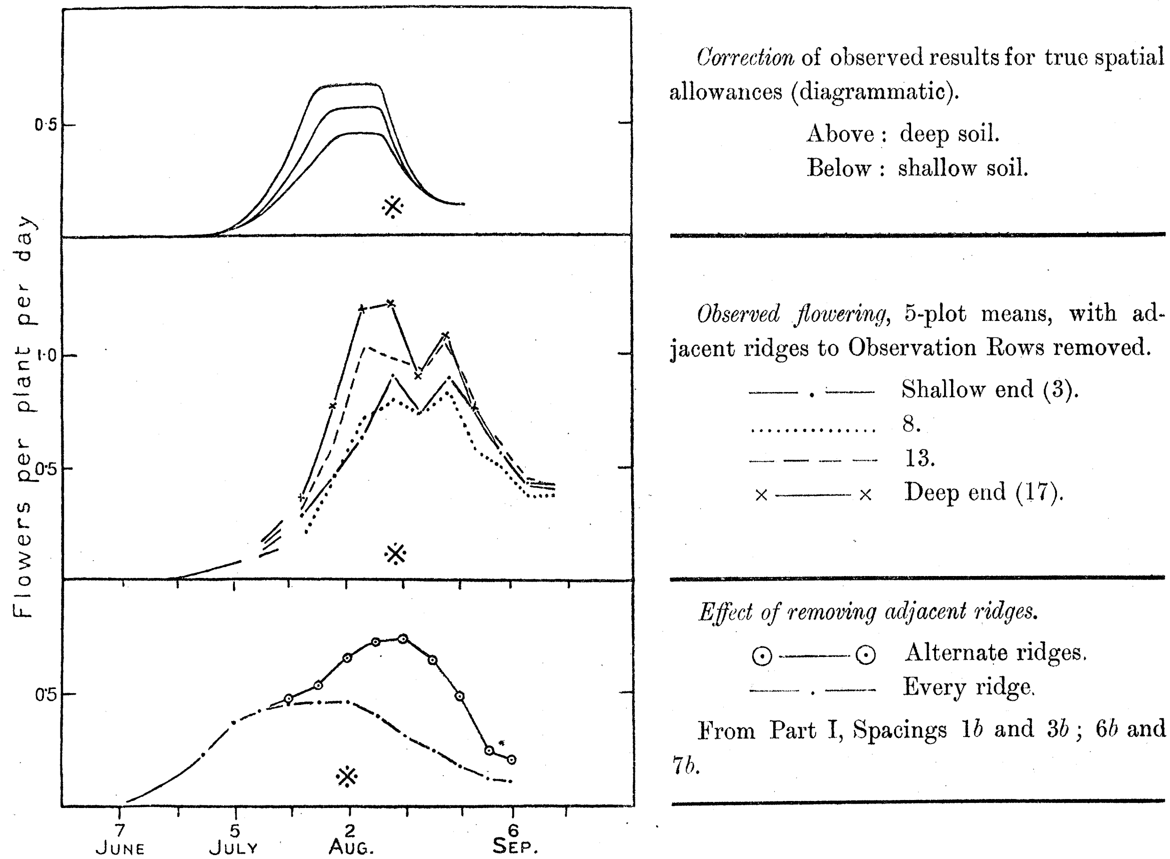

FIG. 15.—Flowering Curves from the Survey Department's "Strip Experiment," Gemmaiza, 1911.
⁎ Rise of the water-table begins.

very scanty, from small numbers of plants, and in this figure they have been steadied by computing five-plot means. It will be seen that the flowering-curve rose more slowly at the shallow end of the strip, and to a lower maximum also than at the deep end. The date of the beginning of the rise of the water-table is marked with a star, and it will be seen that the curtailment of flowering does not take place until nearly three weeks afterwards. In the lower portion of the same figure we have plotted two flowering-curves, computed specially from the data published in Part I, and corresponding respectively to a normal crop, and to a crop of which the alternate ridges have been uprooted. The latter corresponds to the observation rows of the Strip Experiment, and the former to the crop which they were supposed fairly to sample. The effect of the water-table (whose rise in the Spacing Experiment is indicated by another star) is delayed in the former case by about three weeks, while the heights of the two maxima differ in the ratio of 5 to 3. Applying these corrections roughly to the original data (centre) we can re-draw the curves as they stand in the upper portion of the figure. The curtailment of the curves then synchronises with the beginning of the rise of the water-table, and the last uncertainty in the result of this almost classic experiment is removed.

Returning to fig. 14, the form of the curve during the curtailment period in every case plotted suggests that a similar cause was operative. In the case of the Terrace data for 1910 and 1911 the exact movements of the water-table are not known, the well records being useless. We know, however, that the rise in 1910 took place very much later than in 1909, while a note in the author's 1911 field-book gives an inkling as to the date of the rise in that year; it states that "the soil in Terrace IV has been getting wet for the last few days," and is dated October 23. When compared with a similar note in 1909, dated August 8, which states "much water on the surface of IV," it definitely indicates a slow late rise, and this agrees with the behaviour of the 1911 flowering-curve in curtailment.

For 1912 we possess weekly observations of the water-table in five wells, one of these being in the centre of the Spacing Experiment plots, and also a series of soil-water gravimetric determinations throughout the season,* while in 1913 the number of wells was raised to 16, which were observed daily, and studied in a published account.† These two seasons give us critical data.

The flowering-curve of spacing 2*b* in 1912 was not curtailed sooner than July 26. It is, however, almost impossible to date the curtailment with exactitude from a single curve, and we may therefore examine fig. 16, in which the five-day means for spacing 1*b*, 3*b*, and the Field Sowings plot (p. 171) are also plotted. From 1*b* we can expect no definite indication, since this very close sowing was already in process of curtailment by water-strain and bud-shedding (Part I). On the other hand, curve 3*b* is quite definitely unaffected until August 4–5, while curve F.S. ceases to rise on August 2–3. Local soil differences may alter the date of the rise of the water-table within even a few metres distance, and we know that wider sowings show the effect later than close sowings. On the whole, therefore, it seems probable that curtailment in these curves dates from August 2, and it is certain that it does not begin before July 27. If we now transfer this date to the well-level curve for 1912, in fig. 14, the coincidence is very marked; the curtailment has begun definitely when the water-level has risen only 20 cm., and the effect shows no lag or pre-determination, but is practically instantaneous. This implies that the lower roots had grown down almost to the depth of the water-table, which is quite probable in view of our knowledge as to the form and dimensions of the root system, and it further implies that these lower roots are of such importance in the physiological balance of the plant that the asphyxiation of a few centimetres alone is sufficient to arrest the flowering.

In the data for 1913, as plotted in fig. 14, we observe that the curtailment begins most decidedly on August 19-20, and that the water-table was not so low as in 1912

* W. L. B., 'Journal Agric. Science,' 1913, *loc. cit.*

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

when its rise began. We may therefore deduce that the roots would certainly be down in actual contact with the water-table by this date, which is later than in 1912,

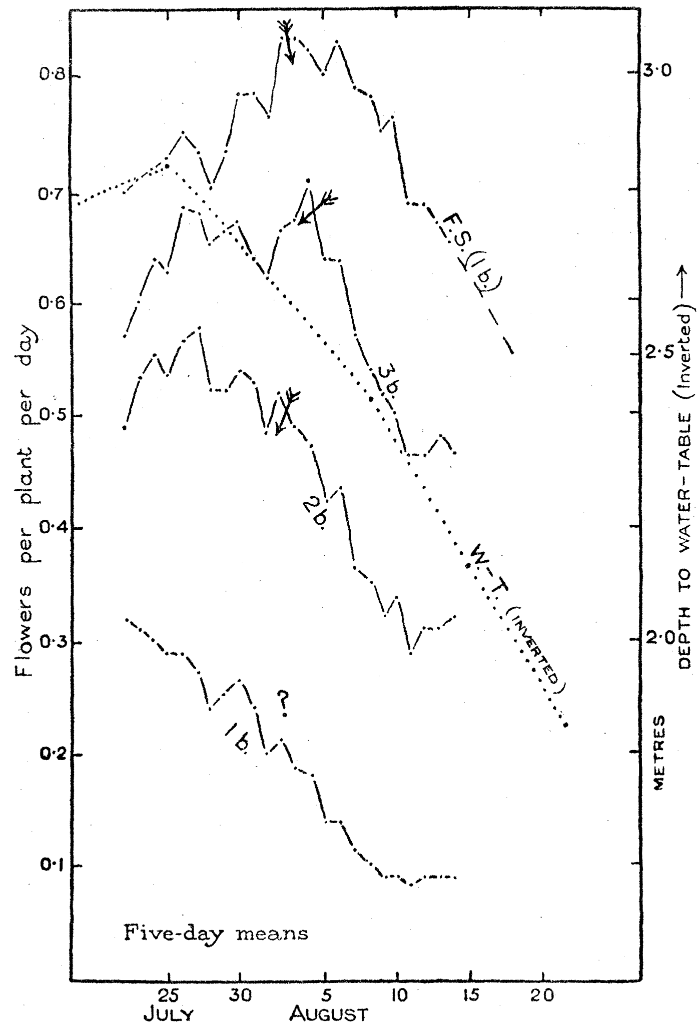

FIG. 16.—Curtailment of the Flowering Curve Effected by the Rise of the Water-table at Giza in 1912 on various Spacings.

and that even a slight rise would therefore be likely to produce an effect. Such is actually the case; the rise of the water-table curve and the fall of the flowering-curve begin simultaneously.

The sensitiveness of this response is very striking. The flowering of the cotton plant seems to be almost as good a test of water-table movements as a series of tube-well readings would be.

Thus far we have not paid attention to the Talbia curve, in fig. 14, from the "wet" plots of that experiment. Its resemblance to the Giza curve is most suggestive of another water-table effect; but the published account states that "the mean depth to the water in the bore-holes was only slightly greater in

September than in August, so that in this experiment there is no effect on the cotton plant of rise of water-level in the autumn." Now, this is a curious slip, for the August–September ratio is quite irrelevant, because the curtailment begins on July 31, and, in the absence of actual data for water-levels, it would be the July–August ratio which affected the curtailment of these Talbia curves. In all probability, therefore, those plots at Talbia which escaped curtailment by soil exhaustion and water-shortage were duly curtailed by a slight rise of the water-table; but since this rise was only a slight one, as is stated in the published account, it was not regarded as a possible operative cause. We, on the contrary, have just seen that so small a rise as one of only 20 cm. may be deadly.

It remains to consider what may be the effect of such fluctuations of the water-table as are found in shallow, undrained land, *e.g.* the shallow end of the Gemmaiza strip. Such fluctuations result from every watering.* There are no daily flowering records from plants grown under these conditions, and no daily well-level records other than the author's. These latter, when combined with the flowering-curve from the Sowing-date Experiment, provide a slight indication that the fluctuations of the flowering-curve may be affected by minor fluctuations of the well-levels, with a small lag; they are not worth further discussion, however. In all probability the root resumes its function if it is not immersed for more than one or two days, so that the curve is not permanently curtailed, but each temporary arrest of growth thus caused must help, if only by accumulation of the depressant factor, as well as by shedding, to keep the maximum of the curve below its normal level. The fertility of the surface soil was judged to be quite uniform throughout the Gemmaiza Strip, and therefore the lower maximum of flowering which was attained at the shallow end might well have been due to such repeated curtailments by the fluctuating water-table; while, on the other hand, it must not be forgotten that the fertility of the lower soil is likely to be affected by water-logging. The water drawn from tube-wells in such soil is often green from ferrous iron.

Additional Factors Determining the Final Yield as Expressed in the Bolling-curve.

It was found by the author in 1909 that the bolling-curves obtained on the terraces were closely similar to the flowering-curves; subsequent work confirmed the possibility thus indicated, of forecasting one curve from knowledge of the other.†

An appeal for voluntary assistance in making a systematic study of the crop by means of these curves was therefore issued in 1910.‡

* W. L. B., 'Cairo Scientific Journal,' *loc. cit.*, Wells 3 and 13.

† W. L. B., 'The Cotton Plant in Egypt,' p. 70.

‡ W. L. B., 'Supplement to the Khedivial Agric. Soc. Year Book,' 1909.

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In the account of the Talbia experiment published by HURST and HUGHES a suggestion was made for determining the yield of a district by sampling a hundred plants at intervals, and in describing the Salaka and Mit Khalaf experiments of 1913, Mr. KEELING proposed a forecasting scheme to be based on flowering data obtained from a few hundred observation rows scattered all over Egypt. Meanwhile the author had suggested a similar project officially, as soon as the last serious gap in our knowledge of the curve had been filled up by the discovery of the causes which determine daily fluctuations in flowering.

Such a forecasting system would obviously be very useful, while it would constitute a great advance on the ordinary methods of subjective estimation. It might even be extended to forecasting of the flowering-curve, in its early part, by means of the growth-curve (figs. 10 and 11), and would thus provide three months' clear warning as to the possible nature of the crop.

Such forecasting would necessarily be conditional, since although it is thus possible to indicate that the bolling-curve will not rise before a certain date, nor above a certain maximum, and must be curtailed after a certain interval, yet the curve then built up by "constructive factors" may be in part destroyed by "modifying factors," such as shedding, or boll-worm.

In general the bolling-curve is a replica of the flowering-curve, with a lower maximum, as we saw in Part I, but Part II provided us with a good example of the way in which this replica might be defaced. Thus, some caution must be exercised when interpreting the final yield in terms of the flowering-curve alone. In order to illustrate this point briefly, without lengthy quotation from the various seasonal data, the fig. 17 has been prepared.

In the upper half of this figure the thin line shows the flowering-curve of the hundred plants (p. 182, and fig. 11), while the thick line represents their daily bolling. Formerly we have dealt with the bolling-curve plotted from weekly totals, since a daily curve is not only tedious to obtain, but is also slightly unreliable, because the opening of the boll is not exactly defined, and a slight subjective error is thereby introduced. The native plant-observer who took duty on the weekly Friday holiday in this series was clearly more critical than his colleagues with regard to the exact definition of a "ripe" boll, or else was lazier, and in consequence we may notice five dips in the curve at seven-day intervals onward from July 2. There are, however, definite fluctuations clearly visible in this curve which are not due to subjectivity of this kind, and these fluctuations underlie the general planing-off effect of the boll-worm in this season (Part II).

The relation of this bolling-curve to its flowering-curve is demonstrated by shifting the two curves over an interval of 51 days. This shift was determined experimentally by marking a number of open flowers, and determining the mean interval elapsing until the bolls opened from them. The difference in amplitude between the two curves as thus arranged represents the loss from shedding, which takes place—if at all—almost immediately after the flower has opened, in most cases. During the early part of the rise of the curve there was clearly an excessive amount of shedding, though not sufficient to obliterate entirely the resemblances between the daily fluctuations of the two curves. This shedding diminished as soon as water

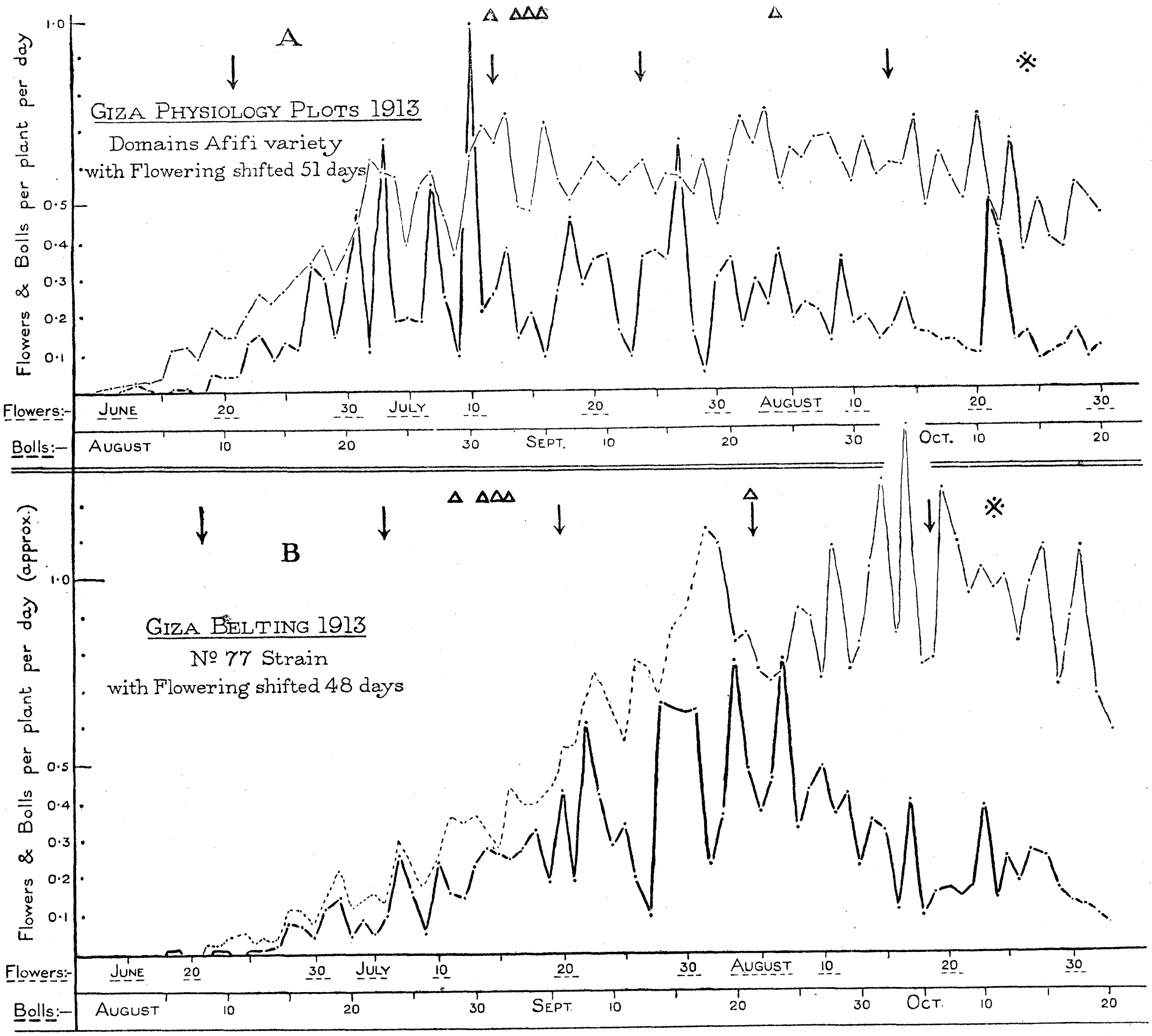

Fig. 17.—Daily Bolling, Giza, 1913.

Signs for irrigation, water-table and hot days as in fig. 8, in relation to the flowering-curves which are plotted in superposition. Thick line: bolling; thin line: flowering.

was given on June 21. After this date the principal modes in both curves correspond to one another until July 10, but after this date there is no general resemblance between the two curves. As the result of an increase in the severity of the plant-to-plant struggle for soil-water, the fluctuations of the bolling-curve come to depend more on the soil-water content, and less on the original number of flowers available.

The effect of watering is usually to produce a mode in the bolling-curve, through reduction of water-strain and thence of shedding, but this effect does not follow the watering of July 11 (arrow), since abnormally hot weather (triangles) counteracted it. The watering-mode is duly displayed after July 24. After this the boll-worm seems to become the dominant factor of the environment, though the mode underneath the flowers of August 21 should be noticed; this mode coincides with the beginning of the rise of the water-table (star), and with the curtailment of flowering (fig. 14); the existence of a mode at this time was first noted in the preliminary Sowing-date Experiment of 1911, and it would seem to be the result of capillary damping of the soil, preceding the actual invasion of the soil by the water-table itself. It acts in much the same way as an ordinary watering, and its effects are similarly traceable in the length and breaking-strain of the lint.*

Turning next to the lower half of fig. 17, we find a similar set of data, taken in the same season, from the close-sown "belting" of pure-strain plants grown round the propagation plots depicted in fig. 13. This set of observation rows was the subject of studies on lint-properties described elsewhere. The shift of the curve is three days less in this case, the maturation period of this strain at Giza having been experimentally determined in previous years as 48 days only. The "fit" of the rising part of the curves is much closer, shedding having been slight, while the subsequent complications are similar to those pointed out in the upper half of the figure. The water-table effect in causing a preliminary and temporary reduction of the shedding is quite distinct.

On comparing similar dates in the two bolling-curves it will be seen that the early modes correspond, since in both they are pre-determined (though at different intervals, 51 and 48 days) by the flowering. The later modes are independent, although the two sites were only 200 metres apart, since the later part of the curve is controlled, through the medium of shedding, by edaphic factors, of which the chief is the soil-water content. The dominating influence of the boll-worm on both curves makes further discussion inadvisable.

The general conclusion of this discussion—which might easily be extended—is that there are so many accidental circumstances affecting the shedding of the flowers that, in the long run, their total effect is fairly uniform, and thus the flowering-curve remains the principal determinant of the general form of the bolling-curve. Conditional forecasts can thus be made with fair certainty, and undue optimism about the crop can at least be avoided, since the bolling in any case cannot exceed the amount which the flowering would lead us to anticipate.

* W. L. B., 'The Development and Properties of Raw Cotton,' figs. 14 and 15.

The Factor of Varietal Constitution.

The plan pursued in the preceding pages has been that of allowing the data to tell their own story, with as little comment as possible, which they are well able to do when arranged in graphic presentation. In watching the reaction of the plant to various environmental factors we have almost entirely neglected the possibility that different varieties may react in different ways. On two occasions we have had an opportunity to point out the existence of very fine shades of difference between certain varieties, and it should be clear from the previous account that the factor of varietal constitution is relatively insignificant.* Having avoided the encumbrance of the text with references to it thus far, it now behoves us to show what effects it is capable of producing, in its reaction with any given set of environmental factors.

In figs. 18 and 19 some flowering and bolling curves have been brought together from the author's records as to the behaviour of several typical pure strains and

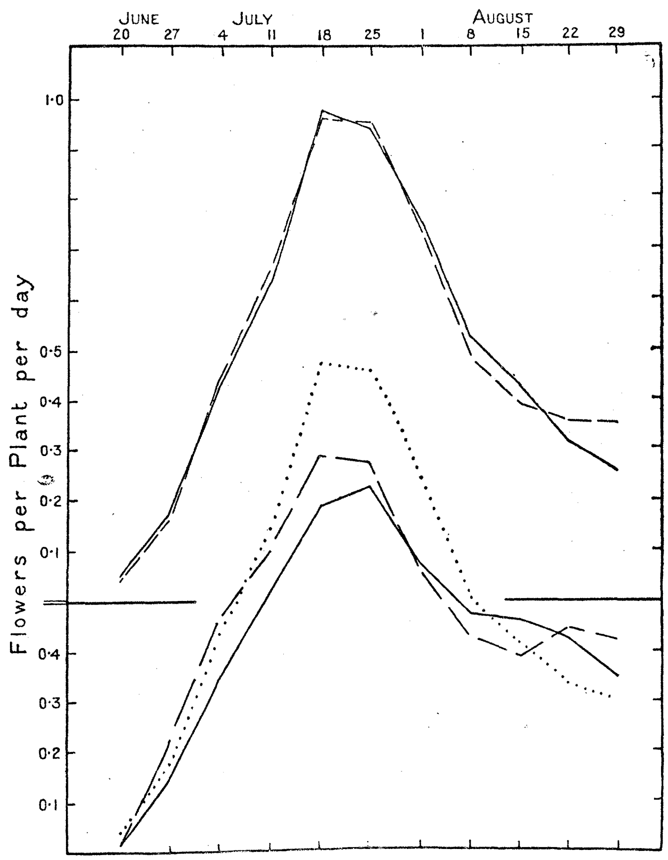

Fig. 18.—Flowering Curves from Precision Observation Rows. (Weekly Totals.)

Below : ——— Domains Assili. — — Assili. .... Afifi (Domains).

Above : Two separate sets of Domains Afifi.

* Discussion being restricted to Egyptian stocks only.

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varieties when undergoing tests in observation rows for their agricultural properties. These rows are scattered over a plot or field which has been planted with an ordinary crop, and in the case of the pure strains they have usually been obtained in this way when only a few grammes of their seed was available.

The upper half of fig. 18 shows the result of comparing two seed samples of the same variety from different sources. The identity of the two curves of weekly flowering rate shows that the method is extraordinarily delicate, and almost faultless. The variety was Domains Afifi, and the mean of the two curves is plotted again in the lower half of the figure, for comparison with two more flowering-curves obtained at the same time, on the same plot, and in the same way, from the variety Assili, and from a selected stock of it known as Domains Assili. All three are different in amplitude, but their general form is much the same.

In the upper half of fig. 19 are plotted two sets of similar comparisons made by means of the bolling-curve, from plots already mentioned elsewhere, to wit, the Terraces in 1911, and the Field Sowings plot in 1912. It will be seen that, although we have introduced further possibilities of complication by using the bolling-curve, yet the difference between the various kinds of Egyptian cotton is trivial as compared with the difference between the two years in question. It should be noticed, however, that the pure strain No. 310 begins very badly in 1912, and the reason for this is a varietal peculiarity; the strain is very liable to shedding under the climatic conditions of Giza; we have seen that the Field Sowings plot was too closely planted, and suffered from hot weather in early July, but No. 310 suffered more than any of its companions. The transference of this strain to the cooler climate of the northern Delta, where the water-strain is less severe, might be expected to improve its behaviour.

That such is the case can be seen in the two sets of 1913 flowering-curves given in the lower half of fig. 19. The curve of largest area is given at Neguila by No. 310, whereas at Giza its curve is the smallest of all. This shows that its intolerance of water-strain is not merely confined to the shedding-response, but is a general physiological peculiarity, affecting the growth-processes throughout. Again, however, the general form of the curves is unaffected by the nature of the variety, and the differences are in details only.

It does not follow from our analysis that these details are insignificant in agricultural practice. In the case of No. 310, for example, the differences shown and indicated in fig. 19 are sufficient to make it mere waste of time and labour to grow this strain outside the northern Delta, not so much on account of the smaller yield as of the inferior quality of the cotton produced. Even the minute differences in time-relationships, which we have formerly mentioned, may be economically important; a strain which has a pre-determination period of 27 days for its flowering (p. 182), and of 48 days for its boll-maturation (p. 200) will ripen its crop nearly a week sooner than another strain in which the equivalent periods are 29 and 51 days, and since this means that the whole bolling-curve is begun sooner, it is a clear gain to the farmer.

Still, and especially when compared with the exaggerated value which popular opinion usually assigns to the factor of varietal constitution, it is evident that the

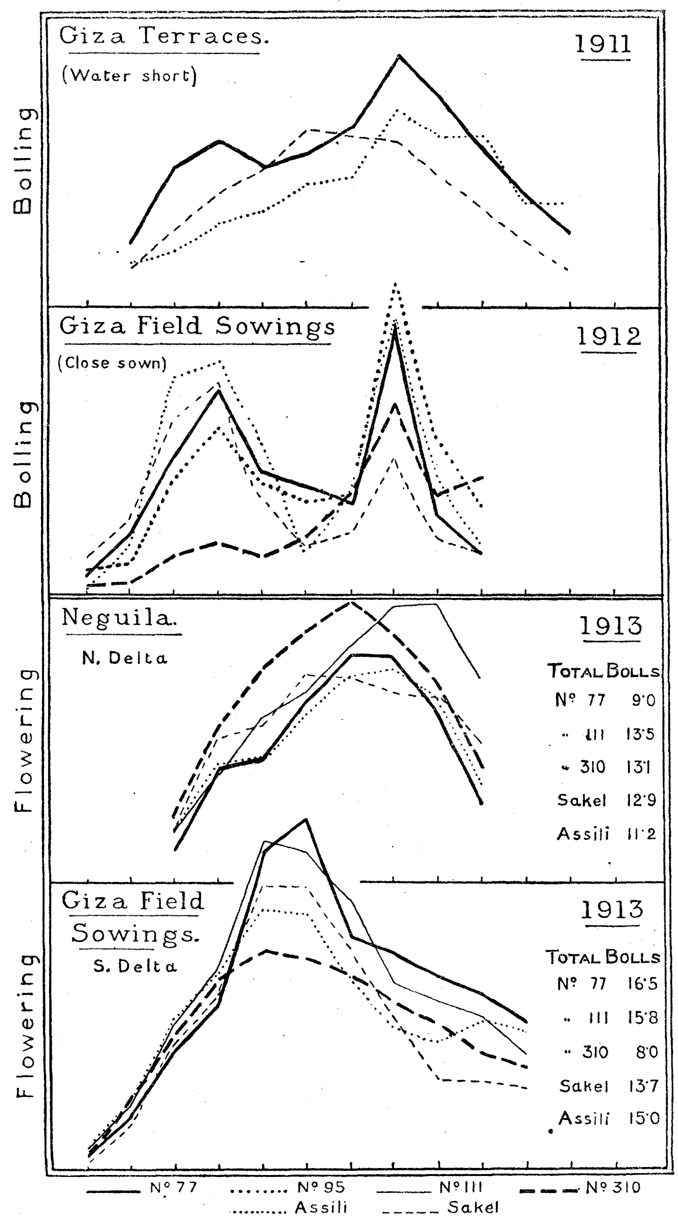

Fig. 19.—Comparison of certain Varieties and Pure Strains in Observation Rows. In two extremely dissimilar sites and in three seasons.

cotton plant in Egypt is the slave of environmental circumstances which permit to it but little display of individuality in the matter of its yield, and the conjecture made by the author in 1910, that the causes of yield deterioration should be sought in the environment, and not in varietal deterioration, seems to be fully justified.

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The Predominant Importance of the Factors which Influence the Root.

The following paragraphs are rather of the nature of a preliminary summary, treating one aspect of our results more fully than it is advisable to do in the Summary proper.

The various stages of these "Analyses" show perhaps rather more attention to the root system than it has usually been possible to give in previous investigations of the physiology of agricultural plants. This is partly due to the arid climate of Egypt, and the consequent induction of a state of water-strain in the plants; the intimate detail in which the behaviour of the plants has been recorded is another contributory cause. The information we have acquired with regard to the function of this invisible half of the plant can therefore be used to amplify the preliminary sketch which was given in 'The Cotton Plant in Egypt.'

The Spacing Experiment extended our knowledge of root-interference, and showed that the function of the individual root under field crop conditions was strictly limited in a lateral direction, and could only be developed downwards. The concurrent investigation of soil-water content* showed that this downwards extension of function applied not only to the intake of manurial constituents of the soil, but also of the water itself, the lower layers of the soil drying up more rapidly than the upper layers towards the end of the season.

The data presented in this Part with relation to root-asphyxiation (p. 191 *et seq.*) confirm this still further, by showing that the immersion of a very small fraction of the total volume of soil which had been at the plant's disposal is sufficient to curtail the flowering-curve suddenly and irremediably. It therefore seems likely that the small portion thus immersed contains almost all the functional roots, whether these be the tap-root with its lower laterals only, or whether they include laterals and tertiaries which have turned downwards when the upper layers of soil in which they were growing—often as far as 2 metres from the main stem—became exhausted.

The functional part of the root-system might thus be compared to a sweep's brush, sweeping out the available nutrient from an hexagonal prism of available soil, and itself remaining of a uniform size once the root-interference effect had begun.

Some further conclusions may be drawn from the remarkable "pan" effect on the 1909 Terraces. In our previous discussion of this matter we assigned no definite date to the time at which the root would reach this pan. On the basis of a number of excavations of roots with the water-jet it was stated in 'The Cotton Plant in Egypt' (p. 37) that the depth attained on May 15 should be about 55 cm. Allowing 28 days for pre-determination, this contact of the roots with the pan should thus be shown by the flowering on June 12, instead of on July 1. In view of the uncertainty which must attach to computations of root-depth from a relatively small

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

number of actual determinations, it is not advisable to insist on the consequent deduction, though it is certainly suggestive—namely, that since the form of the root-brush is that of an inverted hexagonal pyramid, and since the base of this pyramid is about equal to its altitude, then the date on which the pan-effect was actually felt by the plants was that on which the base of the pyramid reached the pan, and not merely its apex; in other words, this was the date on which root-interference began in the "pan" itself, all the soil above having been ransacked by the roots.

If this explanation were valid, it might also be applied to explain the diminished severity of the action of the water-table on wide-sown plants, whose zone of root-interference necessarily does not extend so far downwards as that of a close-sown crop.

The Survey Department experiments on differential watering throw further light on root-function. At Talbia, in 1912, the heavily-watered plants gave a flowering-curve of normal form, while that of the lightly-watered ones rose more rapidly to a higher maximum, and was slowly and prematurely curtailed almost at once. The same result was seen at Mit Khalaf in much less conspicuous form, while in the Salaka plots near by the effect vanished entirely. Some unrecognised variable must have existed as between these three sites, and whatever effect was observed could not have been directly caused by the water. We know from the published account that the Talbia site was rather poor land, with a low percentage of nitrates in its composition, while from the maxima attained by the flowering-curves we may deduce that Salaka was the most fertile of the three. Remembering that the soil evaporation is very rapid in May, and knowing that salty soil accumulates NaCl at its surface in consequence unless it is well watered, it seems reasonable to assume that an underwatered plot of land would similarly accumulate nutrient salts also. In this case he plants would be provided with a more concentrated soil-solution of nitrates when young, but as the root-brush passed downwards it would find the lower soil to be correspondingly exhausted. This would pre-determine the construction of a flowering-curve which began by being typical of rich soil, with a rapid rise and high maximum, but would be curtailed later by soil exhaustion as the roots went deeper, or by toxic after-effects resulting from the water shortage. Such a result would only ensue, nevertheless, if the nutrient salts were acting as a limiting factor at the time, and it would therefore not be shown upon a plot of rich soil. The latter was actually the case at Salaka.

There is an interesting corollary to this deduction, in that if the land at Talbia had contained a dangerous percentage of injurious salt, such as NaCl, the result would have been still to give the same flowering-curve on the wet plots, but a lower and slower curve would have been obtained from the dry plots, where the injurious salt would have concentrated near the surface.

It is beginning to be evident why ordinary plot experiments on the manurial treatment of Egyptian cotton have given such contradictory results as were obtained even by Mr. HUGHES.*

Lastly, we should endeavour to distinguish between the effects of water and of nutrient salts, as such. Here also we find the conception of pre-determination useful. The differential watering was begun at Talbia on May 27–29. It is noted that on July 4, some five weeks later, "the difference between the plots has become noticeable . . . the heavily watered plots have large luxuriant plants with few flowers, and the dry plots have thin small plants with an abundance of flowers." (As a matter of fact the actual difference in flowering on this date was merely as 0·67 : 0·46, which illustrates the subjectivity of inspection methods with cotton.) Further, on August 2, it is noted that the wet plots had "strong bushy plants, while the light watering has given the reverse."

This is merely a particular case of the paradox so familiar to gardeners as well as to cotton growers, but it is one which gives rise to a great deal of mental confusion, or else to the assumption of an inherent antagonism between growth and flowering, forgetting that flowering is the result of growth. In the case of this Talbia experiment its meaning seems clear: limitation of the accessible nitrates was checking cell-differentiation in the terminal buds on the wet plots, while on the dry plots such differentiation was proceeding normally. This pre-determined the frequency of flowering subsequently, when the more abundant nodes of the dry plots were cramped together on short internodes whose extension had been limited by water-shortage. The fewer nodes thus formed on the wet plots were scattered over long, free-growing internodes, whose extension had been limited by temperature conditions mainly, and in which the depressant factor induced by water-shortage was at a minimum. The existence of such a qualification has been indicated elsewhere in these "Analyses" (*e.g.*, p. 178), and these studies thus enable us to understand why the fellah seems to prefer to risk stunting his plants in the early stages of growth; his purpose apparently is not to "draw the roots down in search of moisture" (Part II, p. 414) but he tries to differentiate as many nodes of flowering branches as soon as possible. Having thus obtained potential flowers, growth is encouraged to the utmost, even at the risk of water-logging the soil, though in justice it must be mentioned that this latter bad habit is becoming less common, now that an abundant supply of summer water is not quite such a novelty as it was 10 years ago.

NOTE.—In the original plan of this Part III, a chapter was included which dealt with the relation between these Analyses and the cotton crop of Egypt as a whole for the past two decades. Such a chapter, though of very immediate interest in Egypt, would have no general scientific significance, and it is therefore postponed to a more appropriate occasion for its publication. The principal features of it, with respect both to methods and results, are outlined in this note.

The data employed are the commercial statistics published by the Alexandria General Produce Association, to show the amount of cotton arriving at that port from the interior during every week of the

* HUGHES, F., "Manuring of Cotton," 'Khedivial Agric. Soc. Year Book,' 1909.

season. These "arrivals" embody the whole of the crop of the country, and the weekly data provide a time-distribution.

The method of treatment is to regard these Arrival data as having originated from a bolling-curve, namely, the mean curve for all Egypt. Between the ripening of the bolls on the plant and their arrival in Alexandria for export, the curve is distorted in various ways, such factors as movements of the price and congestion of railway transport having decided influence. A simple method of graphic analysis can be applied to remove most of these distortions, and thus it is possible in most years to plot the mean bolling-curve of all Egypt from the Arrival data.

When so plotted it becomes clear that there has been no permanent alteration of the curve during the last 20 years. The rise varies from year to year. The maximum has been as high in the last quinquennium as in the first. The only systematic change is in the curtailment, which has been taking place earlier of late years than it used formerly to do. Correlating this with data as to the higher level at which the water-table has been maintained of late years, so that a smaller rise is sufficient to immerse the root-holding strata of soil, it follows that this earlier curtailment is due to earlier immersion of the roots.

This analysis of the Arrival data thus provides the final proof as to the validity of the author's explanation of the cause of deterioration in the yield of the Egyptian cotton crop, which for several years was a subject of controversy.

Summary and Conclusions of Part III.

The present communication presents and discusses all the available data regarding the yield of the Egyptian cotton plant which have been obtained in the analysed form of plant-development curves by the author, or by other workers using the author's methods for the solution of technical problems.

The previous Parts have dealt especially with the spatial factor, sowing-date, and the boll-worm's destructiveness. Factors discussed in the present Part include: soil-fertility, hard-pan, soil-depth, water-shortage, over-watering, root-asphyxiation, weather, and climate.

These effects were studied chiefly in their action on the flowering-curve, which represents the daily rate of flowering of an average plant. The relation between the formation of this curve and the antecedent growth-processes, as well as the subsequent yield, is outlined.

The flowering-curve, and consequently the yield-curve, is shown to have a typical form under the conditions of good cultivation. Bad cultivation is such as allows any factor to become limiting when it need not be so, thereby deforming the curve.

The differences of behaviour recorded as between various crops of cotton appear to be straightforward and inevitable consequences of the known environmental conditions, provided only that due regard is paid to the distinction in time between the causation of any effect and its manifestation.

To denote this latter distinction the author has employed the term "Pre-determination." The daily fluctuations of the flowering-curve constitute a striking example of such pre-determination, since they are controlled by weather conditions which obtained a month before the flower opens, and simultaneous fluctuations in the same direction may be shown by all the cotton fields in Egypt.

Some deductions have been made with regard to the function and dimensions of the absorbing part of the root system as distinct from the merely conducting portions.

By a combination of these analyses with a novel treatment of the commercial data concerning the Egyptian crop as a whole, it can be shown definitely that the root-asphyxiation produced by a rising water-table is the prime cause responsible for the deterioration in yield per acre which this crop has undergone.

NOTE.—From the historical point of view, an interesting and truly Egyptian feature of these experimental results is their perversity. Almost invariably it has happened that an experiment planned for the elucidation of some one factor in particular has turned out to have been in reality a study of something quite different.

Thus, the water-table investigation in 1909, on the Terraces, was especially instructive with regard to soil-texture and fertility, while its continuation in 1910 gave information about soil-texture and water-shortage. The variety-trials of 1911 were the means of explaining the water-supply experiments of the Survey Department, while these in their turn, though very carefully directed to the study of irrigation effects, were effectively studies in soil-fertility instead. The analysed part of the data from the Survey experiment in 1911 almost failed to demonstrate anything except the spatial factor, though the results of the plots were conclusive in the desired object. Lastly, our principal accession of knowledge from the variety-trials and water-supply experiments of 1913 lies in the discovery of the widespread nature of the meteorological effects.

It is conceivable that with only a slight accession of knowledge we might use the plant to record the environment.

GENERAL CONCLUSION.

The Physiological Outlook Essential for Effective Analysis of Agricultural Yield.

The purpose of the present three Parts of these Analyses was defined as a statistical analysis of the yield in terms of the plant's development, by the author's method of Plant-development Curves. This method is not limited in its application to Egyptian cotton plants, for which it was first used, but will be available for other crops.

The relation of the results to agricultural research in general would appear to the author to be somewhat as follows :—

In the first place, it should be clear that, although a cotton crop grown under irrigation was peculiarly suitable in some respects for the prosecution of these analyses, yet a further application of the present methods to the study of other crops is a matter of adjustment only, principally in the choice of cardinal points for observation. The superposition of these methods of continuous observation upon those methods of small-plot scattering which are already in use may therefore be expected to link plant physiology more closely to agriculture.

The separation between these two branches of biology is wider than is generally realised. Thus even the maize crop is scarcely understood, and BURTT-DAVY* writes, "Little is known at present of the actual effects of climate upon the maize crop."

* J. BURTT-DAVY, 'Maize,' London, 1914.

HOOKER* notes the same difficulty in attempting to trace the causal connection which is indicated by the statistical relations between the English wheat crop and the weather, while WALTER† points out in his very suggestive work on the sugar-cane crop of Mauritius that his results can only be established firmly by direct study of the growth of the crop.

The last-mentioned writer's statistical analysis of the connection between weather and crop was effected with the intention of constructing a prediction formula to be used in determining how much damage had been caused by a cyclone, with relation to compensation and insurance, just as in Part II we determined the damage caused by boll-worm, and in Part III by the water-table. But our determinations differ from those of WALTER in that they approach the subject from the opposite direction, and even in some cases deduce the environmental conditions from the reactions which the plant displays. Perhaps the most important feature of WALTER'S results is that he found it possible to neglect all rainfall above a certain amount; in other words, he realised that rainfall was a limiting factor only until it intercepted the temperature, which then became a limiting factor in its turn. Nevertheless, such treatment amounts, of necessity, to little more than a *summary* of a complex series of physiological reactions, as we have seen plainly in these present communications; still, it emphasises the importance of the Law of the Limiting Factor in the analysis of these reactions. Without this law to guide us it would be quite disconcerting to find, as we have done, that of two successive waterings of a cotton field one may produce no effect whatsoever, while the next may save the crop.

In the process of unravelling the details of such reactions between the constitution of the protoplasm and the environment in which it exists, the Law of Predetermination seems valuable. It explains such apparently contradictory observations as this: that during July the flowering of a normal Egyptian cotton crop is unaffected by watering, and yet at the same moment the same watering is the only recognisable determinant of the length of the lint hair-cells which are developing inside the bolls.

Armed with the conception of Limiting Factors, and also of the frequent Predetermination of their effects, there would seem to be room for notable advances in knowledge of what might be called "crop physiology" by applying our methods of continuous registration to the development of the plant. The subject is obviously a close relation of Ecology, but without the essential complications introduced in the latter subject by the competition of diverse species. At the same time it is very doubtful whether such investigations will do more—from the farmer's standpoint—than elucidate the reasons for conventional practice, though they might occasionally indicate the path by which advances in physiological knowledge could be directed to application in agriculture, and conversely.

It remains to mention the limitations of the Plant-development Curves as tools for

* R. H. HOOKER, "Correlation of the Weather and Crops," 'Jour. Roy. Stat. Soc.,' 1907.

† A. WALTER, 'The Sugar Industry of Mauritius,' London, 1910.

purposes of research. Their utility is probably obvious; but, in the first place, the data required for their construction must almost invariably be obtained daily throughout the season, since the day is the real time-unit in which a plant measures its experiences. In the second place, they necessitate the employment of labour, even though this be only semi-skilled. Against these disadvantages may be set the fact that they abolish the probable error of plot experiments, thereby making it possible to achieve good results with controlled areas whose dimensions would be dangerously small if the yield were not thus analysed. It is probable that the solution lies in compromise, by first establishing a set of standard data, as complete as possible, for any given crop and district, with which any subsequent observations of salient features could be compared. The establishment of such a set for the Giza Cotton Experiment Station was one of the author's chief aims, more especially because the circumstances made it possible to obtain such data as a mere side issue of the regular work. The desired extension of the observations to minor outlying stations in other parts of Egypt would have provided not only a system of precise Crop Reporting, on the lines of a weather report, but also a system of Crop Forecasts.

Our principal general conclusion is, therefore, that Blackman's Law of the Limiting Factor provides the key by which the intricate relations of any crop to its environment may be satisfactorily unlocked, provided only—

(1) That these reactions are expressed numerically, with definable significance.

(2) That they are duly referred in their origin to that stage of the plant's development at which they were actually induced.

(3) That the crop is treated as an average plant whose physiology is the subject of investigation.

In concluding the present series of publications I am faced with the difficulty of making any adequate acknowledgement for the assistance rendered by many persons in such various ways. The publication of Parts I and II with the name of Mr. Holton as joint author indicates how much these researches owe to his patience and industry, and he in his turn would no doubt wish me to acknowledge the value of our erstwhile Headman of Plant Observers, Mohammed Sorure.

I stand especially indebted in the third Part to my former colleague, Mr. F. Hughes, and to the members of the Survey Department who were charged with carrying out an independent investigation of my views on the water-table effect. In fairness it should be added that this independence was chiefly official, and it gives me pleasure to offer them, in exchange for their help, a solution of the riddle of the Talbia experiment.

Of my friend Audebeau Bey, it is only necessary to point out that he first originated the "water-table hypothesis" of crop deterioration, in collaboration with the late Mr. J. R. Gibson, and has since been a fellow-student of the soil of Egypt.

For criticism and help in the presentation of these Analyses, I am indebted to Dr. F. F. Blackman, whose Law of the Limiting Factor, on which they are entirely founded, has made them possible.

Amongst institutions my principal debt is to the old Khedivial Agricultural Society, under the presidency of the present Sultan of Egypt, for the freedom and support which was given to my studies, without irrational insistence on immediate results. The establishment of the Cotton Experiment Station at Giza, with a field laboratory, on my transference to the Department of Agriculture when first created, enabled the scope and detail of these studies to be extended, as a foundation for my system of pure strain seed supply.

Since the nature of the work made me essentially dependent upon mathematical guidance, I would, at the risk of appearing neglectful of others, especially mention the help received from four mathematicians; to wit, the late Dr. J. Clark, and Messrs. J. I. Craig, F.R.S.E., T. L. Bennett, and F. S. Richards.

Assistance has been available from my wife in all branches of experiment and in computations.

APPENDIX.

Tables of Statistical Data.

In the first Part of these Analyses the statistical data were reproduced *in extenso* except for a few omissions of details, such as the daily flowering and the plot-to-plot determinations of boll weight, etc.

In the present communication it seems advisable to discriminate with regard to the available data, to avoid the cost and bulkiness which would result if every determination employed in the discussion had to be presented in numerical form. The two preceding parts have demonstrated the nature of our material and its statistical treatment, so that some such discrimination may more easily be admitted.

The data for the Terraces (1909–1911) are presented in full, so far as the actual counts of flowers, bolls, plants, etc., are concerned. Similarly for the very small, but very important, set of observations from Neguila. In the case of all but the last, however, much of the computed data has been omitted, only the five-day means being given in 1909, and no p.p.p.d. figures at all in the other two. These will be found, substantially, presented in graphic form in the various figures of the text, and can be verified by re-computation if the reader so desires.

The unpublished Survey Department data from the Gemmaiza Strip Experiment are given in full, but without the computations made from them, which are used in fig. 15.

No figures are presented with respect to the other Survey experiments, but a note on the treatment of the published data is included.

As regards 1912 and 1913, much of the available material has already been presented in Parts I and II. The presentation of the daily flowering data throughout the season from three Spacings and from the Field Sowings plot would involve the printing of some 2000 numbers to make it of real value, while to present the daily means would merely be a duplication of the graphic presentations.

In the unlikely event that any reader should desire to study the original data, the author would have pleasure in giving him facilities for so doing; but for all ordinary purposes the numerical presentment can be obtained with sufficient accuracy by measurement of the diagrams, which are photographically reproduced from the author's own drawings on Bristol board, so that, except for errors in re-measuring due to their reduced scale, they are quite accurate.

Similar considerations apply to the Growth data presented in figs. 8, 10, and 11. The data, to be of real value for further research, require to be reproduced in full detail, the daily elongation of each separate stem and branch being stated, which is scarcely feasible. The graphic presentment alone should therefore suffice.

In conclusion, it might here be stated that no point whatever in any of the graphs employed in these Analyses has been determined by any means other than direct computation from the original data. Even the five-day means have been computed.

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TABLE I.—Season of 1909. The Terraces, Giza.

Variety, Afifi.

For description of the Terraces see text (p. 161 and figs. 1 and 2).

Sowing and dates of irrigation in Table VIII.

Graphic presentment of flowering data in fig. 3.

FLOWERING DATA.

First flowers observed on June 7. Several on June 12 and 13.

Observation rows:—Started on June 14 with the following numbers of plants. I, 40; II, 42; III, 33; IV, 37.

Increased in size on July 1 by including both ridges adjacent to the original one in each terrace, viz.: I, 118; II, 120; III, 100; IV, 109.

The observed numbers of flowers are alone presented in the following Table, so far as regards daily data, but the results of the lengthy computation of successive five-day means are included in the form of flowers p.p.p.d. for the central day of each five-day group. In the case of Terraces I and II these five-day means are corrected (p. 165).

Date.	Flowers counted on				Computed Five-day Means, per plant.			
	I.	II.	III.	IV.	I.	II.	III.	IV.
June—								
*14	6	0	9	18				
15	12	9	9	3				
16	6	0	18	18	0·13	0·08	0·13	0·14
17	18	15	15	18				
18	18	12	12	18				
19	—	—	—	—				
20	—	—	—	—				
21	—	—	—	—				
22	39	42	33	45				
23	33	21	21	42				
24	24	33	42	21	0·31	0·35	0·31	0·31
25	9	27	42	24	0·32	0·32	0·32	0·32
26	33	33	15	39	0·31	0·36	0·36	0·36
27	45	33	42	48	0·36	0·36	0·38	0·37
28	27	39	39	63	0·45	0·44	0·43	0·44
29	45	33	54	30	0·45	0·44	0·45	0·44
*30	48	57	63	63	0·48	0·48	0·48	0·46
July (rows trebled)—								
1	33	33	30	39	0·52	0·49	0·46	0·40
2	59	62	54	58	0·64	0·53	0·50	0·47
3	47	36	29	28	0·64	0·49	0·44	0·42
4	94	54	72	70	0·77	0·53	0·46	0·40
5	51	39	35	33	0·80	0·49	0·40	0·35
6	89	51	38	32	0·87	0·49	0·42	0·37
7	76	41	27	27	0·80	0·48	0·33	0·29
8	71	35	38	40	0·83	0·44	0·30	0·26
9	69	49	28	28	0·76	0·39	0·27	0·24
10	61	23	18	16	0·73	0·39	0·24	0·22
11	60	28	22	20	0·73	0·39	0·23	0·19
12	65	42	15	19	0·76	0·37	0·22	0·17
13	72	35	31	19	0·77	0·37	0·21	0·17
14	79	43	25	20	0·83	0·38	0·21	0·15
15	66	19	13	15	0·88	0·38	0·22	0·15

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TABLE I—*continued.*

Date.	Flowers counted on				Computed Five-day means, per plant.			
	I.	II.	III.	IV.	I.	II.	III.	IV.
July—								
16	87	31	20	11	0·94	0·41	0·21	0·15
17	84	38	21	18	0·88	0·39	0·21	0·13
18	98	53	24	17	0·98	0·45	0·23	0·13
19	55	36	27	9	1·04	0·49	0·22	0·14
20	109	43	21	18	1·06	0·49	0·22	0·13
21	112	51	19	17	1·06	0·47	0·21	0·14
22	96	39	21	9	1·09	0·46	0·20	0·14
23	97	43	16	21	1·04	0·43	0·18	0·13
24	67	33	22	18	0·90	0·39	0·15	0·12
25	89	29	10	11	0·84	0·36	0·14	0·12
26	48	31	5	11	0·75	0·31	0·14	0·10
27	72	26	16	13	0·71	0·29	0·12	0·09
28	54	20	15	6	0·60	0·28	0·10	0·09
29	53	24	12	6	0·59	0·25	0·12	0·08
30	39	24	4	11	0·52	0·23	0·10	0·07
31	44	19	13	10	0·46	0·21	0·10	0·06
August—								
1	39	15	7	5	0·41	0·19	0·09	0·06
2	30	11	12	3	0·41	0·18	0·09	0·06
3	31	18	9	7	0·38	0·16	0·09	0·05
4	40	18	8	7	0·36	0·16	0·09	0·06
5	28	11	8	5	0·35	0·16	0·09	0·08
6	28	15	8	13				
7	27	9	12	12				

* From June 14 to June 30 the figures in the columns "Flowers counted" have been multiplied by 3 to prevent a break in the sequence of the columns.

For plotting of the weekly means subsequent to August 7, see fig. 47 in 'The Cotton Plant in Egypt.' They show no features of particular interest; all remain low, though during the October–November fall, presumably under the control of temperature; the insignificant amounts of flowering are highest on IV, and lowest on I.

The bolling-curves for II, III, and IV are plotted in the same reference.

TABLE II.—Season of 1910. Terraces, Giza.

Variety, Afifi.

Dates of sowing and irrigation in Table VIII.

Graphic presentment of the flowering data in fig. 4; of the shedding from all the terraces, classified as buds, flowers, and fruits, in fig. 46 of 'The Cotton Plant in Egypt.'

FLOWERING DATA.

First flower opened on June 7. Five or six flowers on each terrace on June 13.

The observation rows comprised the whole of Terraces II, III, and IV, with the southern third of I.

The actual observations alone are given below. The numbers of plants observed were: I, 320; II, 342; III, 324; IV, 330.

Date.	Flowers counted on				Notes.
	I.	II.	III.	IV.	
June 20	7	10	9	17	
„ 27	17	12	16	16	
July 9	21	32	17	35	
„ 10	59	52	61	63	Daily to 24th.
„ 11	39	38	47	47	
„ 12	32	41	36	33	
„ 13	56	53	34	47	
„ 14	48	39	42	67	
„ 15	47	45	51	55	
„ 16	80	66	64	87	
„ 17	77	78	63	69	
„ 18	78	114	87	113	
„ 19	92	115	81	102	
„ 20	127	159	92	122	
„ 21	86	98	63	81	
„ 22	146	135	108	157	
„ 23	171	196	131	172	
„ 24	203	219	196	198	Henceforward weekly.
„ 30	304	301	315	351	
Aug. 6	135	230	211	263	
„ 13	186	189	185	197	
„ 20	151	135	159	174	
„ 27	81	82	99	102	
Sept. 3	57	75	67	64	
„ 10	41	62	51	57	
„ 17	37	74	56	41	
„ 24	21	28	29	17	
Oct. 1	37	26	18	15	

TABLE II—*continued.*

SHEDDING DATA.

Each week the soil below the plants was carefully cleared of all sheddings. The classification of these is into buds (unopened flowers), flowers (which had opened but had not set fruit) and bolls (fruit).

Week ending on	Buds.				Flowers.				Bolls.			
	I.	II.	III.	IV.	I.	II.	III.	IV.	I.	II.	III.	IV.
July 9 . .	13	11	20	10	15	13	15	27	2	2	2	—
,, 16 . .	6	14	4	4	24	18	29	36	1	—	2	3
,, 23 . .	7	10	13	25	110	109	97	111	1	—	1	4
,, 30 . .	12	17	4	15	238	188	121	137	2	6	3	2
Aug. 6 . .	24	14	12	13	289	200	198	140	9	10	2	2
,, 13 . .	33	11	10	13	382	225	163	233	11	3	4	3
,, 20 . .	52	39	40	48	375	345	297	368	22	12	13	23

BOLLING DATA.

No bolling data were obtained weekly, but three pickings were taken on Sept. 16, Oct. 1, and Oct. 28. The whole area of Terrace I was picked on each occasion. Weights given in kilogrammes of seed-cotton.

Terrace.	Picking.			Total yield.	Total yield per plant.
	First.	Second.	Third.		
					grm.
I	11·87	8·70	8·72	27·30	?
II	3·32	3·34	3·30	9·96	29·1
III	3·08	2·97	3·38	9·44	29·1
IV	3·77	3·58	4·10	11·45	34·4
Grand total				58·14	

A weight of 58·14 kgrm. of seed-cotton from an area 42 by 10 metres is equivalent to 430 lb. of lint per acre, approximately.

TABLE III.—Season of 1911. Terraces, Giza.

Variety trials by observation rows. Each of the 60 ridges on the terraces was sown and observed independently. The varieties under test were Afifi, Assili, Sakellarides, Voltos, and Yannovitch together with the pure strain No. 77.

Flowering data plotted in fig 5. Dates of sowing and irrigation in Table VIII.

The ridges at the north end of Terrace I received more water than the rest, owing to seepage and leakage through the bank of the water-channel. The development of the plants on these ridges 1–5 was therefore not abnormally limited by water-shortage; ridges 20–29 on Terrace I correspond to the area observed on this same terrace in 1910.

Number of plants observed was:—In ridges 1–5 alone, 149. In Terraces I (as restricted), II, III, and IV, 300 each.

Direct observations alone are given.

FLOWERING DATA.

Date.	Flowers counted on				
	Ridges 1–5.	I.	II.	III.	IV.
June 16	2	0	0	1	1
,, 17	3	0	1	1	3
,, 18	2	0	0	0	4
Interval without observations.					
July 1	81	30	45	19	35
,, 2	52	21	25	28	35
,, 3	93	41	32	34	28
,, 4	78	39	32	24	33
,, 5	86	31	45	27	36
,, 6	76	38	44	30	35
,, 7	55	38	24	23	32
,, 8	56	20	21	26	31
,, 9	88	25	28	19	21
Weekly observations henceforward.					
July 16	103	37	43	39	63
,, 23	71	72	56	49	47
,, 30	81	112	77	69	73
Aug. 6	78	130	95	86	89
,, 13	67	92	103	132	88
,, 20	70	88	108	124	94
,, 27	73	103	85	122	80
Sept. 3	81	90	112	111	109
,, 10	46	51	49	48	52
,, 17	34	34	34	27	28
,, 24	46	30	15	19	19
Oct. 1	29	15	9	4	13
,, 8	11	10	7	10	13
,, 15	10	24	20	13	22
,, 22	15	39	17	12	20
,, 29	5	18	27	19	14

BOLLING DATA.

The bolling-curves for some of the varieties grown are plotted in the uppermost portion of fig. 19.

Table IV.—Gemmaiza Strip Experiment, 1911.

The following are unpublished data from the observation rows of this experiment, for the possession and use of which the author is indebted to the Director-General of the Survey Department. (*Vide* p. 193.)

The computations made from these data are not given, except in graphic form in fig. 15.

Row.	Flowers opened on date.										Notes.	Plants in row.
	July.		August.				September.					
	23.	28.	6.	14.	20.	27.	3.	10.	17.	24.		
1	30	37	47	50	80	50	43	17	6	17	Shallow end	30
2	24	24	30	97	55	88	79	67	42	38	—	33
3	17	29	45	76	45	59	79	55	45	24	—	42
4	28	35	58	63	51	66	30	40	40	35	—	43
5	13	38	54	59	49	84	54	36	23	31	—	41
6	13	37	48	63	56	72	43	52	22	26	—	46
7	11	50	62	87	61	85	50	35	32	56	—	46
8	13	30	62	54	54	66	64	56	35	43	(Stunted)	46
9	14	57	86	79	90	100	62	50	38	31	—	42
10	25	24	53	78	72	49	45	36	33	24	—	45
11	33	41	74	72	80	96	69	43	28	22	—	46
12	11	30	72	68	66	96	66	72	53	47	—	47
13	26	59	91	80	75	98	88	51	40	15	—	45
14	32	70	114	84	108	83	81	54	22	27	—	37
15	37	67	113	134	93	92	56	37	41	30	—	46
16	26	74	105	113	92	95	74	79	41	41	—	39
17	26	78	82	78	50	70	56	28	30	26	—	46
18	32	66	116	92	79	118	76	79	37	29	—	38
19	32	54	106	118	66	80	52	64	36	42	—	50
20	13	44	98	104	87	83	98	39	67	65	—	46
21	25	64	79	100	69	94	70	50	62	38	Deep end	48

Table V.—The Survey Department Experiments.

The published accounts of those conducted at Talbia, Salaka, and Mit Khalaf present the flowering and bolling data in graphic form only.

It need only be mentioned that in all cases where use has been made of these data in Part III, whether smoothed to five-day means, or day by day, they have been handled in numerical form, and not merely copied graphically.

The published diagrams of the flowering and bolling were measured up with specially prepared scales to the second decimal place, and these figures thus obtained were tabulated. The five-day means were then computed arithmetically from these figures.

References :—Talbia Experiments ; 'Survey Department Paper,' No. 31, Cairo, 1913.
Salaka and Mit Khalaf Experiments ; B. F. E. Ruling, 'Cairo Scientific Journal,' 1915.

TABLE VI.—Season of 1913, Neguila.

A group of 11 ridges, each containing 21 holes, constituted a tiny variety trial plot in the middle of a field of commercial crop, near the farm buildings on the estate of Gabriel Bey Haddad, at Neguila in the north-western Delta.

The soil was very sandy, requiring frequent watering (see Table VIII). The 11 ridges were sown as follows, the number being the number of plants finally established. Spacing 40 by 70 cm.

One ridge each of—Afifi, 42; Sakellarides, 41; Nubari, 42; Assili, 39; Strain No. 29, 15.

Two ridges each of pure strains—No. 111, 69; No 77, 61; No. 310, 66.

Total number of plants of all kinds, 375.

Flowering observations began on July 7, a few flowers having already opened. These are plotted in two sets of alternate days in fig. 7, and separately for several varieties in fig. 19.

Since there was no attempt to eliminate soil-variation by scatter of plots or rows, the results must be taken merely as representing the behaviour of a plot of land 8 metres square in the northern Delta. At the same time it was typical of the district in all visible respects.

Since the results are of importance in the general scheme of our subject, the full data are given below.

FLOWERING DATA.

Date.	Flowers counted.	Flowers p.p.p.d.	Five-day mean.
July—			
7	25	0·04	—
8	28	0·07	—
9	41	0·11	0·088
10	33	0·09	0·108
11	50	0·13	0·144
12	53	0·14	0·172
13	93	0·25	0·208
14	94	0·25	0·234
15	102	0·27	0·266
16	98	0·26	0·298
17	114	0·30	0·318
18	154	0·41	0·330
19	133	0·35	0·348
20	125	0·33	0·364
21	130	0·35	0·352
22	141	0·38	0·352
23	132	0·35	0·362
24	—	—	0·370
25	139	0·37	0·385
26	144	0·38	0·372
27	164	0·44	0·366
28	111	0·30	0·366
29	126	0·34	0·414
30	138	0·37	0·430
31	231	0·62	0·496
August—			
1	196	0·52	0·524
2	237	0·63	0·588
3	180	0·48	0·566
4	257	0·69	0·588
5	200	0·53	0·562
6	236	0·63	0·576
7	181	0·48	0·562
8	207	0·55	0·558
9	232	0·62	0·538

TABLE VI—*continued.*

Date.	Flowers counted.	Flowers p.p.p.d.	Five-day mean.
August—			
10	193	0·51	0·560
11	197	0·53	0·560
12	222	0·59	0·540
13	206	0·55	0·570
14	196	0·52	0·564
15	247	0·66	0·570
16	187	0·50	0·572
17	232	0·62	0·576
18	210	0·56	0·542
19	201	0·54	0·526
20	184	0·49	0·502
21	160	0·42	0·485
22	—	—	0·413
23	—	—	0·340
24	124	0·33	0·347
25	100	0·27	0·327
26	164	0·44	0·316
27	100	0·27	0·312
28	100	0·27	0·290
29	118	0·31	0·230
30	59	0·16	—
31	51	0·14	—

NOTE.—In computing the five-day means, where dates are missing from the series of observations, the computed mean is that of four or three days accordingly.

BOLLING DATA.

The weekly intervals were not adhered to in counting the bolls, so that a true bolling-curve cannot be constructed. The interest attaching to the factor of varietal constitution in this site makes it advisable to put on record the data.

Variety.	Bolls ripened from previous date to						Boll-weight on Sept. 15.
	Sept. 1.	Sept 8.	Sept. 15.	Sept. 22.	Oct. 4.	Oct. 25.	
							grm.
Assili	15	6	89	51	159	106	2·27
Nubari	3	17	115	45	182	75	2·90
No. 310*a*	8	13	94	46	233	70	} 2·05
No. 310*b*	6	9	56	38	192	99	
No. 77*a*	0	7	48	23	120	58	} 2·23
No. 77*b*	5	10	57	24	121	67	
No. 111*a*	15	12	79	64	186	137	} 2·13
No. 111*b*	8	9	82	44	206	160	
No. 29	2	8	47	10	80	50	2·35
Sakellarides	2	28	110	58	177	156	2·40
Afifi	5	19	110	51	194	95	2·32

Table VII.—Propagation Plots, 1913.

Giza.			Korashia.		
Date.	Flowering rate.	Number of plants observed.	Date.	Flowering rate.	Adjacent field crop.
June 19	0·04	7852	July 23	0·96	0·9
July 1	0·25	2000			
„ 7	0·41	1200	„ 24	0·97	0·6
„ 19	1·18	700			
„ 27	2·09	1519	Aug. 5	1·75	0·7
Aug. 3	2·53	1519			
„ 10	3·15	1519	„ 16	3·74	0·4
„ 17	4·38	1519			
„ 25	5·03	1519	„ 22	5·32	0·3
„ 31	5·05	1519			
Sept. 7	5·24	1519	„ 29	4·18	0·2
„ 14	5·39	752			
„ 21	6·65*	752	Sept. 9	2·98	0·6
„ 28	5·10	752			

* Highest rate observed on any one plot during season was on this date, viz., 792 flowers on 70 plants, being 11·31 flowers p.p.p.d.

NOTE.—The data for rate in the propagation plots are based on random samples of about 2000 plants.

Those for the adjacent field crop are very approximate, being determined by counting on a single group of some 200 plants taken at random.

Table VIII.—Dates of Irrigation, etc.

Terraces, 1909.

Sown March 18 ? Heavy rain fell on April 19. Much water on surface of soil in IV on Aug. 8.

Irrigated.—May 5, May 29, July 5, Aug. 1 ? Aug. 11. No subsequent dates noted.

Terraces, 1910.

Sown March 20.

Irrigated.—May 5, May 29, July 5, July 30, Aug. 29, Sept. 24, etc.

Terraces, 1911.

Sown April 3.

Irrigated.—May 4, June 27, Aug. 3, Aug. 22, Sept. 12, etc.

Talbia, 1912.

Sown March 17–20.

Irrigated.—May 7–9, May 27–29, June 18–20, July 15–17, Aug. 10–12, Sept. 2–5, Oct. 2–5. (Different amounts to different plots.)

Field Sowings (*Giza*), 1912.

Sown March 25.

Irrigated.—April 25, May 30, June 19, July 21, Aug. 13, Sept. 11, Oct. 17.

Spacings (*Giza*), 1912. (See Part I.)

Sowing-date (*Giza*), 1913. (See Part II, Chart.)

Neguila, 1913.

Sown April 13.

Irrigated.—April 26, May 30, June 13, June 23, June 30, July 8, July 14, July 21, etc.

TABLE IX.—Defoliation of a Plant by the Cotton-Worm.

Photograph published in 'The Development and Properties of Raw Cotton' showing this plant (No. 310 (2) 2) in a very unhealthy state.

Plot watered on June 20. Egg-masses found on following day, and picking of them instituted, except on this plant. Poor land.

Four adjacent plants of the same strain were normal. The mean of these four is given.

HEIGHT OF MAIN STEM IN CENTIMETRES.

Date.	June 18.	July 2.	July 16.	July 30.	Aug. 13.
Normals	40	61	77	91	102
310 (2) 2	56	80	80	80	80
Date.	Aug. 27.	Sept. 10.	Sept. 24.	Oct. 8.	Oct. 22.
Normals	110	114	120	137	144
310 (2) 2	80	80	85	105	115

FLOWERING RATE IN SUCCESSIVE TEN-DAY PERIODS BEGINNING JUNE 1–10.

Periods.	1.	2.	3.	4.	5.	6.	7.	8.	9.
Normals . .	0·05	0·17	0·17	0·45	0·37	0·92	1·00	1·65	1·07
310 (2) 2 .	0·00	0·40	0·30	0·50	0·50	0·70	—	0·20	—
Periods.	10.	11.	12.	13.	14.	15.	16.	17.	18.
Normals . .	1·25	0·87	0·75	0·65	0·12	0·05	0·17	0·10	0·02
310 (2) 2 .	0·20	0·60	0·10	0·90	0·80	0·60	1·60	0·90	0·70

DATES ON WHICH THE FLOWERS OF THE DEFOLIATED PLANT OPENED.

During June.—11, 14, 18, 20, 21, 28, 29.

During July.—1, 3, 5, 7, 8 (photograph taken), 11, 13, 14, 17, 18, 21, 22, 23, 28, 28, 29, 30.

During August.—18, 19 only.

During September.—4, 6, 10, 12, 12, 13, 17, 18, 26, 30.

TABLE X.—Maximum Flowering and Final Yield.

This Table presents on the one hand the approximate sustained rate of flowering during the maximum of the flowering-curve, and on the other hand the final yield of the plots on which the observations were made, the latter being arranged in order of magnitude.

Its purpose is to show that there is no necessary connection between soil-fertility and yield, using the flowering maximum as the index to the former quantity.

A big crop cannot be obtained from poor soil, but good soil may give a very poor crop.

Season.	Site.	Flowering maximum rate p.p.p d.	Yield of lint, lb. per acre.
1911	Gemmaiza, deep end	0·62	600
1909	Terraces I	0·80	500
1912	Giza, Spacing 2*b*	0·53	480
1913	Mit Khalaf	0·70	470
1911	Gemmaiza, shallow end . . .	0·46	440
1910	Terraces	0·60	430
1912	Talbia, wet plots	0·42	420
1913	Salaka	0·80	380
1913	Giza, Mean Sowing-date . .	0·48	380
1911	Terraces	0·35 ?	380
1913	Neguila	0·58	350
1912	Talbia, dry plots	0·70	320
1909	Terraces II	0·50	300
1909	Terraces III	0·48—0·21	240
1909	Terraces IV	0·44—0·15	180

It should be useful to put on record some figures for final yield obtained on the same land at Giza in previous years, before the water-table was raised, by Mr. G. P. FOADEN, and published in the 'Journal of the Khedivial Agricultural Society' for 1899 and 1901. The data are from plots $1\frac{1}{2}$ to 5 acres in area, with various manurial treatments; they are arranged here in groups of comparable plots, each group representing a separate experiment conducted during 1899 or 1900. Figures representing pounds of lint per acre:—750, 700; 960, 950, 1010, 880; 900, 830; 893, 722; 320, 610, 670, 520, 520; 776, 697, 880; 827, 796; 445, 713, 845; 780, 845.

On comparing these with the analysed data given above it is clear that the highest yields could only have been obtained by late curtailment. If the curve of Terrace I in 1909 had remained at the maximum 0·80 until it had been curtailed no sooner than the 1911 or 1913 Giza curves, these high yields would have been approached. It would seem that there is a definite limit of yield per area, which cannot be exceeded, except by raising the boll-weight; it lies in the neighbourhood of 1500 lb. of lint per acre for Egyptian cotton grown at Giza.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

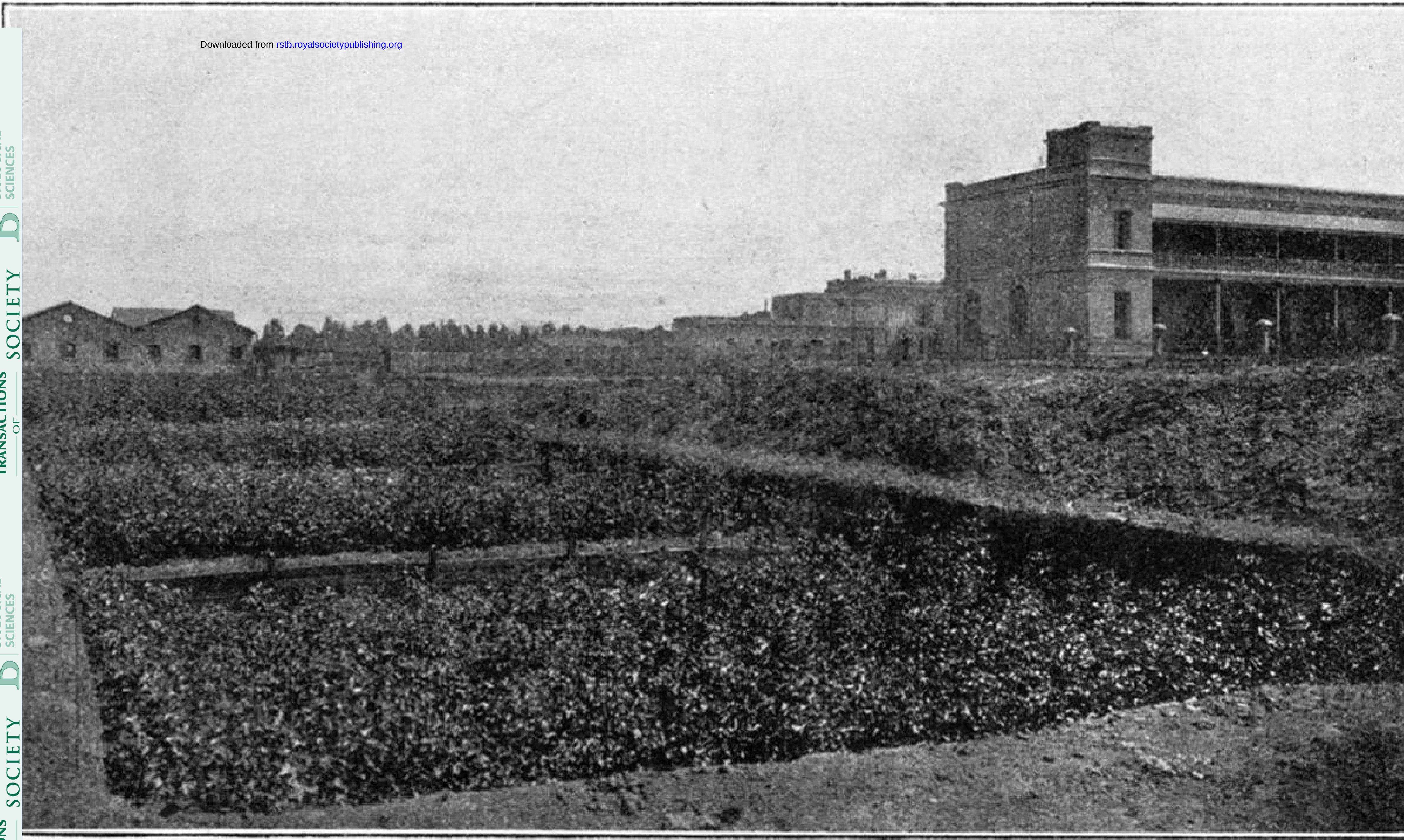

FIG. 2.—The Terraces: Giza, 1909–1911.

Photographed in June, looking north, over Terrace IV towards Terrace I.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES