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The effect of environmental factors on the growth of Alfalfa in the field

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Summary

The measured dry-matter production of a frequently irrigated and heavily fertilized field crop of Alfalfa was compared with the potential photosynthesis calculated from measurements of solar radiation by DE WIT's method. The calculated amounts agreed well with the measured quantities after corrections had been applied for losses due to respiration, root growth and light wasted beneath the crop canopy. The latter term was found to be of major importance reducing the growth to 30 % of the possible.

1. Introduction

The growth of plants can be considered as a physical process in which solar radiation provides the light energy for the photochemical reaction of photosynthesis. Such an approach appears to offer a sound basis for investigations of the relationship between climate and crop yield and the relative importance of various climatic and agronomic factors in limiting yields.

DE WIT (1958, 1959) has recently described a method of calculating growth as a function of the incident light energy. DE WIT's approach assumes a Blackman type of light response with a single light efficiency taken as the mean value for a number of agricultural crop species, it is also assumed in this method that the rate of photosynthesis is not affected by temperature over the range normally encountered.

Other assumptions in the method are that the reflection and absorption of light by crop leaves is independent of angle of incidence and that the leaf orientation is at random. The method of calculation is straightforward. The proportion of incident solar radiation contributing to photosynthesis is graphically derived from date and latitude and then converted to light energy values which, with the single value of photosynthetic efficiency, is used to calculate growth which is expressed as grams CH_2O per m^2 of soil surface. The result is termed potential photosynthesis in that this amount will only be realized when other conditions are not limiting.

In this paper the calculated amount of potential growth was compared with the measured amount obtained from a field crop of Alfalfa (*Medicago sativa* var. *peruviana*) grown at Gilat in the northern Negev district of Israel (150 m M.S.L., 34° 40′ E, 31° 20′ N).

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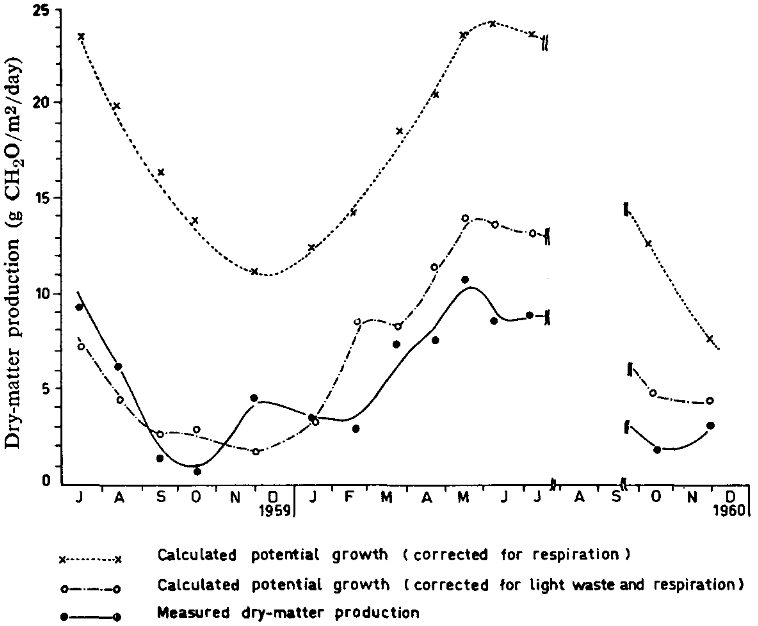
2. Materials and methods

The measurements of growth were taken within a large, level area the cropped portion of which was 120 m by 70 m. The growth data was taken from the plants growing in three simple lysimeters of the type described by GARNIER (1952). Special precautions were taken to ensure that the growth within the lysimeters was similar to that within the rest of the cropped area. The lysimeters were sunk to their rims in the surrounding soil and were filled with soil in the same order and bulk density as that of the undisturbed field. The soil was a fertile and deep loess without a free water table. Before sowing the Alfalfa, a six months' period allowed the soil to settle in the lysimeters. Before sowing, a heavy and balanced fertilizer dressing was applied to the entire area and a further dressing was given halfway through the experiment to ensure that shortage of soil nutrients was not limiting growth.
Every morning two hours of irrigation was given to the entire area (only one hour a day during the four winter months) to ensure that soil-moisture deficits were not limiting growth.
To obtain even and representative growth conditions the lysimeters were sited 44 m downwind from the field edge and were only visited once a week to take measurements of crop height. As a result of these precautions the crop within the lysimeters was indistinguishable from that in the surrounding area.
The Alfalfa was harvested shortly after flowering started; the plants within the lysimeters were cut by hand at the same time and to the same height as those in the surrounding field. The fresh and dry weight of the material was recorded at each of the harvests made during the 18 month duration of the experiment. The average interval between cutting was 31 days with an average crop height of 51 cm before harvest and 15 cm afterwards.
The frequency of cutting and irrigation reduced the ability of the Alfalfa to compete with annual weeds and for a period of two months in the second summer of growth there was a heavy infestation of *Echincholoa colonum,* a native grass. Growth data obtained during this period and also from the first harvest was not used.

3. Results

DE WIT's method was used to calculate the amount of potential photosynthesis at Gilat using local measurements of incident solar radiation for the appropriate growth periods. Respiration losses were calculated from measurements of mean air temperature using the equation given by THOMAS and HILL (1937) showing the temperature dependance of the respiration losses of field crops of alfalfa.
In FIG. 1 the calculated values of potential photosynthesis corrected for respiration losses can be compared with the mean measured dry-weight increment taken from the three replicate lysimeters.
It can be seen from FIG. 1 that the calculated values are nearly four times as large as the measured dry-weight values (which correspond to yields obtained locally in very good field practice.) Calculations of potential photosynthesis in the Netherlands have shown similar large discrepancies with actual measured yields and DE WIT (1959) has suggested that this was because agricultural practice does not ensure the necessary conditions for potential photosynthesis, in particular, non-limiting soil-moisture status, constant concentration of carbon dioxide in the free atmosphere and a closed crop canopy to ensure that none of the incident light is wasted on non-photosynthetic soil surface.

FIG. 1. Calculated and measured dry-matter production



It is obvious that with the daily irrigation applied in this experiment soil moisture was never a limiting factor. It also appears unlikely that the concentration of carbon dioxide varied significantly because of the relatively small area of vegetation in the locality and the proximity of the carbon dioxide reservoir of the Mediteranean (30 km in an upwind direction). However, measurements of the amount of solar radiation reaching the soil surface beneath the crop canopy showed that very considerable amounts of light were wasted despite the superficial appearance of a closed crop canopy.

Weekly measurements of crop height were taken throughout the experiment and, for a six months' period from mid summer to mid winter, were correlated with readings of solar radiation above and below the crop canopy taken at the same time with small field solarimeters (MONTEITH, 1959). In FIG. 2 the fraction of incident solar radiation reaching ground level beneath the crop canopy (Y) has been plotted against the measured crop height (X). Both measurements of solar radiation and crop height were the mean of nine measurements taken at random positions within the three lysimeters.

FIG. 2 shows the fitted line, analysis indicating that the variation in crop height accounted for 76 % of the variation in the fraction of solar radiation reaching the ground beneath the crop. The error term was 16 % of the mean. It is probable that much of this error can be attributed to the large differences in the solar elevation during the six months' period in which the measurements were taken (from 85° in mid summer to 31° in mid winter). Using the line of best fit in FIG. 2 and the weekly measurements of crop height the fraction of solar radiation falling on the ground beneath the crop and so not contributing to photosynthesis was calculated for each of the growth periods between cutting, the average value was 0,77. The calculated values throughout the experiment are shown in FIG. 3.

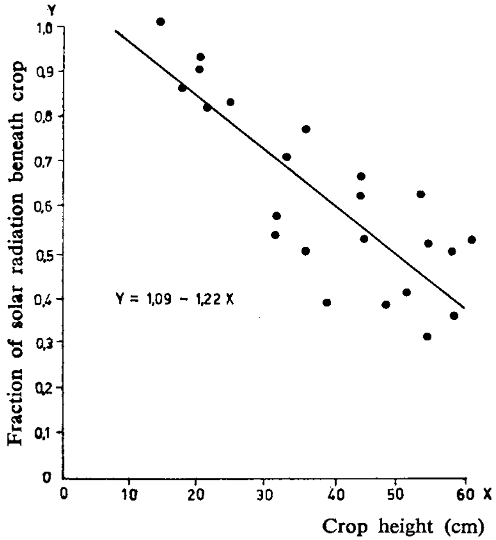
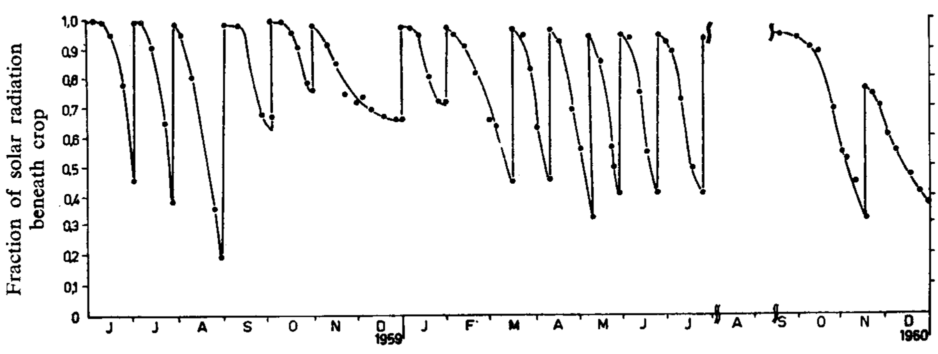


FIG. 2.
The relationship between crop height and the fraction of solar radiation at ground level beneath the crop canopy

FIG. 3. Fraction of solar radiation at ground level beneath the crop canopy



Solar radiation has a changed spectral composition after transmission through vegetation (KASANAGA and MONSI, 1954) and therefore the fraction of photosynthetically active light reaching the ground beneath the crop will differ from the fraction of solar radiation transmitted. The extent of the difference will depend on the proportion of radiation transmitted through the leaves and the proportion that reaches the ground through gaps in the crop canopy as unaltered sunflecks. Visual examination suggested that the latter formed the greater part and this was confirmed by comparing measurements of the proportion of light and the proportion of solar radiation reaching the ground beneath the crop canopy. Such comparisons were made at six different crop heights and it can be seen from these results (FIG. 4) that the fraction of photosynthetically active light wasted on bare ground was approximately 10 % less than the fraction of solar radiation.

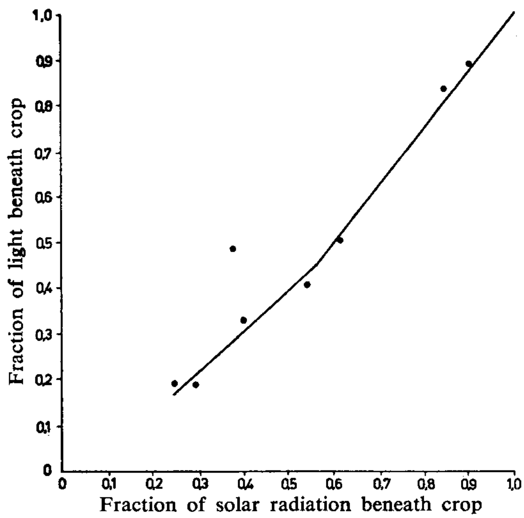


FIG. 4.
Relationship between the fraction of light and the fraction of solar radiation at ground level beneath the crop canopy

Potential photosynthesis was recalculated using DE WIT's formula with solar-radiation values corrected for the wasted fraction and changed light content. It can be seen from FIG. 1 that the corrected values are much closer to the actual measured values of dry-weight increment. The measured growth was 30 % less than the calculated amount. However, the calculated potential growth includes the production of root material which was not measured. SCHUURMAN and MAKKINK's data (1955) shows the relative dry-weight growth of shoots and roots in a mixed pasture receiving differential irrigation and manurial treatments. The results show that the greatest proportion of root growth occurred in the wettest treatment and if a similar proportion of root to shoot growth (30 %) is assumed to have occurred in this present experiment then the difference between the measured and calculated growth would be exactly removed.

4. Discussion

It thus appears that DE WIT's method, after applying corrections for losses due to respiration, light wastage and root growth, gave an accurate estimate of dry-matter production. In view of the number and uncertainties in the correction factors, the simplifying assumptions in the formula and the errors in the measured dry-matter production, it is somewhat surprising that the correlation between the measured and calculated quantities was so high ($r = +\ 0{,}86$).

One of the assumptions in DE WIT's treatment is that photosynthesis is unaffected by temperature which was tested statistically by calculating the multiple regression of solar radiation, corrected for light wastage (X, g cals/cm^2/day) and mean daily air temperature (Z, °C.) on the measured dry-weight production (Y, g/m^2/day). The equation was

$$Y = 0{,}0422\ X - 0{,}0890\ Z - 0{,}6349 \qquad \ldots\ldots\ldots\ldots (1)$$

An analysis of variance was carried out on the data to show the relative importance of solar radiation and air temperature in determining the rate of dry-matter production (see TABLE).

TABLE. Analysis of variance of corrected solar radiation and air temperature regression on dry-matter production

Regression term	Sum of squares	Degrees of freedom	Mean square	F-value and significance	
Regression of corrected solar radiation and air temperature	94,0828	2	47,0414	27,5	P = 0,01
Regression of solar radiation after eliminating the effect of temperature	93,9770	1	93,9770	54,9	P = 0,001
Regression of air temperature after eliminating the effect of solar radiation	8,4055	1	8,4055	4,9	N.S.
Error	17,0873	10	1,7087		

It can be seen from the TABLE that under the conditions at Gilat the dry-matter production of Alfalfa was far more closely and significantly correlated with solar radiation than with air temperature. It is of interest that the latter parameter was negatively correlated with dry-matter increment suggesting that the temperature dependance of respiration on air temperature was of greater importance than any positive effect that temperature may have had on photosynthesis *per se*. This can also be seen by a comparison of the Q_{10}-values of respiration, which was calculated to be — 1,46 over the temperature range occurring during the experiment, with that of dry-matter production (i.e. photosynthesis minus respiration) which was calculated from equation 1 to have a Q_{10} of — 1,18 over the same temperature range. Thus the positive effect of temperature in increasing the rate of photosynthesis was approximately one fifth of the negative effect caused by increasing the respiration rate. It should be noted that the daily mean air temperature during the growth periods ranged from 9° to 26° C.

These results support DE WIT's view that the effect of temperature on rate of photosynthesis may be neglected although any formula for the calculation of dry-matter production must either include a temperature term for calculating the amount of respiration or empirically depend on the correlation between solar radiation and air temperature.

A similar analysis of the relative importance of solar radiation and air temperature has been carried out in England by SALTER (1960) using data on the dry-matter production during the growth of the early summer cauliflower crop. The results of his analysis were opposite to those found for Alfalfa in that the air temperature effect was found to be far larger and more significant than that of solar radiation. An explanation of this difference may be that in the case of the cauliflower crop no correction was made for the non-effective fraction of solar radiation. In a crop such as cauliflower, which initially covers only a very small proportion of the soil surface and only covers the ground completely for a short period before the first harvest, a large and varying proportion of the incident solar radiation will not contribute to photosynthesis and hence the correlation between incident solar radiation and dry-matter production might well be small.

Such an explanation is supported by the fact that when the total incident solar radiation was correlated with the dry-matter production of the Alfalfa crop grown at Gilat the correlation coefficient was only + 0,22 whereas when the corrected values of radiation were used the correlation coefficient was + 0,88. Thus whilst total incident light only accounted for 5 % of the variation in rate of dry-matter production, with a correction for light wastage applied, 77 % of the variance was accounted for.

The agronomic implications of these results are interesting. The potential amount of growth calculated by DE WIT's formula was five times the amount after corrections for respiration losses, root growth and light wastage had been applied. At present there does not appear to be any practical possibility of reducing the respiration losses nor is it known how far the proportion of dry matter devoted to root growth can be altered. However, even when these two losses are included the actual dry-matter production was only 36 % of the possible.

This large difference between the actual and possible yield can be attributed to the fact that only 33 % of the incident light contributed to photosynthesis. FIG. 2 shows that an increase in average crop height should reduce the wastage of light and increases dry-matter production. The maximum height of the Alfalfa crop, in this experiment, was 65 cm and even at this height 10 % of the light was wasted on bare ground. It should be possible by increasing the time interval between harvests and by leaving a greater amount of vegetation at cutting, to increase the average crop height, reduce light wastage and increase growth to a greater proportion of the potential amount.

The effectiveness of such a method of management was tested by extending the time interval between harvests until 48 days instead of the average 31 days and leaving 25 cm of crop after cutting instead of the average 15 cm. The proportion of light utilized by the crop was 46 % in place of the average 33 %. The yield obtained from this growth period was 54 % of the corrected potential growth instead of the average 36 %.

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