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Introduction

The subject of plant morphology is frequently considered a boring topic by both teacher and pupil, and consequently given a somewhat inadequate treatment. Several reasons can be adduced for this unfortunate neglect of a field of knowledge which is, in fact, particularly suitable for intensive study in schools. An unnecessary restriction of teaching types (*e.g.*, broad bean, crocus, sweet pea, etc.) may evoke bored familiarity, or the subject may be given such a superficial treatment that no morphological analysis is achieved and interest is not aroused. Often, a grossly teleological approach is adopted in teaching morphology and many unproven assumptions are made.

The work reported here was designed as a simple student exercise in which a familiar morphological subject, the tulip, is treated in an investigational spirit without, as far as possible, prior assumptions about the functions of the structures studied. Rees (2) draws attention to the dearth of detailed information about the growth cycle of the tulip.

The purpose of this investigation is to study the structure and growth cycle of the tulip through observations spread over one growing season, and in particular, to assess the possible importance of two processes which might contribute to the formation of daughter bulbs. These processes are (a) the accumulation of photosynthate from the current year's foliage, and (b) direct translocation of food reserves from the parent bulb to daughter bulbs.

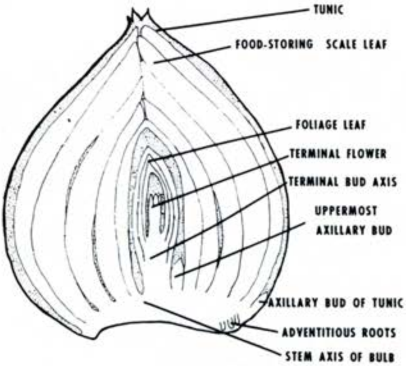

Fig. 1. Tulip bulb, longitudinal section.

A tulip bulb consists of a disc-shaped stem axis from the edge of which adventitious roots arise. The axis bears a spiral succession of scale leaves (Fig.1). The first scale leaf or **tunic** is brown and papery. A proportion of bulbs bear the vestiges of the last season's flower stalk attached laterally outside the tunic. Within the tunic there are generally five fleshy scale leaves which are rich in starch reserves. Each leaf bears an axillary bud at its base.

Rees (2) has found a significant tendency towards more than one bud in the outer scale leaves. Certainly, two buds frequently occur at the base of the tunic. Some or all of these buds are destined to develop into daughter bulbs, their complete development being spread over nearly two and one-half years. The fleshy scale leaves enclose a terminal bud consisting of a bud axis bearing rudimentary foliage leaves and terminating in a flower.

Methods and Materials

1. A stock of commercial bulbs of the Darwin tulip, Parade, was obtained in October 1972; 100 bulbs were planted at four inch spacings in garden soil and the remainder were used for class examination. Students were asked to determine the mean fresh and dry weights of the dormant bulbs, to dissect them, and to investigate the following problems:

   a. What is the chief food reserve of the bulb and where is it stored?
   b. How many scale leaves occur in a bulb?
   c. How many scale leaf axillary buds per bulb?
   d. What is the structure of the terminal bud?
   e. Can a possible annual growth cycle be inferred from the structure of the bulb? If so, what is the maximum rate of vegetative reproduction?

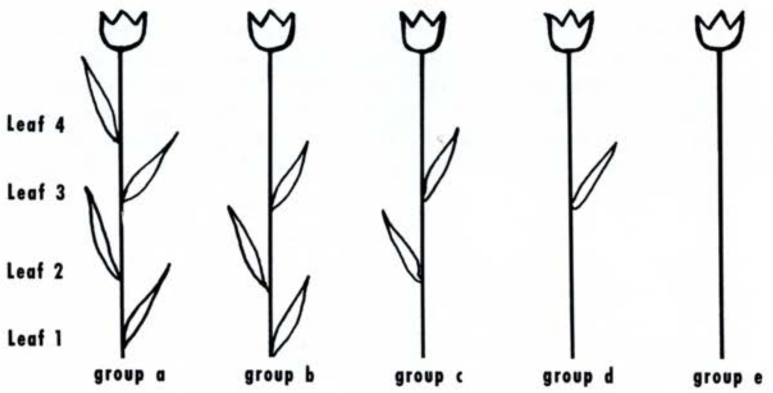

Fig. 2. Defoliation treatments.

2. When aerial growth of the planted bulbs began in the spring of 1973 the plants were grouped as follows (Fig. 2):

Group A and Group B

47 bulbs received no treatment and served as controls. When these bulbs grew they were divided into two groups depending upon the number of foliage leaves present. Group A possessed four foliage leaves per plant and Group B possessed three foliage leaves per plant.

Group C

53 bulbs received a treatment in which their first basal, foliage leaves were removed by cutting the leaves as near the stem axis as possible as soon as the leaves appeared. This treatment was conducted on March 3, 1973. Fifteen of these plants received no further treatment and were designated as Group C.

Group D

38 of the remaining bulbs had their second basal foliage leaves removed on April 4, 1973. 22 of these bulbs received no further treatment and were designated Group D.

Group E

The remaining 13 bulbs had their third foliage leaves removed on April 17, 1973 and designated as Group E.

By the time extension growth of the stem axis had occurred, the following groups of plants could be distinguished as indicated in Table 1. The remainder of the planted bulbs either failed to develop or were damaged.

Table 1

A. Untreated plants with 4 leaves	12
B. Untreated plants with 3 leaves	26
C. Defoliated plants with 2 leaves	15
D. Defoliated plants with 1 leaf	22
E. Defoliated plants with 0 leaves	13
Total plants	88

3. In each treated group, the mean fresh weight and dry weight of the excised leaves was determined. Since there was considerable renewal of the leaf tissue from the basal meristem in the plants receiving treatment, it was necessary to trim defoliated nodes and calculate the fresh weight and dry weight of this residue.

4. All plants were carefully uprooted on August 6, 1973 and the following data collected for each plant:

   (a) Number of daughter bulbs.
   (b) Total fresh weight of daughter bulbs per parent plant.
   (c) Total dry weight of daughter bulbs per parent plant.

5. For a sample of ten plants in Group B, the fresh and dry weights of the whole plant was determined after removal of the daughter bulbs, (i.e., the combined weights of the roots, remnants of the parent bulb, and the aerial shoot system.)

6. All data was submitted to statistical analysis.

Results

After planting the bulbs, field observations indicated a relatively uniform development of the tulips, with few casualties resulting from defoliation. Vegetative development was followed by uniform flowering in early May. By May 13, petal fall had begun. There was some indication that petal abscission occurred up to ten days earlier in completely or partially defoliated plants, but further study is needed to substantiate this observation.

Upon recovery of the bulbs in August, laboratory investigations also indicated uniform development of the mean number of daughter bulbs per parent bulb of all groups of bulbs (Table 2). Sample sizes, however, were insufficient to reveal any significant differences between treatments.

Table 2

Mean Number of Daughter Bulbs Obtained from Five Groups of Tulips

Group	No. of leaves	Sample Size	Mean No. of daughter bulbs	S.E. of mean
A	4	12	2.41	+0.48
B	3	26	2.27	+0.15
C	2	16	2.44	+0.20
D	1	22	2.05	+0.14
E	0	13	2.00	+0.16

Further analysis of the effect of defoliation on the size of the daughter bulbs indicated that total daughter bulb weight was a more useful criterion in determining daughter bulb development. This avoided difficulties in estimating the number and degree of development of the daughter bulbs.

The fresh weight results were highly variable but it was possible to detect a significant weight loss in the defoliated treatments. Dry weight results were less variable and clearly show (Table 3) the effect of defoliation on Groups C, D, and E. It is also to be noted in Table 2 that the possession of a fourth leaf in Group A did not significantly increase daughter bulb yield when compared to the three-leafed plants in Group B. It may be that the total photosynthetic area in the two groups of plants is similar.

Table 3

Mean Total Dry Weight of Daughter Bulbs Obtained from Five Groups of Tulips

Group	No. of leaves	Sample size	Mean total dry wt., g	S.E. of mean
A	4	11	14.72	+ 4.59
B	3	22	14.41	+ 3.27
C	2	16	8.80***	+ 2.96
D	1	22	6.70***	+ 3.16
E	0	12	4.10***	+ 1.83

Differences from plants with 3 leaves,
* $p = 0.05$; ** $p = 0.01$; *** $p = 0.001$

Data concerning the dry weights of all parent bulbs and their excised leaves are shown in Table 4. The mean dry weight of the stems, leaves, roots and parent bulb for Group B plants (measured in June 1973) was 6.61 gm in a sampling of ten plants.

Table 4

Mean Dry Weight Data of Parent Bulbs and Excised Leaves Obtained from Five Groups of Tulips.

Group	Material	Sample Size	Excised Date	Mean dry wt., g
A,B	Parent bulb	10	---	14.92
C	1st excised leaf	53	March 3, 1973	0.38
D	2nd excised leaf	38	April 4, 1973	0.14
E	3rd excised leaf	22	April 17, 1973	0.38

Discussion

The significant differences observed in the mean, dry-bulb weight between bulbs with zero or one leaf; one and two leaves; and two and three leaves (Table 3) are interpreted as approximating the net biomass produced by the photosynthetic processes of each foliage leaf of the experimental plants. By adding these increments, a total mean production of 10.31g biomass was observed for three foliage leaves.

In addition, some idea of the annual, dry-matter produced by a tulip plant may also be obtained by subtracting the mean, dry-weight of the parent bulbs from the total mean of the dry weight of typical foliated plants (Group B) as follows:

Mean, Dry-Weight of Daughter Bulbs Harvested in June, 1973	**14.41 g**	**(1)**
Mean, Dry-Weight of Accessory Vegetation of the Daughter Bulbs Harvested in June, 1973	**6.61 g**	**(2)**
Total Mean, Dry-Weight of Tulips Harvested in June, 1973	**21.02 g**	**(3)**
Mean, Dry-Weight of Parent Bulbs Planted in October, 1972	**14.92 g**	**(4)**
Net Mean Annual Dry-Weight Gain Per Tulip Plant	**6.10 g**	**(5)**

The estimated annual dry-weight computed by this method is comparable to the observed results published by Rees (2) for three Darwin cultivars.

The discrepancy between the **estimated** annual, mean dry-weight accumulation (10.31 g) in Group E tulips is accounted for by the loss of biomass due to respiration. This loss in weight was not observed in the control plants (Group B) due to the photosynthetic activity of their leaves. According to Briggs, Kidd and West (1) an annual fluctuation in dry weight occurs with weight loss in the early stages of growth but is followed by a weight recovery period as the emerging plants acquire foliage.

Figure 3 schematically represents the hypothetical fluctuation of the growth curve of a tulip plant and was constructed with the three following considerations:

a. Point L represents the mean dry-weight of parent bulbs planted in October. Point M is derived from data computed from defoliated plants in Group E as follows:

Mean Dry-Weight of Group E Daughter Bulbs	**4.10 g**	**(1)**
Mean Dry-Weight of Accessory Tissue	**6.61 g**	**(2)**
Total Mean Biomass of Group E plants	**10.71 g**	**(3)**
Mean Dry-Weight of Parent Bulbs	**14.92 g**	**(4)**
Net Biomass Accrued	**-4.21 g**	**(5)**

This negative value is interpreted as the biomass lost due to plant respiration and is plotted as Point M. Line LM represents the hypothetical rate of respiration of tulip bulbs. No data was collected to show precisely how this respiration rate was distributed over the growing season.

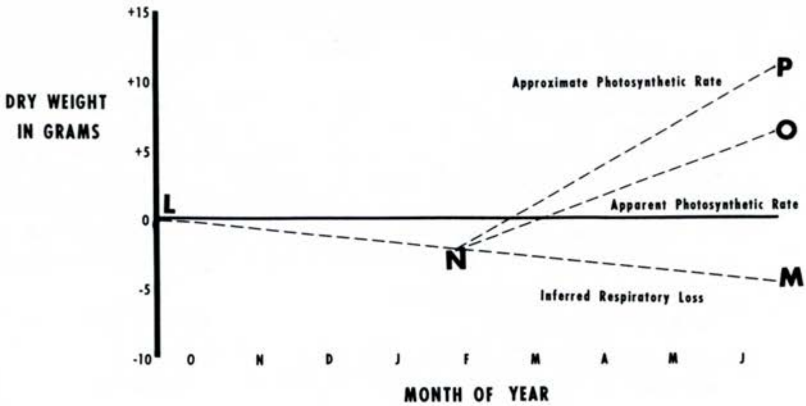

Fig. 3. Photosynthesis rates in tulips.

b. This respiratory loss can also be assumed to have occurred in typical Group B foliated plants, which, in fact, made a final dry weight gain, thus:

Mean Dry-Weight of Daughter Bulbs of Group B Plants	**14.72 g (1)**
Mean Dry-Weight of Accessory Vegetation	**6.61 g (2)**
Total Dry-Weight of Group B Plants	**21.33 g (3)**
Mean Dry-Weight of Parent Bulbs of Group B Plants	**14.92 g (4)**
Net Mean Dry-Weight Gain of Group B Plants	**6.41 g (5)**

In Figure 3 the observed biomass increase of 6.41 g is plotted at point 0. Since this increase in biomass could have occurred only after February when foliage began appearing above the ground, point N is plotted on the inferred respiratory loss line LM above the February intercept. Line NO thus represents an estimated rate of the **observed** biomass accumulation due to photosynthetic activity of plants with all leaves present (Group B).

c. As previously noted, during the growing season an estimated 4.21 g of biomass was consumed in respiration. It can be inferred that the gross biomass produced by tulip plant was thus approximately 10.62 g (6.41 g + 4.21 g). 4.21 g of which was used as food for energy rather than in growth of plant tissue. Point P plotted at 10.62 g thus represents the estimated gross synthesis activity of the plant at the end of the growing season. Point 0 represents only that apparent portion of photosynthesis that produced plant growth. Line NP closely approximates the total photosynthetic rate of production of the biomass of the tulip bulb during the growing season. Part of this latter biomass production (4.21 g) was dissipated as energy and the bulk (6.41 g) was used in the construction of plant tissue. A great deal of the tissue produced concerned the formation of daughter bulbs. Not taken into consideration in the total estimated photosynthetic rate is the respiratory activities of the leaves and stems during the growing season.

Conclusion

This experiment poses many interesting questions concerning experimental design and interpretation, both of which stimulate rigorous thinking and controversy. Many other experiments are suggested for tulips and other herbaceous perennials. For example, correlations could be made between the total dry weight produced by the tulip plant and the leaf surface exposed. The primary educational benefit of such an exercise results from the student being able to conduct a scientific investigation without expensive resources, complex techniques, or sophisticated theoretical background and knowledge.

Literature Cited

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