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NOTE ON LEAF AREA INDEX IN A SOLITARY PLANT

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1. Introduction

This paper deals with some observations on the leaf area of a solitary plant of *Helianthus annuus*, the large annual sunflower. This plant species exists in a number of different forms, e.g. a rather loosely branched type with numerous flower stalks in the axils of subsequent leaves and fairly small leaves and flower heads. On the other hand, the more 'classical' type usually grows higher (3–7 meters), develops a thick, unbranched stem, rather short internodes, numerous very large leaves and a single very large flowerhead.

At suitable spots this plant variety develops as a typical solitary plant. This may happen on planting in a single row at sufficiently large mutual distances. On planting in a field the minimum distance required in our climate is $\geqslant 2$ m.

The present observations deal with a single solitary plant of the latter type (see fig. 1), and were made towards the end of the growing season in 1973 (1–5 October). The most striking feature of this type of plant, in its most characteristic development, is that the leaves hang around the stem, with their leaf blades more or less bent downwards so that they build a green cylinder, or a green coat with a rather large diameter, around the stem. It is obvious that this leaf pattern, in a solitary plant builds an excellent light trap, which may be essential for the large amount of growth this plant achieves in a short time (from ca 15 May to 1 October in our climate).

2. Measurements

The following estimations were made:

1. The height of the plant.

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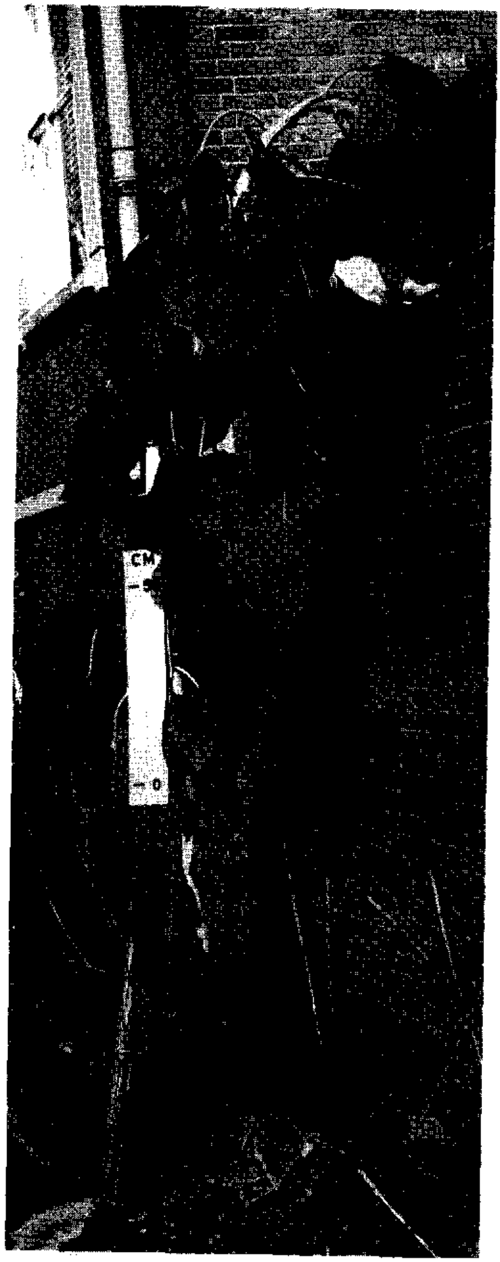

FIG. 1. The sunflower plant at which the measurements discussed were made.

TABLE 1. Stem thickness at various heights.

Distance from stem base (cm)	Stem diameter (cm)	Average (cm)
0	5.9/6.1	6.0
50	4.9/5.0	5.0
100	5.1/4.6	4.9
150	4.8/5.3	5.1
200	4.6/4.9	4.8
250	4.0/4.2	4.1
300	3.2/2.9	3.1
just below flower	4.1/3.6	3.9

TABLE 2. Length of successive stem internodes from bottom to top (cm).

16.5 – 17.8 – 20.3 – 22.0 – 20.1 – 2.7 – 10.8 – 5.5 – 5.1 – 3.7 – 4.3 – 5.5 – 3.1 – 6.4 – 9.2 – 3.4 – 7.3 – 6.5 – 5.0 – 6.0 – 5.6 – 5.4 – 4.0 – 6.2 – 5.5 – 4.2 – 5.9 – 3.7 – 4.0 – 7.3 – 3.3 – 5.6 – 5.0 – 2.8 – 5.9 – 3.2 – 5.8 – 4.6 – 3.4 – 3.8 – 5.6 – 3.2 – 7.0 – 4.6 – 6.1 – 10.8 – 9.0 – end piece 29.5

2. The stem diameter at various distances along the stem (Table 1).
3. The number and length of the subsequent internodes (Table 2).
4. The number of leaves; the petiole length, leaf length and leaf width of each leaf (Table 3).
5. The size of the flower head and the number of seeds (Table 4).
6. The separate fresh and dry weight of the various plant parts: roots, stem, leaves (together), flower, seeds (Table 5).
7. The size of the green cylinder, formed by the leaves (see text and Table 6).

3. COMMENTS ON THE ITEMS MENTIONED UNDER 2

Ad. 1. The height of the plant from rootbase till flower head was ∽ 355 cm.

Ad. 2. The data of Table 1 show that the stem is thickest at its base, tapers very gradually towards the top where it thickens again a little just below the flower head.

Ad. 3. Table 2 shows that in total 47 internodes were counted, plus an 'end-piece'. The internodes are rather long below, then decrease abruptly in length, and increase a little again towards the top.

Ad. 4. At the harvest date 38 leaves (numbered 3–40) still were present. The lower ones had somewhat smaller leafblades; petiole length and size of the blade furtheron showed very little variation. Still higher, from leaf 33 on, the petioles were again shorter; the blades still had about the same length; re-

TABLE 3. Dimensions of leaves

Leaf no	Length of petiole cm	Lamina Length (L) cm	Lamina Width (W) cm	Leaf surface ($\frac{1}{2}$ L W) cm ^{2}
3	32.2	35.1	30.5	550
4	31.4	32.5	36.0	570
5	32.8	37.9	38.7	730
6	32.8	37.6	37.0	695
7	30.8	36.9	39.3	725
8	34.3	41.8	47.7	995
9	34.4	41.8	42.5	910
10	35.0	40.0	43.7	870
11	33.4	40.3	43.0	870
12	33.7	39.7	44.2	880
13	33.4	37.2	38.0	710
14	34.3	43.8	46.4	1001
15	31.9	39.4	46.0	900
16	31.3	37.3	38.7	720
17	32.0	38.2	44.2	850
18	34.6	40.5	44.9	910
19	30.5	38.5	44.8	855
20	34.0	42.8	49.4	1006
21	34.9	39.0	46.3	900
22	34.5	41.8	48.0	1000
23	29.8	38.0	44.0	830
24	31.7	40.2	45.2	910
25	34.8	42.5	47.5	1002
26	29.8	42.7	44.4	950
27	32.6	44.0	48.6	1006
28	27.7	42.5	43.0	910
29	33.0	43.4	44.3	960
30	30.6	42.5	43.8	930
31	26.1	42.0	42.0	880
32	32.0	46.1	42.5	980
33	25.9	45.1	42.9	970
34	23.3	44.7	37.0	830
35	25.6	48.6	40.1	980
36	19.5	43.3	37.9	820
37	19.0	44.8	37.2	830
38	17.5	43.1	36.0	780
39	12.0	36.5	30.0	550
40	11.0	39.0	29.6	576
			Total	32341 ($\backsim$ 3.2 m^2)

markably the width somewhat decreased; only in the highest two ones both length and width decrease. Leaf surface of the individual leaves was estimated by considering them as triangles ($O = \frac{1}{2}L \times W$). This probably somewhat underestimates the real value. We have, however, not attempted at introducing

TABLE 4. Data on flower head.

Diameter (cm) (various directions)	33 – 32 – 31 – 31 – 31
Total amount of seeds	1603
(including absent ones)	(284)
Surface of flowerhead	804 cm^2
(emptied from seeds by birds)	(135 cm^2)

TABLE 5. Data on fresh and dry weight

	Fresh weight (g)	Dry weight (g)	%
Roots	1435.2	264.36	19.6
Stem	4367.3	884.95	20.4
Leaves	2137.5	484.22	22.8
Flower head	1728.6	170.45	9.8
Seeds	354.7	139.54	39.0
Total		1943.52	

TABLE 6. Diameter of leaf 'cylinder' at various stem heights.

Height (cm)	Diameter (cm)	Circumference cylinder ($\pi d = 2\pi r$) (cm)
100	50	158
150	60	190
200	70	220
250	50	158
300	50	158
Average	56	176
Height of cylinder: 200 cm		

a correction factor. As may be seen from Table 3, the average size per leaf is ∽ 900 cm^2, the total area of the 38 leaves present at harvest was ∽ 32300 cm^2, or ∽ 3.2 m^2.

Ad. 5. The size of the flower head is about the same as that of an average leaf; 1600 seeds were still present, ∽ 300 had been removed by birds, covering ∽ $^1/_6$ of the surface of the flower (Table 4).

Ad. 6. Total dry weight at harvest was a little less than 2 kg (Table 5), by far the largest weight was in the stem. The seeds cover only 7.1% of total dry wt, or ∽ 8% if no seeds had been romoved. Dry wt percentage of roots, stem, and leaves was 20%, that of the flower head was only 10%; on the contrary that of the seeds was near 40%.

Ad. 7. In order to estimate the size of the cylinder of green leaves, attempts were made to measure its diameter. Data were taken from the plant in situ, but, unfortunately, later on, on closer consideration, the values recorded appeared far too large and utterly improbable. We have, therefore, made use of the photograph of figure 1, accompanied by a scale (see the picture) to obtain data about the diameter of the cylinder. This yielded the data of Table 6 which we have used in further calculations and considerations. The diameter of the cylinder appears to vary from $\backsim$ 50 cm in the lower and higher parts of the plant to 60–70 cm in the middle parts. This yielded an average diameter of 56 cm, corresponding to an average circumference of 176 cm. Measurements could be taken from $\backsim$ 100 cm to $\backsim$ 300 cm above ground so that the height of the cylinder is about 200 cm; its total surface (πdh) is $\backsim$ 35200 cm^2, or 3.52 m^2.

4. Discussion of data

The data of Table 6 indicate that the surface of the cylinder is roughly just as large as the total surface of the leaves. In principle all leaves covering the cylinder could expand besides and above each other. This corresponds with the impression the plant makes. However, this ideal situation will rarely be fully reached; in reality the leaves will mostly overlap in part and leave some holes between them. But the arrangement obviously enables a very good use of the light by a maximum amount of leaf surface. Accepting the classical definition of the leaf area index (LAI) being unit leaf area/unit covered surface, with respect to the cylinder this would be $323/352 = \backsim 0.9$. Usually, 'unit covered' is referred to the soil surface covered by the plant. Strictly speaking, this would be the basis of the leaf cylinder, viz. $\pi r^2 = \pi \times 28^2 = \backsim 2450\ cm^2$. Using this figure LAI would amount to $32300/2450 = \backsim 13.2$. Certainly, in a case as this, such a figure would have no real significance, since the morphological structure of the plant enables it to receive much more light than is due to reach its 'ground surface'.

It occurs to us that problems of leaf area index and net assimilation rate have been discussed at length in relation to surfaces covered by crops, wood, etc., however, hardly in relation to solitary plants, especially those which show a specific morphological adaptation to the situation as described above. If we take that 2 m mutual distance might be a reasonable condition for this type of development in sunflower in a field – there are some indications that this is not unreasonable – we might assume that each plant then has the amount of light due tot 4 m^2 soil surface at its disposal.* (In this way *Gladiolus* crops have, e.g., been considered (1)). It has been stated above that the dry wt developed is about 2 kg. Taking this to require roughly 4 m^2 soil surface, it yields a production of 5000 kg/ha total dw. Compared with total dry wt.

* It may be worthwhile to notice that this is remarkably close to the surface of the 'leaf cylinder' developed.

production data compiled elsewhere (2, 3) this means an efficiency of incident photosynthesizable radiation of $\backsim$ 0.68%. The yield in dry wt. of seeds still is only $\backsim$ 8% of total dw. (cf. above), corresponding to an efficiency of only $\backsim$ 0.05%. It should, however, be remarked that optimal development of dry wt. in a solitary plant need not coincide with optimal dw. production per unit area for the same plant species. Production of each individual plant then may decrease if number exceeds this decrease. We have some old sunflower data pointing in this direction (unpublished so far). Starting from very wide planting, increase in density will increase surface yield, but, from a certain point onward, will decrease individual plant yield. Morphogenetic differences (e.g. leaf size, stem thickness versus stem length, size of the flower head) will arise (see also ref. 1, for *Gladiolus*). In this sort of studies it will be appropriate, if one likes, to introduce NAR's for the separate plant organs, thus doing justice to the arising morphogenetic differences owing to differences in experimental conditions. This was preliminarily attempted in our group in a study on onion growth (4).

It has been demonstrated above that one can derive for the solitary plant of *Helianthus* considered, two very different values for the leaf area index, viz., 0.9 taking the 'cylinder surface' as reference, and 13.2 taking the actually covered soil surface as a reference. In any case the range between these values includes the 'normal' range usually adopted for herbaceous and woody plants in closed plantation, viz., about 3 to 4 which means that each part of soil surface on the average is covered by 3 to 4 layers of leaves, so that the light on the average passes 3 to 4 leaves successively.

It is obvious that in the case of the solitary sunflower plant one will arrive at a figure for LAI between 1 and 13 if one might consider the oblique projection of the plant on the soil at various positions of the sun, i.o.w. its shadow on the soil. This, however, does not look a very promising procedure for realistic production analysis, since obstacles may interfere during part of the day and, furthermore, on cloudy days the whole procedure hardly remains valid. Moreover, the amount of light the sunny side of the plant receives, and that received by the shaded side will widely differ on sunny and cloudy days.

Many years ago we designed a 'spherical radiation meter' for measuring the influx into a space rather than that received on a flat surface (5). Furthermore, a method was advised for relating both types of values. Probably, this method might be used for estimating the influx onto the leaf cylinder, at various times of the day and at various types of days, or one might simultaneously apply flat light meters (preferably with 'cosinus correction') at characteristic spots of the leaf 'cylinder'.

It still should be remarked that we are fully aware of the fact that measurements at a single plant cannot claim scientific accuracy as such. However, they are used here simply to illustrate a principle, i.e. to show some features of interplay between morphogenetical development and production data in a solitary plant.

5. Summary

Solitary plants have the possibility to adapt to environmental conditions in developing morphogenetic features which help them to catch a maximum of light, i.o.w. they may 'cover much more ground' than corresponds with their horizontal projection. This renders the notation LAI (leaf area index) rather arbitrary. So, a solitary sunflower plant of the type described (see fig. 1) developed a leaf area of $\sim 3.2\,m^2$, together building a leaf cylinder of $\sim 3.5\,m^2$ surface (LAI ~ 0.9) on a soil surface of $\sim 0.25\,m^2$ (LAI ~ 13.2). The development of this type of plant would require $\sim (2 \times 2) = 4\,m^2$ soil surface, remarkably similar to the surface of the leaf cylinder. These features require further observations.

6. References

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