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The influence of weather conditions on growth and development of a maize crop in the Netherlands

by

M. Fathan, L. Sibma and H. van Keulen

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Contents page

Introduction

During a number of consecutive years crop growth rate and dry matter distribution, both in different plant parts and in horizontal layers, were studied in a maize crop, mainly for the purpose of collecting input and validation data for a crop growth simulation model, as described by De Wit (1965) and Brouwer and De Wit (1968). As the weather conditions during the growing season in 1971 differed considerably from those in 1972, this presented an opportunity to compare the growth and development patterns in both years for two purposes, viz. 1. to get a better insight into the influence of climatic factors on growth and development and 2. to test the validity of the simulation model by comparing actual and calculated data.

Materials and methods

The experiments in both years were carried out at the same site, a clay soil with sufficient moisture supply in the polder "Oostelijk Flevoland". Before sowing the area was fertilized with 185 kg N and 190 kg P per hectare. The maize variety Caldera 535 was sown in rows, 40 cm apart with a plant distance in the rows of 25 cm. In 1971 the maize was sown on April 19 and in 1972 on April 25. A randomized block design was used with four replicates: each replicate was 9 x 2 m = 18 m^2. During the growing period the crop was harvested nine times, at intervals of approximately 10 days, starting three weeks after emergence. For each harvest two strips of 2 meter length were taken from each replicate, the total sample comprising 4 x 20 plants. The plants were cut from top to bottom in layers of 25 cm height. This was done by means of a hedge trimmer running over a metal wire frame which could be placed at the appropriate height without disturbing the crop structure appreciably. The plant material of each layer was put into a plastic bag carried into the laboratory and divided into leaf blades, leaf sheaths, stalks and cobbs + husks. First the area of the leaf blades was determined with an automatic leaf area meter. To determine the dry weight of each fraction, they were dried at 70 °C until virtually dry and then heated to 105 °C for a short time to remove the residual water. At the experimental site the following climatological data were collected: air temperature (maximum, minimum and mean

^{o}C), global radiation (J cm^{-2} day^{-1}), rainfall (mm day^{-1}) and windspeed (m sec^{-1}).

In 1972 the separate plant samples were analysed for total nitrogen by the Kjeldahl method, nitrate nitrogen content by N-potentiometry (N-electrode) and total sugars by the method of Van der Plank.

Results and discussion

Weather

The weather data are summarized in Table 1 as average values for 10-day periods and per month. The differences between the two years occur mainly in the first four 10-day periods. During this time, the maximum temperature is much higher in 1971 than in 1972, average values for the 40-day period being 20.2 and 16.1 ^{o}C, respectively. The minimum temperatures show a much smaller difference with values of 8.4 and 8.2 ^{o}C, respectively. The cloudy and rainy weather in 1972, with average radiation values of 1396 J cm^{-2} day^{-1}, however, prevented the rise of temperature that occurred in 1971, when bright days prevailed with an average radiation of 1542 J cm^{-2} day^{-1}.

The weather data as an average over 30 years are presented in Table 2.
These average temperatures and radiation data are in between those of 1971 and 1972. This demonstrates that 1971 was more favourable and 1972 less favourable than normal. The monthly rainfall in May and June exceeds the average considerably in both years.

Dry matter production

The great differences in weather conditions during the first six weeks of the growing season are reflected in the growth of the maize crop, as shown in Figure 1a, which shows the dry matter production and its distribution in the various plant parts. Although the well-known S-shaped growth curve is found in both years, the onset of the higher crop growth rate is about three weeks later in 1972. From emergence until early July there is hardly any increase in dry weight. This could be attributed to a low photosynthetic activity, as a result of insufficient chlorophyll formation.

In accordance with the observations by Alberda (1969), the seedlings had a yellowish appearance and presumably a low chlorophyll content. After mid-July, when the day-time temperatures exceeded 20 ^{o}C, vigorous growth started and the average daily growth rate from then till the end of August is virtually the same for both years, viz. 228 kg ha^{-1} day^{-1} in 1971 and 218 kg ha^{-1} day^{-1} in 1972 (Sibma, 1968). The calculated growth rates (CGR) for the different periods are given in Table 3, along with the average leaf area index (LAI), the relative growth rate (RGR) and the net assimilation rate (NAR).

A great difference in leaf area index is observed between the two years, with maximum values of ca. 5.5 and 4, respectively. This difference was caused mainly by changes in the size of the leaves, both width and length being affected in approximately the same way. The specific leaf weight, calculated from the weight of the leaves at maximum leaf area index was 45 $g.m^{-2}$ in 1972 and 51 $g.m^{-2}$ in 1971, showing hardly any influence of the weather situation.

Despite the differences observed in LAI, none of the growth attributes, i.e. CGR, RGR and NAR, deviate substantially during the growing period. A possible explanation for this phenomenon, especially in the first part of the growing period, is to be found in these variables all reflecting the balance between photosynthesis and respiration. During this period there is a difference in standing vegetation of about 5000 kg ha^{-1}, which with an average composition would require 75 to 100 kg H_2O ha^{-1} day^{-1} in maintenance costs (Penning de Vries, 1974). This figure does not compare unfavourably with the difference in gross photosynthesis between the LAI's of 3.5 and 5.0, respectively, calculated with the method of De Wit (1965). Thus, despite the higher leaf area index and the resulting increase in energy absorption, the net growth rate hardly increases, and as a consequence the relative growth rate is even higher in 1972.

This reasoning holds for so long as most plant parts consist of dissimilatory tissue. As the growth of the crop proceeds an increasing part of the total dry matter consists of non-respiratory tissue. Consequently, towards the end of the growing period this explanation applies to a less extent.

Distribution of dry matter

At harvest there was not only a difference in the total amount of dry matter produced, but also a distinct difference in the distribution of that material between the various plant parts, as shown in Figure 2. While in the favourable year 1971, almost 50% of the final weight was in the cobs, this percentage was as low as 30% in 1972. The remainder of the material in the latter case is found in the stalks, leaves and sheaths, in both years comprising ca. 40% of the total dry weight. The explanation for this phenomenon is, that in 1972, due to the adverse weather conditions cob primordia were poorly developed. The photosynthates available during the grain filling period could not be accommodated by the cobs and were transported to the stalk, where accumulation of reserves took place. This process occurs also in Figure 1, where at the beginning of the cob filling period the growth rate of the stalks decreased, after which it increased again.

As in 1971 sugar contents were not analysed, this statement could not be checked for differences in soluble carbohydrates. Comparison with data of another experiment in 1973, a normal year, showed a considerably higher rate of increase in sugar content in stalks and leaves in 1972. Similar phenomena have been reported for rice, where unfavourable conditions during the formation of the hull (especially nitrogen shortage, or reduced photosynthetic activity due to shading) may lead to a physical limitation of grain filling and hence to increased reserve-levels in the rice straw at harvest (Van Keulen, 1977).

This process of accumulation of reserves may also be responsible for the relatively early and rather sharp decline in total growth rate after the mid-September. Although the weight of leaves remains constant, there is no increase in total dry weight any more. This may have been caused by a sharp reduction in photosynthetic activity of the leaves, resulting from a too high level of soluble carbohydrates, as it is generally accepted that there is a negative feedback of reserve level in the leaves to photosynthesis.

Simulation results

Crop growth for the two experimental years was also simulated, using a modified version of the simulation model as described by Brouwer and De Wit (1968). A short description of this version is given by Van Keulen & Louwerse (1974).
In the simulation runs the measured leaf area data were introduced in order to avoid difficulties connected with insufficient knowledge about crop morphogenesis. The chemical composition of the material, as determined in 1972, was used in both years, which may have been an oversimplification in view of the foregoing discussion. Crude protein contents were calculated from total N minus nitrates, multiplied by 6.25, while intelligent guesses were introduced for mineral content, percentage fat lignin and organic acids.

The simulation model calculates total dry matter production and does not describe the partitioning between the various plant parts, so that total dry weight is the single variable open for comparison. The calculated and measured data for both years are given in Figure 3.

When looking at the graphs, a number of phenomena can be observed. In the period of spring growth the model considerably overestimated the actual growth rates.

During the grand period of growth, the calculated rates of increase in dry weight are underestimated considerably for both years. The calculated values are virtually identical in both cases, like the observed ones (Table 3), but they differ in level in both years. An attempt at explaining these discrepancies, brings to light the inherent problems connected with models in which only gross output data are amenable for validation (Van Keulen, 1976). The rate of increase in dry weight is the result of the balance between gross photosynthesis and respiration, the latter quantity including both growth and maintenance processes (Penning de Vries, 1974). Without additional information obtained by a comparison between calculated and measured rates of these processes, it is highly speculative to distinguish between them, in explaining the observed differences in growth rate. Nevertheless, if this method is adopted, the most likely explanation is an underestimation of the photosynthetic capacity of the maize leaves. This is based on the one hand on respiration in the model being calculated as the sum of a term proportional to dry weight and one proportional to current photosynthesis. In turn, this leads to an identical error, irrespective of the amount of dry matter present. On the other hand it has been observed that canopy photosynthesis of maize measured in the field, is simulated properly only, when photosynthesis-light response curves of individual leaves are applied that were measured on leaves also grown in the field. The photosynthesis-light response curves of plants grown in the greenhouse always are considerably lower. But as stated above, only circumstantial evidence leads to this conclusion.

Conclusions

Considering the experimental results, it may be concluded that an advantage in the early development of a maize crop grown in the Netherlands, is maintained throughout the growing season and manifested in full in the final dry matter yield. Grain yield may be affected even more pronounced, when conditions during cob initiation are unfavourable, leading to poorly developed cobs, which cannot accommodate the available photosynthesis products after flowering. Improvement of environmental conditions in the early growth stages in the Netherlands, mainly temperature conditions, by adapted management practices may therefore increase the production potential of maize considerably.

With respect to the simulation model it must be remarked that the results obtained here once again point out that validation based on "gross output" only, leaves many questions to be answered. It would of course be possible to obtain more accordance between observed and calculated data by adaptation of one or a number of the parameters of the model. This course has not been chosen, because it would have turned the simulation technique into a complex way of curve fitting. Efforts were rather directed at developing a mobile laboratory, suitable for the measurement of the relevant processes, like photosynthesis, respiration and transpiration in a crop stand in the field

(Louwerse & Eikhoudt, 1975). Results of experiments with this equipment will enable the submodels of the various processes in the crop growth model to be tested and may thus lead to a better description of these processes. Moreover, only in these close connections of simulation and experimentation will models yield reliable results.

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Table 1. Climatological data in Oostelijk Flevoland. 1971 and 1972.

Month	Day number	Decade	Air temperature °C Max 1971	Max 1972	Min 1971	Min 1972	Radiation $J.cm^{-2}$ 1971	1972	Rainfall mm 1971	1972	Windspeed $m.sec^{-1}$ 1971	1972
May	121-130	I	18.0	17.3	5.1	8.4	20611	15583	7.2	17.9	2.2	3.7
	131-140	II	21.5	12.9	9.9	6.3	18254	13263	42.1	46.7	1.5	4.6
	141-151	III	19.0	16.7	8.7	9.5	18354	17489	18.7	32.5	1.2	7.1
Total			-	-	-	-	57219	46335	68.0	97.1	-	-
Average			19.5	15.7	7.9	8.1			-	-	1.6	5.1
June	152-161	I	22.2	17.4	10.5	9.0	18534	15031	0.0	29.8	1.5	3.7
	162-171	II	16.9	17.4	8.4	8.4	10780	19044	65.6	13.1	2.8	4.0
	172-181	III	18.4	18.4	10.4	11.3	17940	13924	33.7	34.3	3.0	4.2
Total			-	-	-	-	47254	47999	99.3	77.2	-	-
Average			19.2	17.9	9.8	9.6			-	-	2.4	4.0
July	182-191	I	24.9	18.3	11.0	12.3	22220	11796	0.0	41.1	1.0	3.5
	192-201	II	21.0	22.3	8.6	12.4	17877	23679	0.9	0.0	1.2	3.2
	202-212	III	22.4	22.2	14.2	15.4	15073	13317	30.7	69.2	1.5	3.4
Total			-	-	-	-	55170	48792	31.6	110.3	-	-
Average			22.8	21.0	11.3	13.4			-	-	1.2	3.4
August	213-222	I	22.9	21.0	13.8	11.9	15612	14421	22.1	26.3	2.8	3.9
	223-232	II	21.7	19.4	12.3	12.2	13551	15808	12.2	24.7	2.6	3.9
	233-243	III	21.2	19.1	12.1	10.9	13899	15934	30.7	1.2	2.8	3.8
Total			-	-	-	-	43062	46163	65.0	52.2	-	-
Average			21.9	19.8	12.7	11.7			-	-	2.7	3.9
4 m Total							202713	189291	264	337		
4 m Average			20.8	18.5	10.4	10.7					2.0	4.1

Table 2. Climatological data in the Netherlands as an average of the period 1931-1960.

Month	Day nrs.	Air temperature °C		Radiation[1] J.cm^{-2}	Rainfall mm	Windspeed m.sec^{-1}
		Max	Min			
May	120-150	17.7	7.1	50971	51.5	6
June	151-181	20.7	10.1	53289	58.0	6
July	182-212	21.9	12.2	49062	76.8	6
August	213-243	21.8	12.0	42649	88.0	6

1) Radiation 1941-1970.

Table 3. Dry matter increase in $g.m^{-2}$ per period, leaf area index (LAI), calculated growth rate (CGR), relative growth rate (RGR) and nett assimilation rate (NAR), in 1971 and 1972

Date	Number of days	Differences of dry matter $g.m^{-2}$	Average LAI	CGR	RGR	NAR	Total radiation $J.cm^{-2}$
1971							
June 27							
	16	413.0	3.49	25.8	0.08	7.70	
July 13							
	14	427.8	5.42	30.6	0.04	5.65	
July 27							
	14	93.0	5.38	6.6	0.006	1.23	
August 10							
	14	374.8	4.87	26.8	0.021	5.50	
August 24							
	21	264.9	4.30	24.0	0.015	5.60	
Sept. 13							
Total	79		-	-	-	-	121834
Average	-		4.69	22.96	0.032	5.14	1542

1972							
July 19							
	8	200.0	2.98	25.0	0.12	8.40	
July 26							
	12	259.9	3.90	21.6	0.049	5.55	
August 7							
	9	96.6	3.65	10.7	0.017	2.94	
August 16							
	12	336.6	3.43	28.0	0.034	8.15	
August 28							
	14	199.9	3.82	14.3	0.013	3.74	
Sept. 11							
Total	55		-	-	-	-	76803
Average	-		3.56	19.92	0.047	5.76	1396

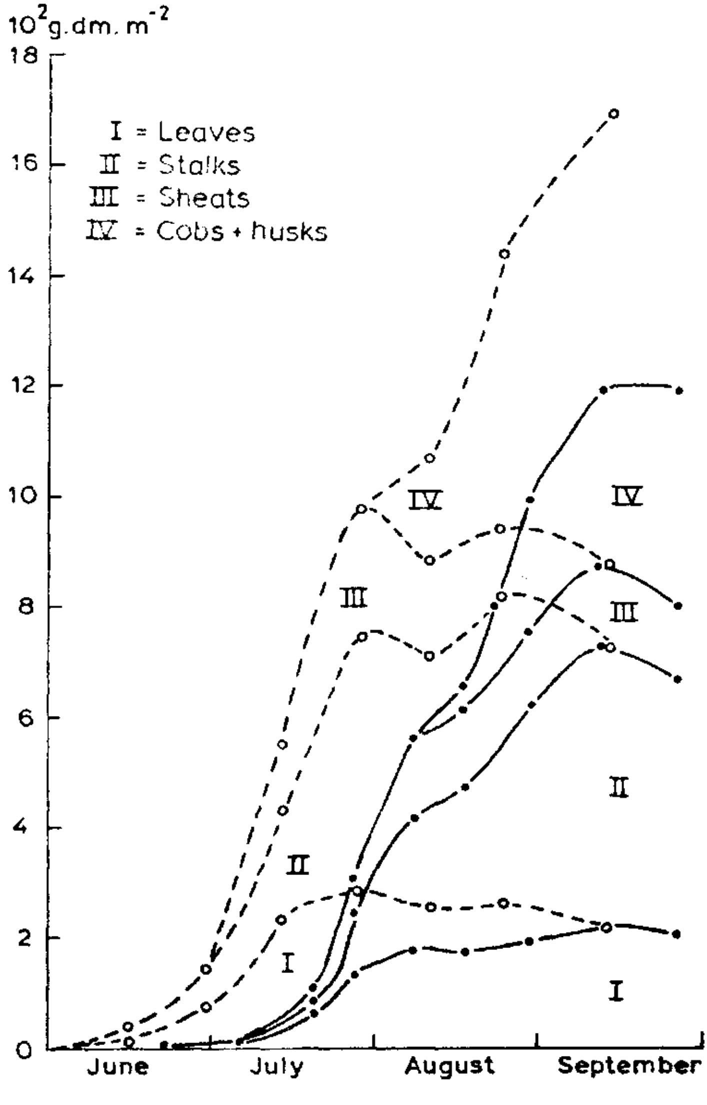

Fig. 1. Total dry matter yields of maize separated in leaves, stalks, sheaths and cobs.

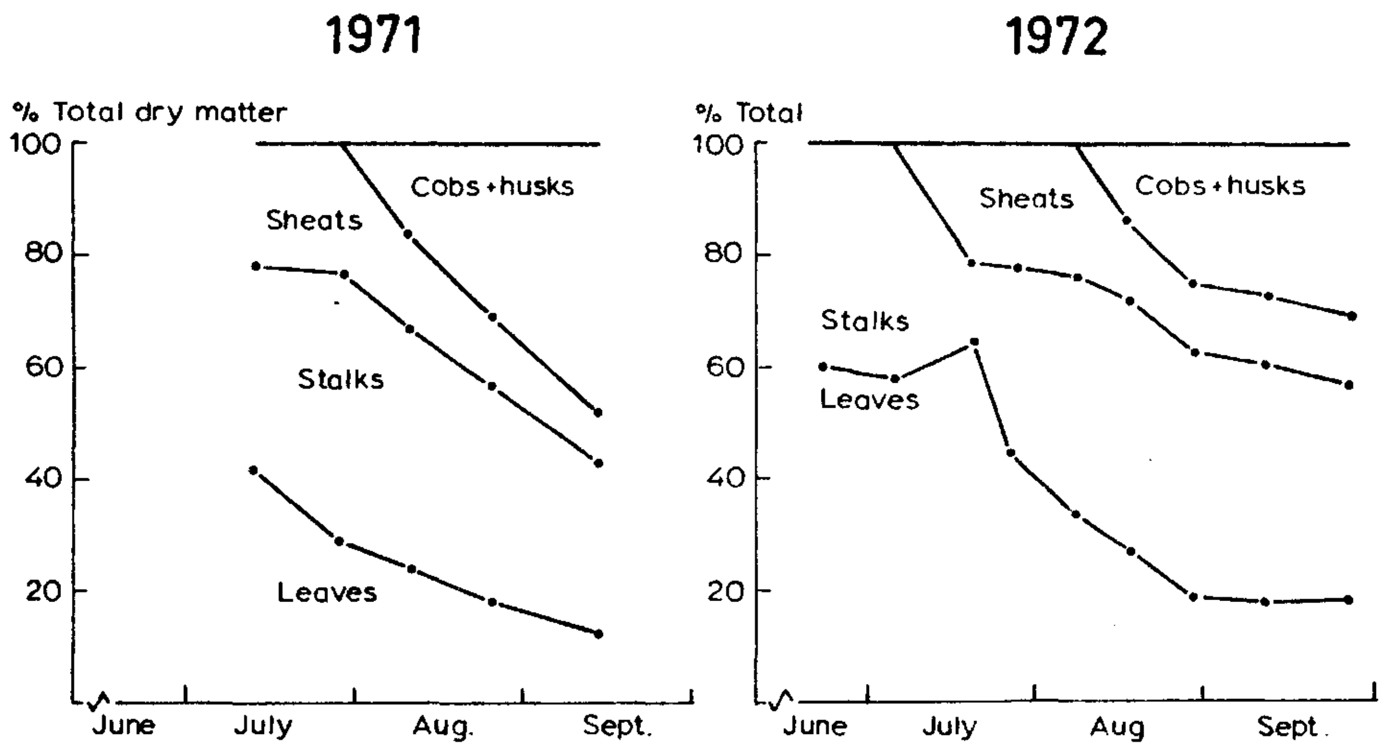

Fig. 2. Actual and simulated dry matter yields of maize.

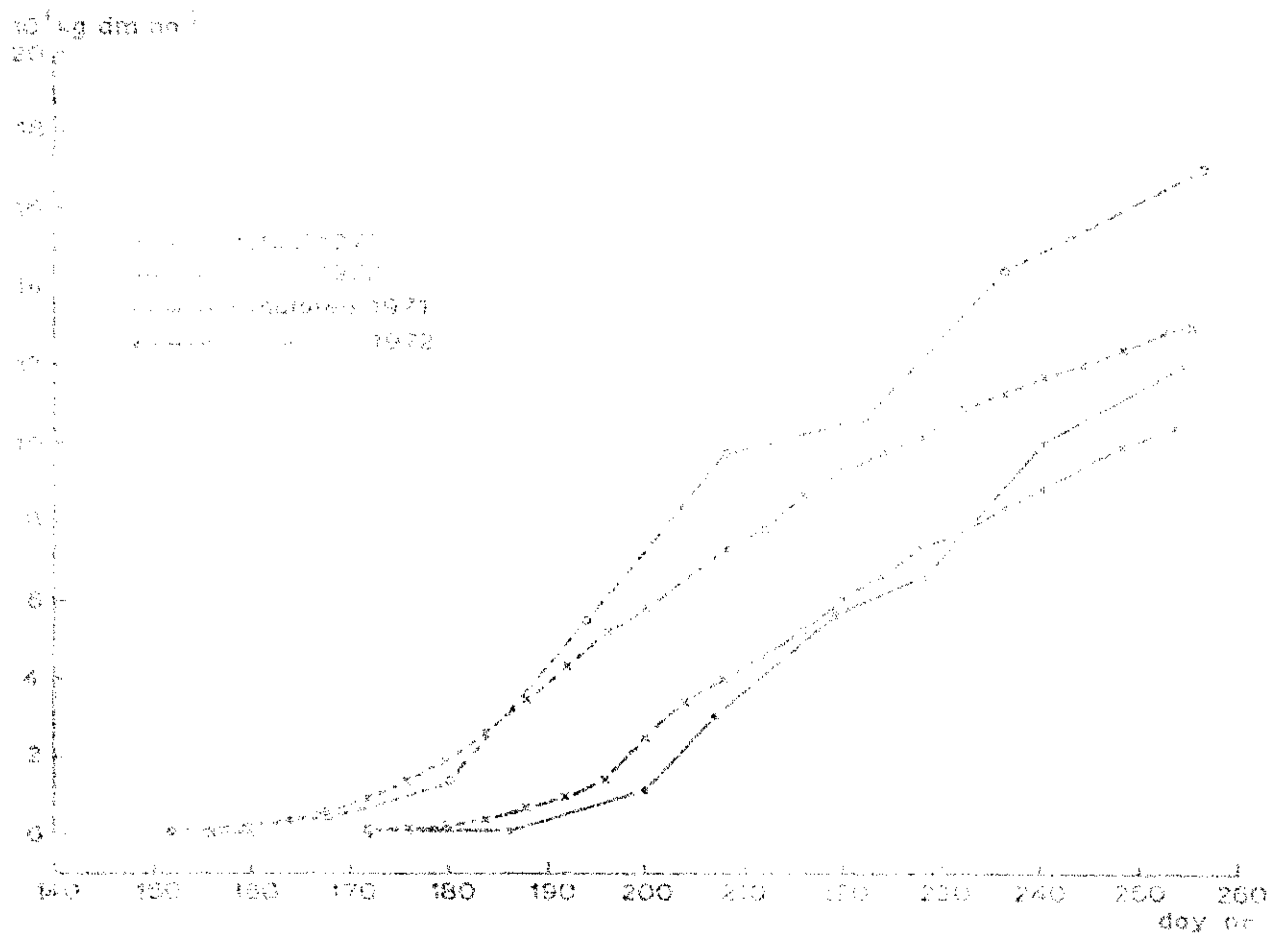

Fig. 5. Change in dry matter distribution in maize in 1971 and 1972.

Erratum:

Fig. 2. Change in dry matter distribution in maize in 1971 and 1972.

Fig. 3. Actual and simulated dry matter yields of maize.