

THE INFLUENCE OF TEMPERATURE ON MORPHOLOGY AND GROWTH RATE OF BEAN SEEDLINGS

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SUMMARY

Bush bean seedlings were grown at 16 and 25°C and two light intensities. At 25°C the relative growth rate (RGR) was twice that of 16°C and plant development took half the time. This suggests a linear proportionality between relative growth rate and temperature in this range because the minimum temperature for growth and development is about 8°C for bush beans. This relation implies that the relative growth rate has a specific maximum which depends on temperature. Slow extension growth induced by low temperature leads to a high level of carbohydrate reserves under conditions of high light intensity. This explains why at 16°C the dry matter content of seedling leaves rises gradually whereas it remains practically constant at 25°C. This also explains why leaf area per unit leaf dry weight drops at 16°C (*fig. 2*) so that leaf area ratio (LAR) decreases after reaching a maximum (*fig. 1*). This, however, does not lead to a drop in relative growth rate which suggests that a compensation through a higher net assimilation rate (NAR) occurs.

At 25°C the decline of RGR in low light intensity is relatively strong, probably because of a high respiration level. Light intensity and temperature have little influence on the specific weight of leaves (*fig. 4*). Furthermore leaf area per unit fresh leaf weight appears to be proportional to the inverse of leaf thickness (*fig. 5*). These findings suggest that inner leaf structure maintains a certain homogeneity independent of outward conditions.

Cotyledons are exhausted by the young seedling at a constant rate which is higher in high temperatures and low light intensities.

INTRODUCTION

In a preceding paper (VAN DOBBEN et al. 1981) the influence of the radiation level on plant form and growth rate was studied. It could be shown that for bean seedlings with unfolded leaves at 25°C the relative growth rate (RGR) is constant at a radiation range from about 60 W/m² upward. This could be explained in this way that a lower net assimilation rate (NAR) is compensated by a higher leaf area ratio (LAR), leaves remaining thinner as radiation is lower. Besides the shoot/root ratio (fresh weight) and also stem ratio show higher values. The final seedling weight, however, remains significantly lower. This could be explained by the fact that in the early stages of seedling development the formative adaptations which lead to differences in LAR take some time during the period of unfolding. In this phase the low light treatment attains a retardation which cannot be made up in later stages although the same RGR may be reached in comparison with the high light controls.

In May 1981 a similar experiment was started in two glass-houses with temperatures of 16 and 25°C, respectively. The purpose was to study the influence of temperature on seedling development and the eventual interrelations with the radiation level.

2. METHODS

The choice of the bush bean variety (Berna), the preparation of the seedlings and the nutrient solution were the same as described in VAN DOBBEN *et al.* (1981). The 16°C glass-house was well air-conditioned, in the 25°C one the temperature rose to somewhat higher values during sunny afternoons. Two radiation levels were applied in each glass-house by shading a set of plants with white cheese cloth. This treatment reduced the radiation level to about 40 W/m² whereas above the unshaded plants in full sunshine at noon 195 W/m² was measured.

Plants were harvested every day (25°C) or every second day (16°C). Fresh and dry weight of separate organs and leaf area were measured.

3. RESULTS AND DISCUSSION

3.1. The influence of temperature on the relative growth rate (RGR)

The values for RGR recorded in *table 1* have been assessed by plotting logarithmic values of total dry weight against time. The results did not deviate significantly from figs. 9 and 11 in VAN DOBBEN *et al.* (1981) apart from the fact that the growth rate in 16°C was halved in comparison with the rate at 25°C. This agrees with a retardation in development of the seedlings which at 16°C took twice the time required at 25°C. Minimum temperature for growth and development of *Phaseolus* beans is about 8°C. Calculated from this value 16 and 25°C agree with 8 resp. 17°C, about a doubling. This indicates a linear proportionality between temperature and growth rate in this range. RGR apparently reaches a specific maximum which depends on temperature. In other words: under favorable conditions of radiation and nutrition the growth process itself limits growth. This accords with findings of many authors, e.g. HUNT & HALLIGAN (1981). For the growth rate of perennial rye-grass a Q_{10} of 1.92 was found in the range 10–20°C at radiation saturation. For this species the minimum temperature for growth is about 0°C. The same applies to small cereals. From results of VAN DOBBEN (1962) it can be calculated that a rise from 10 to 16°C (+ 60%) gave an increase of RGR in rye from 105 to 164 (+ 60%) and in wheat from 72 to 105 (+ 45%). This also supports the conclusion that relative growth rate shows a specific maximum which depends on temperature.

In accordance with MILTHORPE (1959) and many other authors it may be concluded that the temperature reaction of growth can be explained principally by a change in LAR and to a lesser degree by a change in NAR, which is less temperature-dependent (*table 1*). Low temperature, therefore, retards extension

Table 1. Characteristics of morphology and growth rate of bean seedlings at a comparable stage, respectively 18 days (16°C) and 9 days (25°C) after unfolding of the first leaves.

Irradiation Temperature	200 W/m ²		40 W/m ²		
	16°C	25°C	16°C	25°C	
Relative growth rate (mg g ⁻¹ day ⁻¹)	130	260	92	135	
Leaf area ratio (cm ² per g dry plant weight)	160	260	260	440	
Net assimilation rate (RGR/LAR)	0,8	1,0	0,35	0,30	
Area of seedling leaves (cm ² per plant)	250	250	235	190	
Total leaf area per plant (cm ²)	280	360	280	240	
Specific leaf area (fresh) (leaf area in cm ² per gr fresh leaf weight)	38,5	46,1	58,8	65,4	
Specific leaf area (dry) (leaf area in cm ² per gr dry leaf weight)	334	440	670	893	
Specific weight of leaves (g.cm ⁻³)	0,72	0,70	0,65	0,70	
Leaf thickness in mm	0,35	0,30	0,25	0,22	
Weight ratio fresh (fresh weight per unit total dry weight)	<ul style="list-style-type: none"> stem leaf shoot root 	2,3	2,4	4,3	4,4
		5,1	5,6	5,6	6,8
		7,4	8,0	10,0	11,2
		4,2	2,5	3,5	3,0
Weight ratio dry (dry weight per unit total dry weight)	<ul style="list-style-type: none"> stem leaf shoot root 	0,20	0,26	0,34	0,37
		0,60	0,60	0,49	0,50
		0,80	0,85	0,83	0,88
		0,20	0,15	0,16	0,12
Dry matter content in %	<ul style="list-style-type: none"> stem leaf shoot root 	9,0	11,0	8,0	8,7
		11,8	10,0	8,9	7,3
		11,0	10,6	8,5	8,0
		4,9	5,7	4,9	4,8

growth rate more than assimilation, especially in species from moderate climates but also in crops from sub-tropical origin such as maize and *Phaseolus* beans. This leads to a high level of carbohydrate-reserves which are not immediately used for the development of new tissues. This phenomenon is well known for grasses (ALBERDA 1965) and small cereals (VAN DOBBEN 1962). The present results (table 1) show a difference in dry matter content between leaf blades in 16°C (11,8%) and 25°C (10%) which can be explained in this way. Figures are lower in the low light intensity (8,9 and 7,3% respectively) and would most probably have been lower in the high light intensity when photosynthesis had been limiting growth. The difference in dry matter content between the treatments 16 and 25°C widens during seedling development.

In the present experiment the influence of the light intensity at 25°C was much the same as in the earlier experiment (VAN DOBBEN et al. 1981). In both experiments LAR was appreciably higher in the low light intensity but NAR decreased relatively stronger with as a result a drop in RGR of about 50% (table 1). At 16°C the increase of LAR was relatively the same as at 25°C but RGR was only 30% lower. This is easy to explain. The gross synthesis will be limited by the (low) light intensity and will thus be the same in both temperatures. The respiration, however, will be higher at 25°C and therefore NAR will be lower

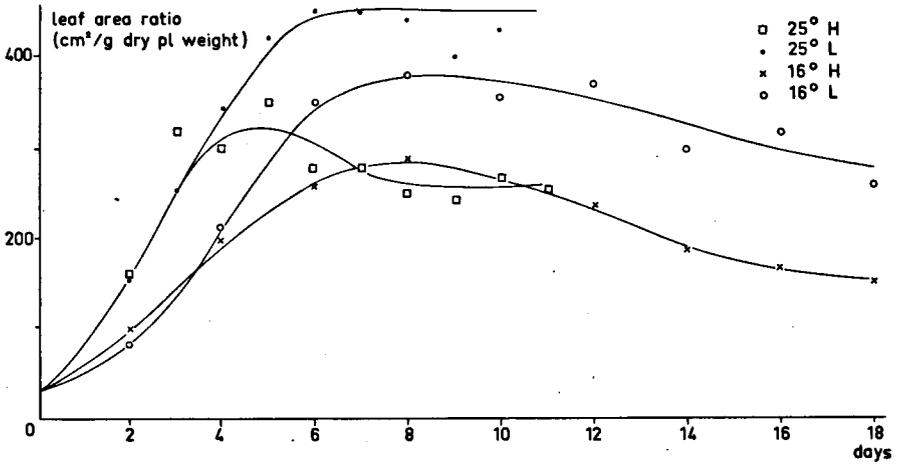


Fig. 1. Unfolding of the leaves of a bean seedling. Course of the leaf area ratio (LAR).

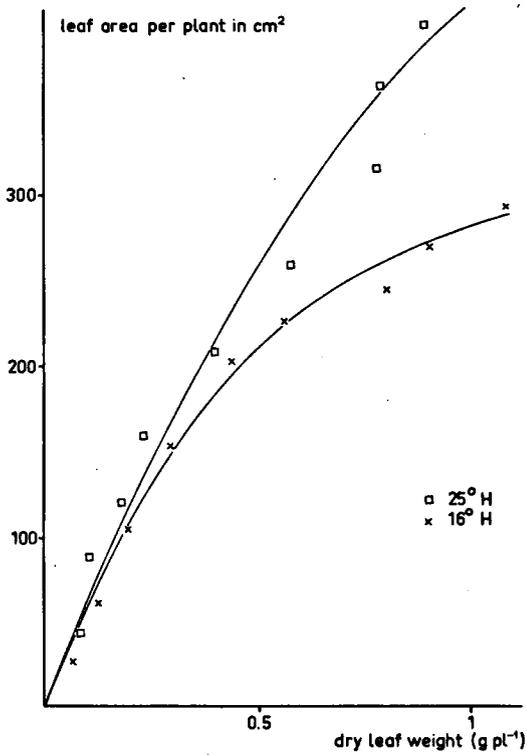


Fig. 2. As fig. 1. Leaf area plotted against dry leaf weight.

with as a result a sharper drop in RGR. Under conditions of strong irradiation NAR is higher at 25°C, but under weak light the lower temperature wins.

3.2. Changes in LAR and NAR during seedling development

As *fig. 1* shows LAR tends to decrease during seedling development after reaching a maximum, especially at 16°C. This course can at least partially be explained by a gradual rise of dry matter content in the lower temperature. This rise corresponds with a decrease of the specific leaf area (SLA), which can be derived from *fig. 2* where leaf area is plotted against dry leaf weight. The decline of SLA is far stronger in 16°C. During the same period RGR does not change which again indicates that it has reached the specific maximum for the given temperature. This implies that the drop of the leaf area ratio is compensated by a higher NAR. This accords with the experience of several authors studying seedling growth as cited by HUNT & HALLIGAN (1981), e.g. POTTER & JONES (1977). This compensation indicates that under these circumstances net assimilation is regulated by the growth rate.

3.3. The influence of temperature on the morphology of the leaves

Leaf thickness (*fig. 3*) was calculated from leaf volume divided by leaf area.

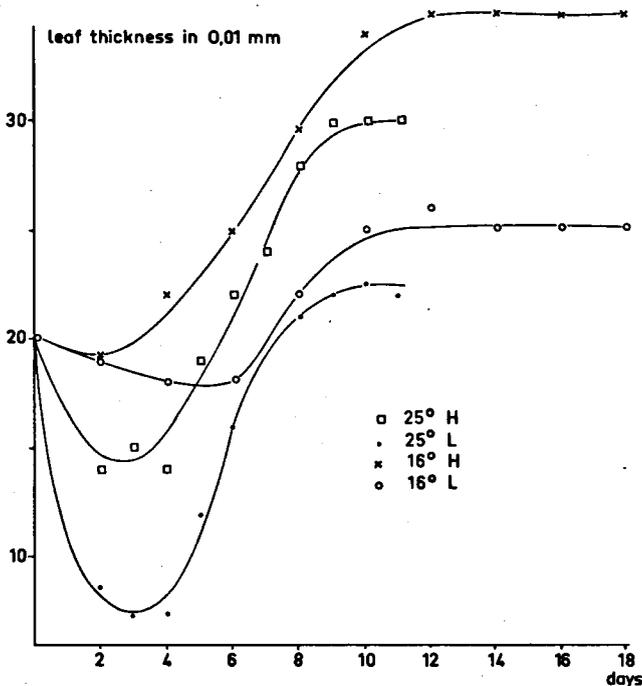


Fig. 3. As *fig. 1*. Course of leaf thickness.

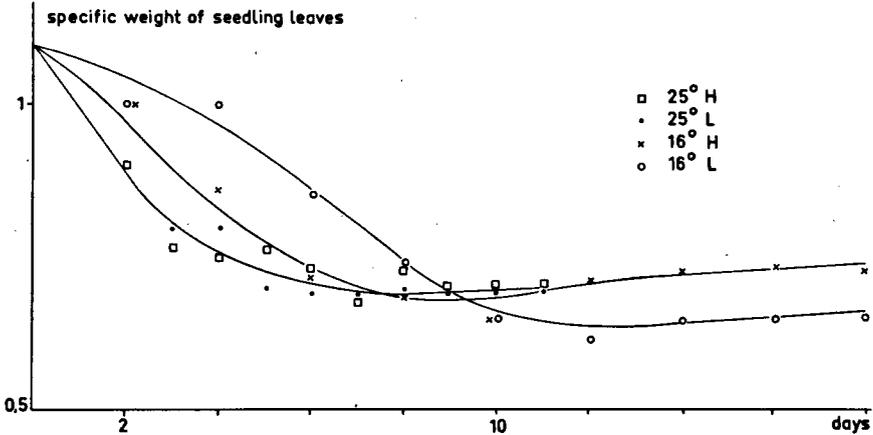


Fig. 4. As fig. 1. Course of the specific leaf weight.

This gives average values – surface relief caused by nerves is neglected. Leaf volumes were measured by immersion of leaves in a calibrated cup. This provides the opportunity to follow the course of specific weights during the unfolding of leaves (fig. 4).

It appears that folded leaves show a value above 1 which indicates that little or no intercellular space has been formed at this stage. During unfolding specific weights fall rather rapidly to about 0,7 with little difference between treatments. It seems reasonable to assume that the specific weight of a leaf is determined mainly by the presence of intercellular space. This implies that this space takes up about one third of the total leaf volume.

The fact that the large differences in leaf thickness do not lead to comparable differences in specific weight indicates that a proportionality exists between total volume of mesophyll tissue and intercellular space. This seems plausible from a functional point of view.

The very deep drop of leaf thickness in the first days of leaf development shown by the treatment at 25°C – weak light does not correspond with a difference in course for specific weight in comparison with the control in strong light. The relation between mesophyll mass and intercellular space develops apparently in the same way in both light treatments.

As table 1 shows, the temperature has no influence on the leaf dry weight ratio but the fresh weight ratio is higher in 25°C, because of a lower dry matter content. In consequence the specific leaf area is higher, not only the leaf area per unit dry weight (compare fig. 2) but also per unit fresh weight. From the relation

$$SLA = \frac{\text{leaf area}}{\text{leaf weight}} = \frac{\text{leaf area}}{\text{leaf volume} \times \text{spec.weight}} = \frac{1}{\text{leaf thickness} \times \text{spec.weight}}$$

it can be derived that SLA (fresh weight) is proportional to the inverse of leaf thickness in view of the fact that there is no significant difference between the

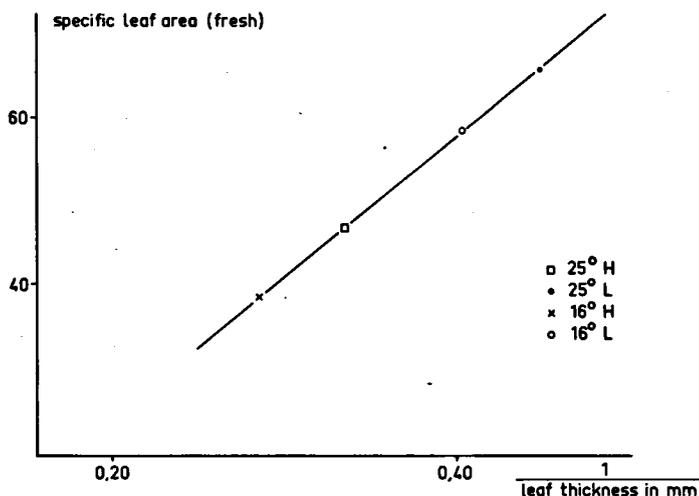


Fig. 5. Specific leaf area (fresh) in $\text{cm}^2 \cdot \text{g}^{-1}$ plotted against the inverse of leaf thickness for a fully developed bean seedling.

specific leaf weights of several treatments. *Fig. 5* confirms this expectation. This also points to a certain homogeneity of the inner leaf structure at several treatments.

3.4. The influence of temperature on dry matter distribution

Fig. 6 gives distribution diagrams as used in the earlier paper. To keep the picture more surveyable the dry weights of organs are plotted only against the total dry weight of seedlings minus cotyledons. This is also done with the cotyledons themselves, which gives a clear picture of their exhaustion which appears to be linear until the moment at which the reserves are gone. Further the weight of the ternary leaves emerging towards the end of the seedling stage are added to the total leaf weight and not to stem weight as done in the earlier paper. This gives the expected straightening of distribution lines of leaves and stem. There are some differences between the comparable 25°C treatments of both experiments. For instance the stem-root ratio was significantly higher in the first set of experiments (VAN DOBBEN et al. 1981). Here we must take into account that the plant material originating from the same commercial bush bean variety may have some genetic difference in subsequent years.

Where the influence of temperature is concerned in the present study, it appears that the cotyledons are exhausted earlier at high temperature, not only in time (time is not plotted in *fig. 6*) but also relatively. This can be explained by a higher respiration.

The fact that cotyledons are also earlier exhausted in the low light treatments meets the stronger requirement of the seedlings under these conditions.

A further significant temperature effect can be seen in the stem weight ratio which is much higher in high temperature. It is a well-known fact that bush

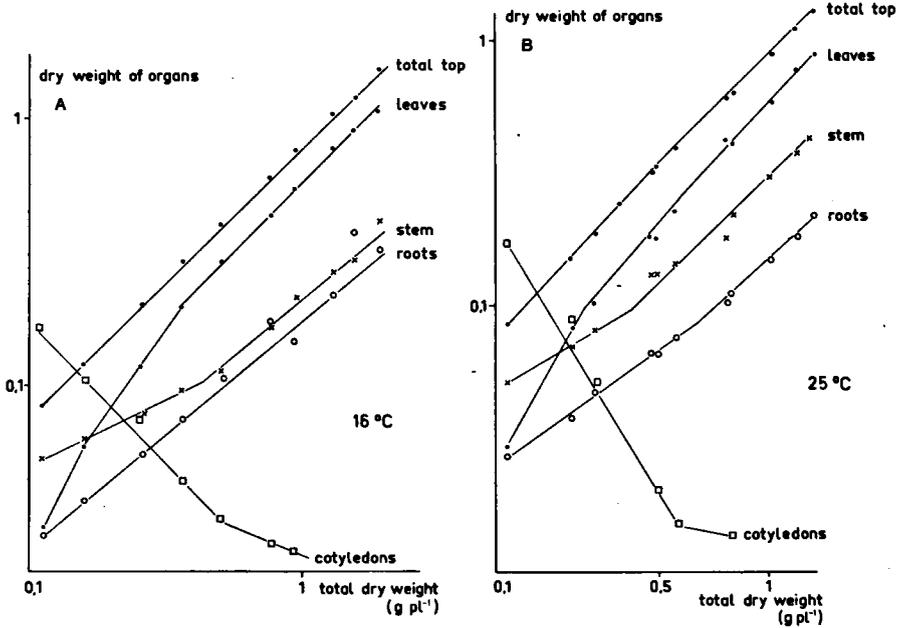


Fig. 6. Dry weight of bean seedling parts plotted against total plant weight minus cotyledons during seedling development. Logarithmic scale.

A: 16°C, B: 25°C.

beans form tendrils more readily at high temperature. Under these conditions they are relatively long and thin and have a high dry matter content because of relatively much epidermis tissue.

In *table 1* data from the end of the seedling period are given, corresponding with the right hand sides of *fig. 6*. It is clear that the shift to a higher share of the stem – mainly caused by tendrils extension – is especially clear in the treatments with a low light level. This is in accordance with the former set of experiments (VAN DOBBEN *et al.*, 1981) where this shift was even more extreme. There is little difference in reaction between 16 and 25°C in this respect. The same applies to the shift in shoot-root ratio to a higher level under low light conditions. This shift is far stronger in fresh weight compared with dry weight and this reflects the considerable difference in dry matter content. This difference is also responsible for the fact that leaf weight ratio (dry) is lower under weak light but leaf weight ratio (fresh) is higher.

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