Physiological analysis of variation in growth and yield of *zea mays* due to differences in time of sowing

I — Pre-flowering period, growth characters, growth attributes and morphological components of growth

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INTRODUCTION

THE economic yield of a field crop consists of a small fraction of total biological yield. This economic fraction is grain in crops like maize, wheat and barley. Most of the carbohydrates in grain comes from the photosynthates produced after ear emergence (Allison, 1964 ; VanEijnattan, 1963 ; Allison and Watson, 1966). Thus the carbohydrates manufactured before ear emergence are not of any direct practical importance for the yield of grain. However, how much carbohydrates would be synthesized by the plants at the time of ear emergence is important in determining the yield of grain and this amount depends on the capacity and intensity of the photosynthetic surfaces available at the time of ear emergence. The growth before ear emergence is therefore important in the sense that it provides the source (Photosynthetic surface, stem surface, leaf laminae and ear surfaces) for the manufacturing of carbohydrates accumulated in grains.

Effect of temperature on growth characters, growth attributes and morphological components of growth in maize was analysed in detail by Jain (1968) under controlled environmental conditions. But it is

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difficult to control the environmental conditions in the field. At the same time the results obtained under controlled conditions in laboratory cannot be relied upon till they are confirmed in the field. The only possible way of getting variation in climatological characters at the various stages of crop growth is by planting the seeds at different times. These variations are however, natural and beyond control.

Chikov (1965) reported a relationship between : (1) leaf number in maize varieties and the accumulated temperature above 10°C from sowing to ear emergence ; (2) the interval between sowing and ear emergence as a function of mean soil temperature and (3) the accumulated air temperature between ear emergence and tasseling as a function of leaf number. The number of leaves, rate of emergence and longevity of hybrid maize leaves varied due to varieties but were slightly affected by dates of sowing each separated by about 10 days (Eik and Hanway, 1965). Nearly all leaves attained their full areas before the 12th leaf was completely unfolded Ross and Vlasova (1966) also recorded the increase in area of maize leaves with increase in leaf position on shoot till 8th leaf, the area of subsequent leaves decreased slowly and was minimum for the last (13th) leaf.

Briggs *et al* (1920) studied maize plants sown at different dates under the same conditions and concluded that NAR was positively related with mean day temperature (or mean daily maximum) and negatively related to mean might temperature (or mean daily minimum). Gregory (1926) also concluded that NAR was completely controlled by the factors of temperature and radiation. Thorne (1960) reported a linear decrease in values of NAR, RGR (relative growth rate) and RLGR (relative leaf growth rate) with increase in age of sugar-beet, potato and barley plants. Gibbon (1966) recorded a maximum NAR of maize between 6 and 8 weeks after sowing as 0.446 g dm^{-2} wk^{-1} (0.637 mg cm^{-2} day^{-1}) for no nitrogen plots and 0.530 g dm^{-2} wk^{-1} (0.756 mg cm^{-2} day^{-1}) for nitrogen plots.

MATERIALS AND METHODS

The experiment was conducted in summer season under temperate climatic conditions of Heverlee (Belgium) situated at 50°52′ N latitude, 4°4′ E longitude and 25 m altitude. The soil was basically sand with an organic carbon content of 1.5 percent and pH 6.6. The climatological data indicated in Fig. 1 were recorded from the following sources :—

(1) Temperature and relative humidity: Automatic hygro-thermographs installed in the middle of the field on a basement 10 cm above the ground level. Mean values of temperature were caliberated by measuring the area of thermographs by "*Planimeter*".

(2) Rainfall data were collected from the rain gauge installed at a distance of 30 m from the field.

(3) The data on total radiation, sunshine hours and wind velocity were taken from the bulletin de Institute Royal Meteorologique de Belgique a Ucle (25 km from the field).

The seeds of maize variety Inra hybrid 244 were sown at five different dates, i.e., 4th, 13th and 23rd May and 2nd and 13th June. A spacing of 50 cm between rows and 25 cm within rows was maintained in the plots of 6 × 2 m.

Sampling : Four plants from each plot were sampled at an approximate interval of 10 days from four different replications. However, four more plants from each plot were measured intact in the field for the precise estimation of growth attributes (Jain, 1970a). Thus the estimated values are the mean of 32 plants (4 × 2 × 4) for the first three stages and 16 (2 × 2 × 4) for the last two stages of growth.

The methods employed for estimating different aspects of growth (Jain, 1970a) and the characters, attributes and morphological conponents studied have already been reported (Jain, 1968). However, for ready reference they are summarised as follows :—

1 : *Growth characters :*

(*a*) Stem—Surface area(πdh dry weight πr^2hxk

(*b*) Leaves—Leaf area = KLW : dry weight = Leaf area x dry wt per unit area (leaf area)

2 : *Growth attributes or physiological components of growth 9*

(*a*) Net assimilation rate NAR (E)

$$= \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\text{Log}_e L_2 - \text{Log}_e L_1}{L_2 - L_1}$$

(*b*) Relative growth rate (RGR)

$$= \frac{\text{Log}_e W_2 - \text{Log}_e W_1}{t_2 - t_1}$$

(*c*) Relative leaf growth rate (RL)

$$= \frac{\text{Log}_e L_2 - \text{Log}_e L_1}{t_2 - t_1}$$

3 : *Morphological components of growth :*

(*a*) Leaf area ratio (LAR) = Leaf area/plant weight

(*b*) Leaf wt. ratio (LWR) = Leaf wt./plant weight

(*c*) Specific leaf area (SLA) = Leaf area/leaf weight

LAR = LWR × SLA

RESULTS

The growth studies were analysed in three different aspects, namely ; (I) The Growth Characters, (II) The Growth Attributes and (III) The Morphological Components of Growth.

(I) GROWTH CHARACTERS

The growth of shoot was analysed separately for stem and leaves.

Stem : The stem growth was measured in terms of surface area (πdh) and its dry weight was estimated from its volume (πr2h).
The results are given in table 1.

Table 1 : Mean surface area and dry weight of stem for five consecutive stages of growth at an interval of 10 days :

Mean values at the various stage of growth		*Different dates of planting*				
Stage	*character*	*D1 4th May*	*D2 13th May*	*D3 23rd May*	*D4 2nd June*	*D5 13th June*
1st	Surface area cm–^{2}	16.7	36.6	55.4	39.0	31.8
	Dry weight mg.	235	523	991	562	434
2nd	Surface area	97.6	144.7	146.3	99.4	61.5
	Dry weight	1864	4229	4256	2255	1027
3rd	Surface area	313.4	411.0	324.4	230.8	156.5
	Dry weight	8583	14390	11226	6893	4512
4th	Surface area	562.4	707.4	526.6	403.5	384.3
	Dry weight	20085	28664	23178	15793	15973
5th	Surface area	1088	996	1029	711	733
	Dry weight	50561	44160	48671	32040	30190

It is evident from table 1 that the growth of stem in early sown plants of maize (D_1, D_2 and D_3) was better than late sown (D_4 andD_5) plants. But even in early sown plants the earliest (D_1) was not much better than later (D_4). The surface area as well as the weight of the stem was higher in D_2 and D_3 plants almost at all the five stages of crop growth.

Leaves : Similar to the growth of stem, the growth of leaves was better in early than late sown plants (Fig. 2). The leaf area was highest for middle sown (D_3) plants folowed by D_2 and was lowest for D_1 at the first stage of growth. But the leaf area was highest for D_2 followed by D_1 plantings during the last two stages of growth. Maximum increase in leaf area per day were recorded during the 2nd to 4th stages of growth (31 to 51 days after germination) in all treatment plots. But there was a gradual increase in weight per unit area of leaf with increase in age of the plants.

The growth of individual leaves on main shoot of the plant at the various stages of growth are given in Fig. 3, 4 and 5.

Each leaf starts with a rapid growth followed by a gradual decrease in rate of growth, ultimately reaching to its complete cessation after attaining its maximum size. The maximum area of each leaf is attained at a definite physiological stage and after a few days the leaf starts drying and ultimately falls off.

The differences in leaf area of various leaves were much more for the upper 10 to 13 than the lower nine leaves. These differences can be explained on the basis of (1) time of leaf blade initiation (2) the rate of growth and (3) the maximum area attained by each leaf at last sampling.

The growth of 10th and 11th blade in D_1, D_2 and D_3 started after 31 days after germination, whereas, there was no visibility of blade 10th and 11th in D_5 and 11th in D_4 treatments at this stage. The differences were still wider for the 12th and 13th leaves. The area attained by 13th leaf in D_2 was about five times of D_4 and 10 times of D_5 at the time of last sampling.

The maximum area attained by leaf 7-13 were higher for D_2 and D_1 and least for D_5 treatments. Maximum leaf area attained by 9th leaf was highest in the early plantings (D_1 and D_2) as against leaf 8th for the three late plantings. Thus the early sown plants (D_1 and D_2) produced larger number of leaves and higher leaf areas per plant.

(II) GROWTH ATTRIBUTES

The results of growth attributes are given in table 2.

Table 2 : Mean values of net assimilation (Ea) relative growth (R) and relative leaf growth rates (RL) in relation to time of plantings and age of the plants.

Growth attribute and unit of expression	*(a) In relation to date of planting*							
	D1	*D2*	*D3*	*D4*	*D5*	*D5 SEm*	*LSD*	
1. Ea mg cm^{-2} day^{-1}	0.715	0.628	0.596	0.637	0.559	±0.092	—	—
2. R mg mg^{-2} day^{-1}	0.121	0.097	0.079	0.103	0.089	±0.0173	—	—
3. RL $cm^{-2}cm^{-2}$ day^{-1}	0.092	0.067	0.057	0.095	0.057	±0.0218	—	—

Growth attributes	*(b) In relation to age of the plants**						
	A1	A2	A3	A4	SEm	LDS	1
Ea mg cm^{-2} day^{-1}	0.720	0.578	0.577	0.633	±0.083	—	—
R gm mg^{-2} day^{-1}	0.175	0.099	0.077	0.057	±0.155	0.034	.047
RL cm^{-2} cm^{-2} day^{-1}	0.161	0.076	0.038	0.018	±0.019	.042	.058

* Interval between observations = 10 days

1 : *In relation to time of planting* :

There was a continuous decrease in the rate of assimilation with delay in planting except for D_4 where it was higher than D_2 and D_3 plantings. The mean rate of assimilation in D_1 was 25 per cent higher than D_5, but the differences were statistically not significant.

Similar to the rate of assimilation, there was also a gradual decrease in relative growth and relative leaf growth rates with delay in planting from D_1 (4th May) to D_3 (23rd May). However, the values of relative growth rates for D_4 (2nd June) were comparatively higher than D_3 and that of D_5 were comparable to D_3. No significant difference in values of all these growth attributes was however recorded due to the effect of time of planting.

2 :*In relation to age of the plants* :

There was a continuous decrease in the values of all growth attributes with increase in age of the plants. But the differences were statistically significant for relative growth rates (R and RL) and not for the net assimilation rate (Ea). Thus the decreased in values of relative growth rates was mainly caused through decreased rate of leaf growth (capacity of the plants) with little variation in the net assimilation rate (intensity—assimilation per unit area) of the photosynthetic surfaces.

3 : *Correlation and regression studies :*

As the temperature was the most important factor for variation in all these growth attributes correlation studies were made between the mean temperatures (Plainmetric estimation of the thermographs) above 10°C and the values of different growth attributes. The results are given in table 3.

Table 3 : Values coefficient of correlation (r) and regression (b) of growth attributes on mean temperatures above 10°C.

S. No.	*Characters studied*	*Value of r*	*Value of b*
1.	RL and temperature above 10°C (degree days)	0.641**	0.0324
2.	R and temperature	0.798**	0.0287
3.	Ea and temperature	0.803**	0.0835

**Significant at 1% level

All the three growth attributes were significantly related to mean temperature above 10°C. An increase in temperature above 10°C per day increased the leaf growth rate by 0.024 cm^{-2} cm^{-2} day^{-1}, the mean growth rate (dry wt.) by 0.028 mg mg^{-1} day^{-1} and net assimilation rate by 0.0835 mg cm^{-2} day^{-1}.

(III) MORPHOLOGICAL COMPONENTS OF GROWTH

The morphological components of growth consists of leaf area ratio, leaf weight ratio and the specific leaf area were estimated at the five consecutive stage growth from the five different treatment plots. The results are given in table 4.

Table 4: Mean values of leaf area ratio (LAR) leaf weight ratio (LWR) and specific leaf area (SLA) of plants in different treatment plots :

Morphological components	*(a) In relation to time of planting*				
	D1	D2	D3	D4	D5
	4th May	*13th May*	*23rd May*	*2nd June*	*13th June*
LAR cm^2/mg.	0.155	0.143	0.118	0.151	0.163
LWR mg/mg.	0.533	0.507	0.526	0.548	0.540
SLA cm^2/mg.	0.278	0.256	0.221	0.267	0.285
	(b) In relation to age of the plants				
	A1	A2	A3	A4	A5
	11	21	31	41	51
	(Approximate days after germination)				
LAR cm^2/mg	0.223	0.191	0.143	0.099	0.066
LWR Mg/mg	0.661	0.621	0.568	0.463	0.341
SLA cm^2/mg	0.338	0.301	0.252	0.214	0.195

There was a gradual decrease in the values of LAR and SLA with delay in planting from 4th May to 23rd May. However, the values of subsequent plantings were larger for all the three components (LAR, LWR and SLA) for the last two plantings (D_4 and D_5).

The values of LAR, LWR and SLA were decreasing with increase in age of the plants. The effect of age appeared to be much more conspicuous than the effect of time of planting. The proportionate decrease in LAR was larger than in values of LWR and SLA.

DISCUSSION

Growth characters :

The growth of plants sown at different times can be explained on the basis of the total radiation received by different plants at the various stages of growth. Total temperature, radiation and sunshine hours received by D_1 (4th May) planting during the period of 21-31 days were maximum (Fig. 1). This exactly coincides with the growth of D_1 plants which was minimum during the initial stages of growth followed by a rapid rise in rate of gorwth (21-3- days) as compared to plants in all other treatment plots. The growth of D_2 (13th May) and D_3 (23rd May) plants during the periods of 21-31 and 31-41 days was also superior to the late plantings of D_4 (2nd June) and D_5 (13th June). This may again be attributed to the minimum temperature and radiation received by late sown plants (Fig. 1). Chikov (1965) also reported the closer relationship between mean tempertures above 10°C and the growth of leaves in maize.

But contrary to the direct relationship of growth with the amount of radiation and heat energy received in these plants, the growth of plants was slow in late sown plants (D_6) even during the period of 41-61 days after germination when the radiation and heat energy received by these plants was maximum. This can be explained on the basis of two facts :

(1) The period of maximum was between the age of 31 to 51 days. The higher radiation and heat energy received by late sown plants (D_5) was too late to compensate the loses caused due to their deficiency during the early stages of crop growth.

(2) The plants might have responded to the energy received and the rate of photosynthesis have increased to certain extent, but the amount of photosynthetic surface intercepted with solar energy was relatively smaller than in other plants and the total amount of dry matter synthesized even during these stages of growth in D_6 treatment plots might be poorer than other treatment plots. Thus the light and heat energy received during the early stages of maize growth was comparatively more important because of its cumulative response for a larger period of plants life cycle than the energy received during the later part of the season.

The growth of individual leaves follows the same trend in the field as under the controlled temperature conditions (Jain, 1968). The area of each leaf increases first rapidly then slowly, the leaf attained its maximum size and finally starts drying after maintaining the maximum size for sometime. The differences in growth of leaves in the field and the controlled environmental conditions were recorded in respect of : (1) the rate of leaf appearance was comparatively slower in the field than under the controlled temperature conditions and (2) the total leaf area particularly the width of leaves was more in the field than under controlled conditions. Low soil temperatures and wider spacings in the field might be responsible for these differences. Decrease in values of L/W of epidermal cells due to low temperatures was also reported by Jain (1970b). The higher leaf area (maximum) attained by each leaf in the field as compared to the controlled conditions in the cells may be attributes to the larger spacing (50 × 25 cm.) in the field than in the cells (20 × 20 cm.). Thus the higher light and heat energy received by early sown plants gave a better start during the initial stages of growth which could not be compensated by the late sown plants even if there was a rich supply of light and heat energy during the later part of the season.

Eik and Hanway (1965), however, recorded only slight differences in the number of leaves, rate of emergence and longevity of leaves by growing at different dates each separated by 10 days. This may be because of greater climate differences in the present treatments than the experiment of Eik and Hanway (1965). Moreover, all these differences appeared simply due to the higher ontogenetic development of plants initiated due to the superior conditions of light and heat in the early sown plants. Watson (1965) and Blackman (1956) also observed the effect of temperature on leaf formation. Jain (1968) and Thorne *et al* (1967) while working on maize and sugar-beet respectively under controlled conditions also suggested that plants respond better to the light and temperature during the early stages of crop growth.

Growth attributes :

The mean growth rate of dry matter (R) and leaf area (RL) were not statistically different for different treatment plots, but the variation due to age of the plants was statistically significant. Decrease in the rate of growth attributes (NAR, R and RL) with increase in age of the plants is now almost an established fact and have been reported by Throne (1960) for sugar beet, potato and barley and by Jain (1968) for maize. The maximum average value of relative growth rate was recorded as 0.175 mg mg^{-1} day^{-1} at the age of 11-21 days (table 2) which resembles with the maximum value reported by Hammond and Kirkham (1949) in maize as 0.159 g $g^{-1} day^{-1}$. The maximum rate of assimilation reported by Gibbon (1966) between 6 and 8 weeks after sowing as 0.446 and 0.530 g dm^{2} wk^{-1} (0.637 and 0.756 mg cm^{-2} day^{-1}) were in complete agreement with the values of NAR in the present investigations (0.633) mg cm^{-2} day_{-1} during 41-51 days after germination (table 2).

Morphological components of growth :

Contrary to the growth characters and growth attributes, the value of the morphological components of growth, i.e., LAR, LWR and SLA were highest for D_2 followed by D_1 and D_4 treatments (table 4). As there was a continuous decrease in all these characters with increase in age of the plants, the opposite effect on the time of sowing on the morphological components of growth can again be attributed to the slow ontogenetic development of late sown plants. The differences in growth of plants sown at different dates also attributed to the differences in rate of ontogenetic development of plants while discussing the growth of leaves in this paper.

SUMMARY

The growth of maize plants was analysed in the field in relation to the date of planting. The differences in growth of stem and leaves were related to the variation in light and heat energy received by plants sown at different dates. The results were compared with the results recorded under controlled conditions.

It was inferred that under temperate conditions where the radiation and heat energy is limiting factor for growth, the energy received during the early stages of crop growth (21-41) days after germination) was more beneficial than the later part of the season. The period 21-41 days also coincides with the periods of maximum growth of leaves. The data confirm the results recorded under controlled environmental conditions. It is suggested that maize should be sown in these area only a few weeks (3-5) before the maximum intensity of sun.

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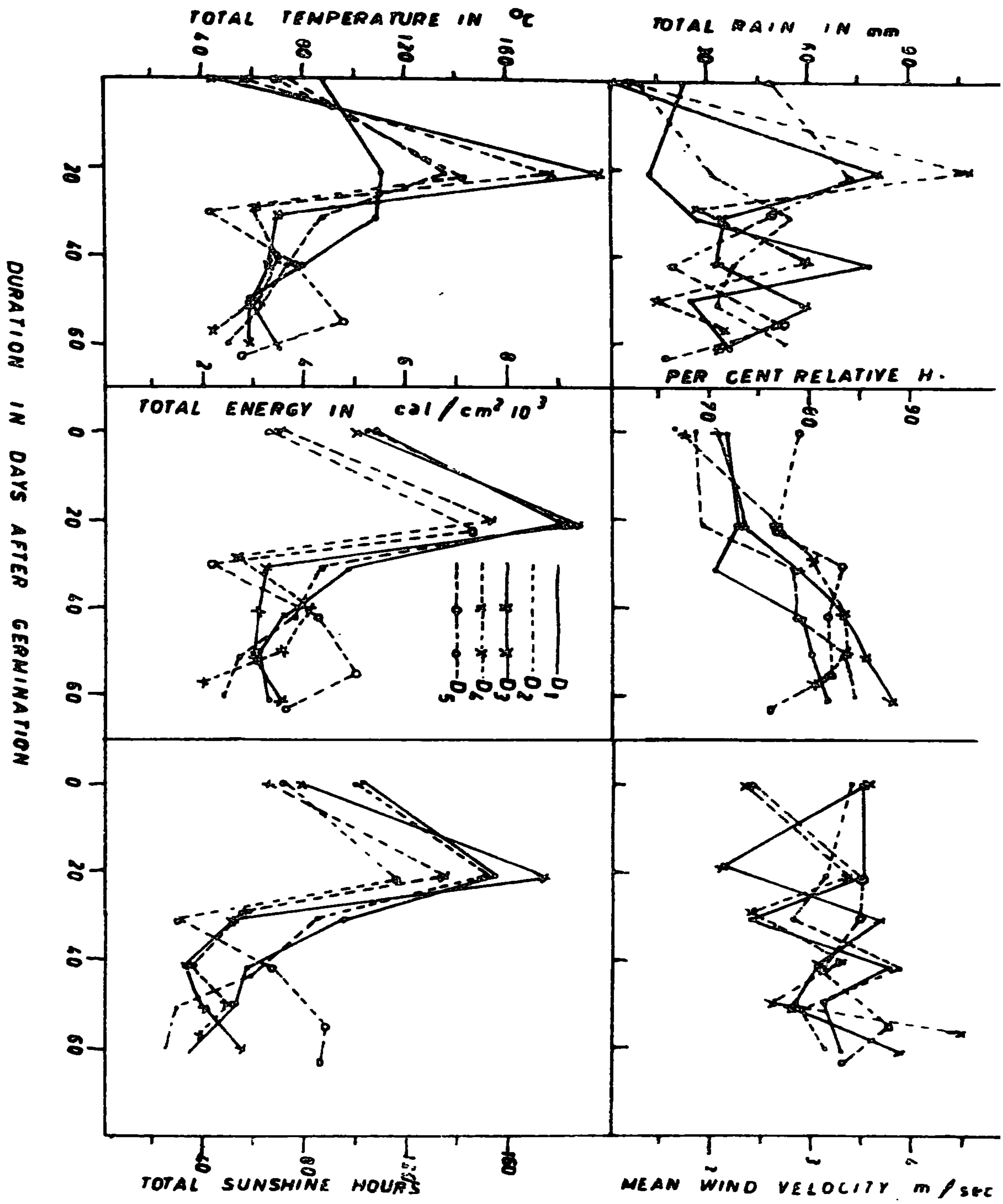


FIG. 1. MEAN CLIMATOLOGICAL DATA OF THE FIELD

FIG. 2 - MEAN GROWTH OBSERVATIONS:- LEAF

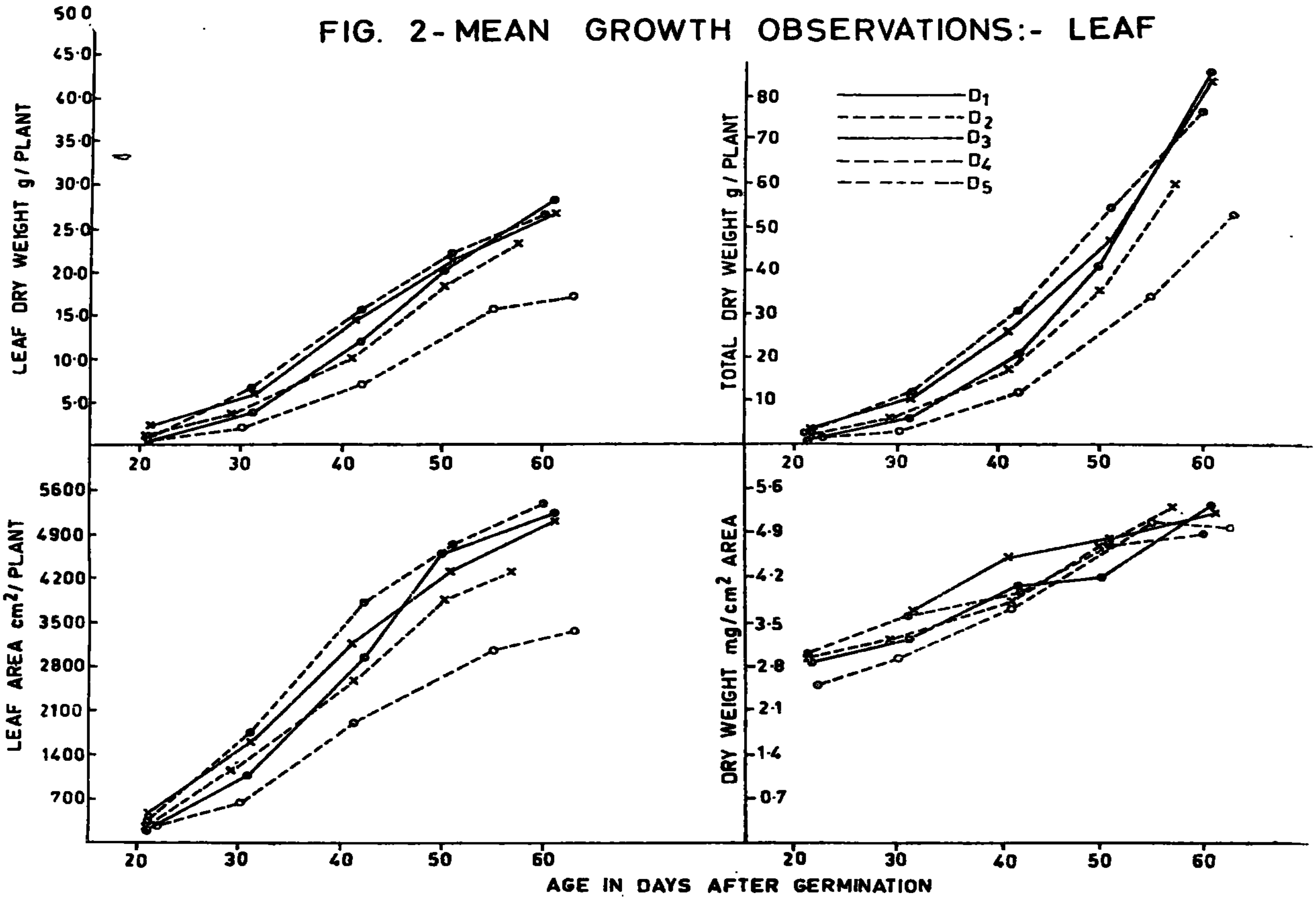
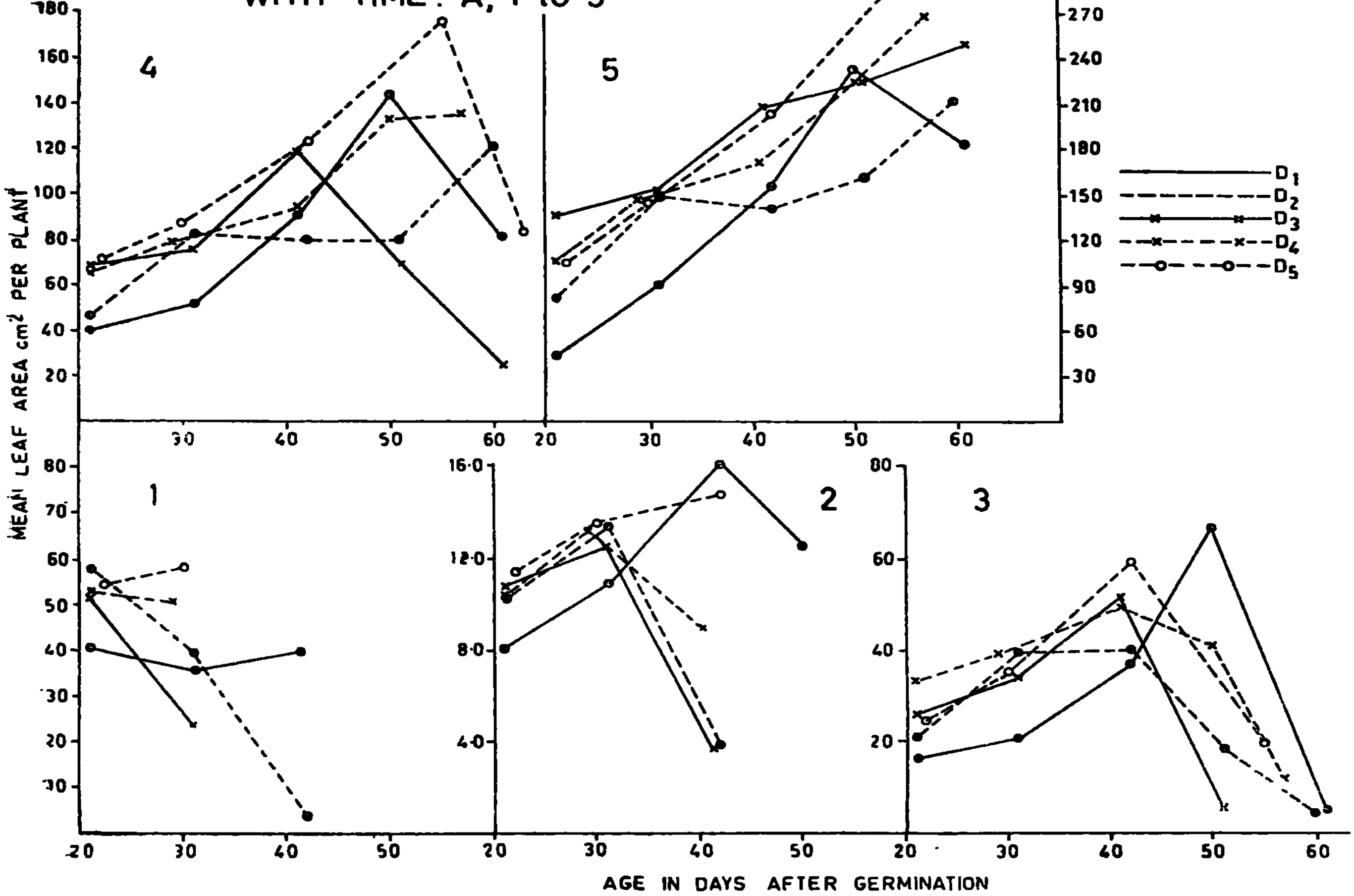


FIG.3 -GROWTH OF INDIVIDUAL LEAVES WITH TIME: A, 1 to 5



FIG· 4-GROWTH OF INDIVIDUAL LEAVES WITH TIME: B, 6 to 9

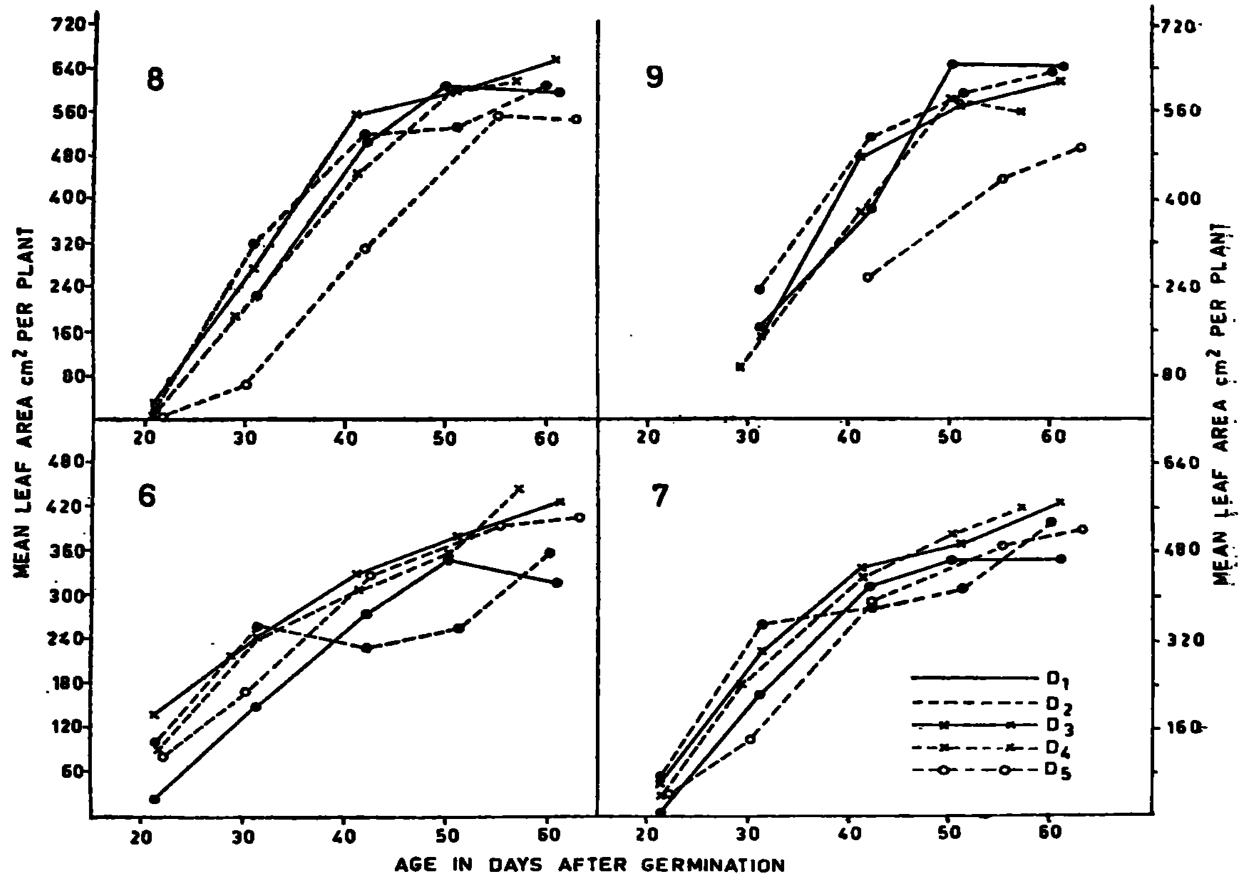


FIG.5 - GROWTH OF INDIVIDUAL LEAVES WITH TIME : C. 10 to 13