The Flowering Curve of the Egyptian Cotton-plant.

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With three Tables and seven Figures in the Text.

THE introduction of the more precise methods of the plant physiologist in the analysis of agricultural experiments has been particularly

FIG. 1. Flowering curves of Cotton. I, data of W. L. Balls, Giza, 1909. II, ditto, 1911. III, Bahtim, 1917. Three years' rotation; farm-yard manure plots. IV, Bahtim, 1920. Pilon, varieties experiment.

successful in the case of the Egyptian cotton crop. Flower counts, boll counts, and growth data, all first inaugurated by W. L. Balls, are now extensively used in Egypt. Since the season of 1917 a large number of flowering curves have been obtained at the Bahtim Experimental Station relating to cotton under many different conditions of experiment. Although the intensity curve of flowering (flowers per plant per day) is of greater interest to the physiologist, yet to the agriculturist a summation curve represents much more satisfactorily the actual condition of the plant at any given moment, and these curves have been used at Bahtim since the present

FIG. 2. Flowering curve of Cotton, Bahtim, 1920. Sakellaridis, plants topped and water restricted in August.

series of observations was started. One striking feature of the summation curve (total flowers per plant up to the date given) was the fact that the irregularities were more or less smoothed out and a characteristic S-shaped curve was always obtained. Other data published by W. L. Balls (1912) and B. G. C. Bolland (1917) gave similar summation curves.

It will be seen from the analysis of some of the typical records that this summation curve can be expressed with considerable accuracy by the following equations:

$$\frac{dx}{dt} = kx(a-x) \quad \text{or} \quad \log_e \frac{ax}{a-x} = kat \quad \text{or} \quad \log \frac{x}{a-x} = K(t-t_1),$$

where a is the final number of flowers eventually obtained, x is the number of flowers up to time t . k and K are constants where

$$K = ak \log e = 0.4343 ak,$$

and t_1 is the time when $x = \frac{a}{2}$.

FIG. 3. Flowering curves of Cotton from dates of sowing experiment, Bahtim, 1920. VI, Pilion sown March 1. VII, Pilion sown April 1. VIII, Sakellaridis sown March 1. IX, Sakellaridis sown April 1.

The origin of the time scale can be taken at any point, but usually the date of the first flower is taken and the time counted in days from this point. t_1 fixes the position of the curve as a whole along the time scale.

Fig. 4. Theoretical curve $\frac{dx}{dt} = 0.0025 x (31.2 - x)$ against t and actual daily flower counts. Sakellaridis sown March 1. Bahtim. Dates of sowing experiment, 1920.

The equation is that of an autocatalytic chemical reaction and was originally formulated by W. Ostwald, who pointed out the similarity between growth processes and autocatalysis. T. B. Robertson (1908-1915) has elaborated the idea still further and prepared a series of tables for use in connexion with this equation. H. S. Reed (1920), working in California, has shown that the equation can be applied in many cases, and gives data for pear-trees and *Helianthus* so as to show the applicability to earlier published data on growth.

The flowering curve of the cotton-plant is probably particularly suited for analysis along these lines. W. L. Balls (1915) has already shown that

FIG. 5. Flowering curves (flowers per plant per day) of Cotton-plants. Pilon. Variety test. Bahtim, 1920. The broken line indicates the familiar five-day mean flowering curve. (See also Fig. 6.)

the flowering curve reproduces in its earlier stages the growth curves of the preceding month, and there is no doubt that the curve as a whole gives a very fair representation of the growth of the plant. The simplicity with which flowering records can be obtained, the unitary character of the records independent of measurements either of length or of weight, and the large number of plants which it is possible to observe, make it possible to present data of reasonable accuracy and to smooth out irregularities due to individual plant variations. In most of the cases quoted below counts have been made on four hundred plants.

The method employed in obtaining the curves is illustrated from the data given in Table I, following the methods usually adopted by the physical chemist. For a number of values of x and t the corresponding

value of K has been calculated, and it will be seen that K is practically constant over the whole range of the observed data. From the average value of K the actual theoretical curve can be calculated, and this has been done in a number of cases which are given in the figures. The original data from which the values of the constants have been calculated are given in Table II and the constants themselves in Table III.

FIG. 6. Flowering curves of the dates of sowing experiment, Bahtim, 1920. Sakellaridis and Pilon are well-known commercial varieties.

In Figs. 4 and 5 are given the $\frac{dx}{dt}$ calculated curves together with the familiar flowers per plant per day; in one case (Fig. 4) the actual daily counts are given, while in Fig. 5 the more usual five-day mean curve is given. It is only possible to smooth out these intensity curves after the summation curve has first been constructed from the data and then analysed along the lines given in this paper.

In Fig. 1 (1), representing the flowering curve given by W. L. Balls for

Giza, 1909, it is interesting to note that the curve has been cut off rather sharply after July 30. It is significant to note that according to W. L. Balls the yield at Giza in 1909 was cut down very early by the rising water table due to an exceptionally early and high Nile flood.

Very few, if any, of the Bahtim curves so far examined show this feature, and there is reason to believe from other evidence that the water table plays

FIG. 7. Smoothed flowering curves (flowers per plant per day) of the Bahtim dates of sowing experiment, 1920. PM, Pilion sown March 1. PA, Pilion sown April 1. SM, Sakellaridis sown March 1. SA, Sakellaridis sown April 1.

a relatively unimportant part in the Bahtim experiments. It ought to be possible by this method of analysis of the summation curves to indicate reasonably sharply the influence of any specially marked disturbing factor on the yield of the plant.

The possibility of the application of a series of these curves to an agricultural experiment is illustrated in Figs. 6 and 7, which give the flowering curves calculated from the data of the dates of sowing experiment at Bahtim in 1920.

TABLE I. Flowering Records of Cotton-plants. Bahtim Experiments
Dates of Sowing, 1920.

Pilion sown April 1. See Figs. 3 (VII), 7.

$$a = 38.5. \quad t_1 = 50.$$

Observed values.		K (calculated).	Calculated values from which curves are drawn.		
Flowers per plant.	Days.		x	t	$\frac{dx}{dt}$
x	t		x	t	$\frac{dx}{dt}$
0.0	5		1	17.9	0.110
0.0	10		2	24.3	0.214
0.3	15	(0.060)	4	30.9	0.404
1.2	20	0.050	5	33.1	0.491
2.3	25	0.049	8	38.1	0.715
3.7	30	0.049	10	40.7	0.835
6.2	35	0.048	12	43.0	0.932
9.4	40	0.049	15	46.0	1.033
14.2	45	0.047	18	48.8	1.082
19.2	50	0.047	20	50.7	1.084
24.4	55	0.048	22	52.3	1.063
28.7	60	0.047	25	55.5	0.989
32.3	65	0.048	28	58.7	0.861
35.2	70	0.051	30	61.2	0.747
36.5	75	0.050	32	64.1	0.609
37.3	80	0.049	35	70.4	0.359
37.8	85	0.049	36	73.6	0.264
38.2	90	0.052	37	78.4	0.163
38.3	95	0.051	38	88.6	0.056
38.3	100	0.046	38.3	96.6	0.022
38.4	105				
38.4	110				

Average value of $K = 0.049$

$$k = \frac{0.049}{0.4343 \times 38.5} = 0.0029$$

TABLE II. Flowering of cotton-plants. Flowers per plant up to date given. Bahtim experiments.

Time in days from commencement of flowering.	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110
1917.	0.4	0.8	1.6	3.1	4.6	6.9	10.2	14.1	17.0	19.2	21.7	23.3	24.2	24.5	24.8	25.0	25.1	25.1				
1920.	1.	0.2	0.7	1.8	3.3	5.3	7.8	11.3	14.4	17.6	20.1	22.1	23.7	24.4	24.9	25.2	25.4	25.6	25.7			
2.	0.3	1.6	3.0	4.6	7.3	10.5	14.7	18.4	22.5	25.8	28.3	30.7	32.3	33.0	33.3	33.6	33.7					
3.	0.2	1.3	3.0	5.0	7.8	11.8	17.3	22.7	27.4	30.4	33.2	35.6	37.6	38.4	38.8	39.1	39.3	39.5	39.6	39.7	39.7	39.8
4.	0.0	0.0	0.3	1.2	2.3	3.7	6.2	9.4	14.2	19.2	24.4	28.7	32.3	35.2	36.5	37.3	37.8	38.2	38.3	38.3	38.4	38.4
5.	0.3	1.1	2.3	3.5	5.2	7.5	10.2	12.7	15.4	17.9	20.3	22.8	25.2	27.1	28.3	29.4	30.0	30.5	30.8	31.0	31.1	31.1
6.	0.0	0.0	0.2	0.8	1.4	2.2	3.3	4.8	7.0	9.3	11.7	14.5	17.1	19.8	21.7	23.5	24.5	25.2	25.8	26.1	26.3	26.4

Flowers per plant calculated from data of W. L. Balls, 'The Cotton-plant in Egypt', p. 65 (1912).

Time in days from beginning of flowering.

Giza, 1909. 0.3 0.9 2.4 5.3 8.2 11.9 14.8 16.3 17.3 18.0 18.5 19.0 19.4 19.6 20.0 20.6
1911. 0.4 1.3 2.0 3.5 5.2 7.8 10.7 13.8 16.7 19.6 23.0 24.5 25.5 26.0 26.5

TABLE III. Values of constants used in plotting the flowering curves in Figs. 1-7.

Variety and treatment of cotton-plants.	a	K	k	t ₁	Date of origin. t = 0.
Giza, 1909 (W. L. Balls)	.	.	.	.	June 11
Giza, 1911 (W. L. Balls)	.	.	.	.	June 18
Bahtim, 1917. Three years' rotation Sakellariadis. Farm-yard manure plots.	21.0	0.044	—	40.0	June 19
	27.0	0.032	—	56.0	
	25.0	0.052	—	38.0	
Bahtim, 1920.					
1. Sakellariadis. Plants topped and watering restricted in August	25.7	0.047	—	38.0	June 10
2. Pilon. Variety test	34.0	0.044	0.0030	38.5	June 13
3. Pilon sown March 1. Dates of sowing experiment	40.0	0.044	0.0025	39.0	June 13
4. Pilon sown April 1. Dates of sowing experiment	38.5	0.049	0.0029	50.0	June 13
5. Sakellariadis sown March 1. Dates of sowing experiment	31.2	0.034	0.0025	45.0	June 13
6. Sakellariadis sown April 1. Dates of sowing experiment	26.6	0.038	0.0033	58.0	June 13

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