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TRANSPIRATION AND GROWTH OF *PHASEOLUS VULGARIS* L. AS AFFECTED BY WIND SPEED

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1. INTRODUCTION

Although the amount of water, metabolically used by the plant, is very small in relation to the amount transpired, water uptake, transport, and transpiration are associated with important vital functions.

Several studies, also from this laboratory (e.g. KUIPER 1962, WASSINK and KUIPER 1959 and ABD EL RAHMAN, KUIPER and BIERHUIZEN 1959), have shown that the effect of external factors (e.g. light intensity, temperature, and others) on transpiration, dry weight production and morphogenetic features often are distinctly correlated. The present paper presents some results on controlled wind speed in this respect.

Transpiration is chiefly determined directly or indirectly in the vapour phase. Hence, some of its main features can be understood from the properties of gas diffusion processes. For a quantitative analysis, FICK's diffusion law has been frequently applied (e.g., PENMANN 1948, BANGE 1953). On this basis, the vapour pressure deficit, and the various resistances along the diffusion path, have been evaluated. A general result was that the stomatal mechanism plays a dominating rôle in determining the overall resistance, and thus in transpiration control.

Several studies on the effect of wind on transpiration have been carried out. In short term experiments, STÅLFELT (1932) observed a linear relationship between transpiration and wind speed, up to 0.5 m/sec. WRENGER (1963) concluded that the rate of transpiration reached a maximum after a very strong increase, and decreased thereafter, sometimes down to values below the 'still air' value.

KUIPER (1961) mentioned three wind effects, viz., decrease of the resistance of the laminar air layer, decrease of the temperature difference between leaf surface and free air mass, and decrease in stomatal aperture (particularly in the case of limited water supply to the plant).

According to YAMAOKA (1958), increase of wind speed from 0 to 1.0 m/sec decreases transpiration. At still higher wind speeds, transpiration remained constant. This is confirmed by data of WHITEHEAD (1962). The decrease in transpiration is due to a decrease in temperature difference between leaf surface and air mass, which results in a lower vapour pressure deficit.

Investigations about wind effects on growth under laboratory conditons are not numerous. SATOO (1953) found a retardation in growth of *Robinia* seedlings under field conditions at a wind speed of 2.5 m/sec. WHITEHEAD (1962) obtained the same result with *Helianthus*, applying four different wind speeds from 0.5 to 15 m/sec. LORCH (1958) mentioned mechanical damage of leaves as the most important wind effect. GÄUMANN and JAAG (1939) assumed that cells of shaken leaves do not function normally under wind conditions. KAHL (1951) confirmed this in experiments with a rocking machine, resulting in depression of photosynthesis. DENEKE (1931) found an increase in CO_2-supply to the leaves with increasing wind speed up to 2–3 m/sec, resulting in a higher rate of photosynthesis.

From the above, it is evident that wind velocity affects the rate of transpiration. The present observations on the effect of wind speed on transpiration and growth have been carried out with bean plants at constant air temperature, air humidity and light intensity.

2. MATERIAL AND METHODS

Beans *(Phaseolus vulgaris* L., var. Widusa) were soaked for 24 hours, and then sown in fine gravel. Eight days after sowing (August 27, 1965), ten representative plants were harvested, and initial values of leaf area, leaf thickness, fresh and dry weight of leaves, stems, and roots were measured.

For the experiment, 40 plants in 4 groups of 10 were used. Each plant was placed in a plastic cup, containing about 300 ml nutrient solution. Total fresh weight of each plant was measured. With the aid of fans, the 4 groups of plants, A, B, C, and D were submitted to vertical upward wind streams with a velocity of 0, 1.0, 1.4, and 1.6 m/sec respectively. Wind speed was measured at plant height with a cup anemometer (table I). Each group of plants received light from 10 daylight fluorescent tubes of 120 Watt each (Philips, type TL MF 120 W/33 RS), during 12 hours per day. The light intensity was 1.1×10^5 ergs/cm^2.sec, measured at plant height with a cosinus-corrected light meter in horizontal position. The experiment was carried out in a conditioned room with the air temperature set at 20°C and the relative humidity at 70%. Thermo-hygrographs recorded the actual values for the 4 groups of plants, as given in table I.

Table I. Wind speed in m/sec, air temperature in °C, and relative humidity in %, for the four different treatments.

Group of plants	Wind speed (m/sec)	Temperature (°C)	Rel. humidity (%)
A	0	19 ± 1	70 ± 3
B	1.0	18 ± 1	70 ± 2
C	1.4	18 ± 1	70 ± 2
D	1.6	18 ± 0.5	70 ± 3

The temperature of the nutrient solution and that of the leaf surface were less than 1 °C higher than the recorded air temperature. During 3 weeks (August 27 to September 17, 1965), daily values of transpiration were measured for each plant by weighing cups with nutrient solution only. The daily loss of weight is assumed to be equal to the evapo-transpiration by the plant plus its nutrient solution, and to the evaporation of the nutrient solution respectively. Every day, nutrient solution was added to equal the loss of weight, and, once in 5 days, the solution was renewed. At the end of the experiment (September 17) fresh and dry weight of leaves, stem and roots, total leaf area, and mean leaf thickness were determined for each individual plant.

In order to estimate evaporation of the nutrient solution under equal shading conditions as obtaining in the evapo-transpiration measurements, the following procedure was adopted. A 100 ml erlenmeyer flask, filled with water, was placed into the cup with the solution and provided with a bean plant of the same size as the experimental plants. Before weighing, the erlenmeyer flask with the plant was, of course, removed.

All data given are averages of groups of 10 plants, with the standard deviation of the average.

3. Results and discussion

Total water use, final leaf area, mean leaf thickness, and increase of fresh and dry weight of leaves, stem and roots, as affected by wind in our experiment, are given in table II. The top/root ratio (the final weight of leaves and stem, divided by the final weight of roots) has been calculated for fresh and dry weights. We have also calculated the water requirement, viz., water use per unit increase in dry weight (g/g), and the related ratios water use per unit increase in fresh weight (g/g), and per unit leaf area (g/cm^2). These data are also presented in table II. Since only one harvest, at the end of the 3-weeks period was taken, comparison of total water use with leaf area is rather ambiguous. Probably, increase in leaf area during the experiment (leading up to about flowering of the plants, from the initial stage with 2 small leaves) was about linear, and it would be certainly more realistic to compare total water use with the average leaf area between initial and final ones. However, since this value has not been exactly determined, and our purpose only was to obtain comparable data for the various wind speeds, we have referred total water use only to final leaf area. In figure 1 (a and b) the data of table II are plotted as percentages of their maximum values. The standard deviation of the mean values, given in tabel II, is about 10 per cent or less, except for the increase in fresh weight of roots, where it amounts to about 15 per cent.

Although the difference between water use at 1.0 m/sec and at 0 m/sec is rather small, total water use decreases with increasing wind speed, in accordance

TABLE II. Effect of wind speed on various growth data of bean plants (*Phaseolus vulgaris* L.) grown under controlled conditions (temperature 20°C, relative humidity 70%, light intensity 1.1 × 10^6 ergs/cm^2.sec). Figures between ( ) correspond to curves of figure 1.

Group of plants	Wind speed (m/sec)	(*1*) Total water use (g)	(*2*) Final leaf area (cm^2)	(*3*) Mean leaf thickness (mm)	(*4*) Increase in fresh weight of leaves (g)
A	0	245.00 ± 24.90	375 ± 32	0.21 ± 0.004	9.14 ± 0.81
B	1.0	252.48 ± 25.91	338 ± 34	0.19 ± 0.006	8.33 ± 0.90
C	1.4	201.09 ± 16.08	286 ± 21	0.19 ± 0.006	6.87 ± 0.52
D	1.6	169.01 ± 11.94	256 ± 12	0.21 ± 0.004	5.88 ± 0.25

Group of plants	Wind speed (m/sec)	(*5*) Increase in dry weight of leaves (g)	(*6*) Increase in fresh weight of stem (g)	(*7*) Increase in dry weight of stem (g)	(*8*) Increase in fresh weight of roots (g)
A	0	1.25 ± 0.10	2.38 ± 0.22	0.36 ± 0.03	5.10 ± 0.71
B	1.0	1.10 ± 0.08	2.50 ± 0.30	0.38 ± 0.03	4.36 ± 0.75
C	1.4	1.02 ± 0.06	2.01 ± 0.15	0.35 ± 0.02	3.20 ± 0.50
D	1.6	0.91 ± 0.05	1.71 ± 0.08	0.32 ± 0.01	2.79 ± 0.22

Group of plants	Wind speed (m/sec)	(*9*) Increase in dry weight of roots (g)	(*10*) Increase in fresh weight of total plant (g)	(*11*) Increase in dry weight of total plant (g)	(*12*) Top/root ratio fresh weight (g/g)
A	0	0.39 ± 0.04	16.63 ± 1.66	2.00 ± 0.15	2.40 ± 0.11
B	1.0	0.36 ± 0.05	15.20 ± 1.94	1.83 ± 0.16	2.64 ± 0.14
C	1.4	0.27 ± 0.05	12.08 ± 1.15	1.64 ± 0.10	2.94 ± 0.20
D	1.6	0.24 ± 0.02	10.38 ± 0.50	1.47 ± 0.07	2.67 ± 0.13

Group of plants	Wind speed (m/sec)	(*13*) Top/root ratio dry weight (g/g)	(*14*) Total water use/ increase in fresh weight (g/g)	(*15*) Total water use/ increase in dry weight (g/g)	(*16*) Total water use/ final leaf area (g/cm^2)
A	0	4.72 ± 0.29	15.26 ± 0.52	125.24 ± 4.99	0.67 ± 0.03
B	1.0	4.80 ± 0.32	17.34 ± 1.61	139.06 ± 10.90	0.76 ± 0.06
C	1.4	5.81 ± 0.39	17.04 ± 1.02	122.37 ± 6.17	0.71 ± 0.04
D	1.6	5.86 ± 0.44	16.87 ± 1.07	115.69 ± 7.44	0.66 ± 0.04

with results of YAMAOKA (1958), WHITEHEAD (1962), and, in general, also with those of WRENGER (1936). Final leaf area (fig. 1a, curve 2) decreases to the same degree. With increasing wind speed, the increase in fresh and dry weight of total plant, leaves, stem, and roots (fig. 1a, curves 4–8, and fig. 1b, curves 9–11) decreases, except for the increase in fresh and dry weight of the stem (fig. 1a, curves 6–7) at wind speeds from 0 to 1.0 m/sec. These results agree with those of WHITEHEAD (1961), LORCH (1958) and SATOO (1953). It was also found that damage of leaves increased with wind speed. According to KAHL (1951) this results in a lower photosynthetic activity, owing to drying around small cracks and tears in the leaves.

From these results, one may first conclude that, in our experiments, the plants were hardly affected by transpiration-increasing wind effects (as, e.g., decreasing resistance of laminar air layer, increasing transpiration at the lee side). On the other hand, transpiration-decreasing wind effects (decreasing temperature difference between leaf surface and free air mass, decreasing stomatal aperture) were of more importance. In general, transpiration may exceed water supply at high wind velocities, resulting in a higher water stress in the plant and ultimately in the closure of stomata (physiological drought). In our experiment, which was of long duration, the plants in several respects adjusted themselves during their growth to the various conditions. In accordance herewith, differences in leaf moisture were found to be small, and remained within 3 %. A linear relation was found between fresh weight or dry weight of the leaves and the leaf area. This is in accordance with the observation that variation in leaf thickness (fig. 1a, curve 3) was insignificant.

From our results it is evident that the depression in water use, leaf area, and growth with increasing wind speed, as found, is of real importance. The influence of small differences in light intensity, temperature, air humidity, or water supply was negligible. The increase in CO_2-supply with wind (DENEKE, 1931) did not appear to be of importance in our experiment.

The top/root ratio for both fresh weights (fig. 1b, curve 12) and dry weights (fig. 1b, curve 13) increases with increasing wind speed. The former is lower, resulting from the fact that the moisture content of the roots is higher than that of the tops. The increase of the top/root ratio with increasing wind speed is due to the fact that the increase in weight of the roots is lower than that of the top. The reason for this could either be a lower water need of the top (decreased total water use) or a higher water uptake efficiency of the roots. It should be noted that our observations are restricted to bean plants under specified conditions; WHITEHEAD (1961) found an opposite effect of wind on the top/root ratio of sunflower.

Total water use per gram increase in fresh weight, per gram increase in dry weight, and per cm^2 leaf area (fig. 1b, curves 14, 15, and 16 respectively) show almost identical pictures. The three ratios increase up to 1.0 m/sec and decrease at higher wind speeds, but the differences are relatively small.

In conclusion, it appears that wind affects various aspects of the physiology of plants. It seems likely that all effects, including those on dry weight production

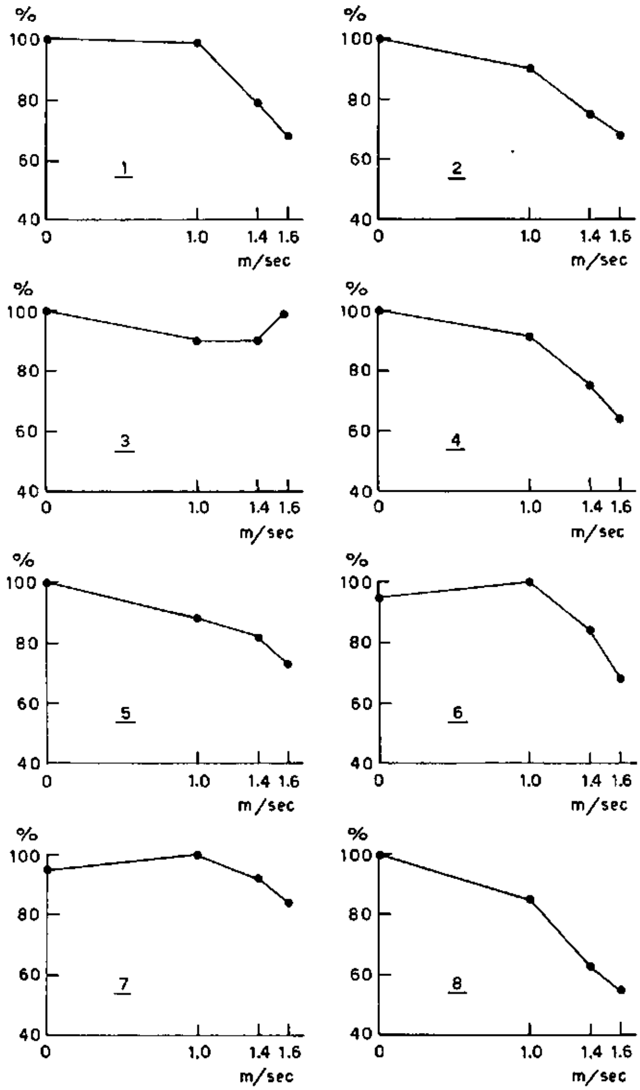

Figure 1a.

FIGURE 1 (a and b). Effect of wind speed on various growth data of bean plants *(Phaseolus vulgaris* L.) grown under controlled conditions (temperature 20°C, relative humidity 70%, light intensity 1.1 × 10^5 ergs/cm^2.sec). Data are percentages of maximum values.

Curve 1: Total water use.
Curve 2: Final leaf area.
Curve 3: Mean leaf thickness.
Curve 4: Increase in fresh weight of leaves.
Curve 5: Increase in dry weight of leaves.
Curve 6: Increase in fresh weight of stem.
Curve 7: Increase in dry weight of stem.
Curve 8: Increase in fresh weight of roots.

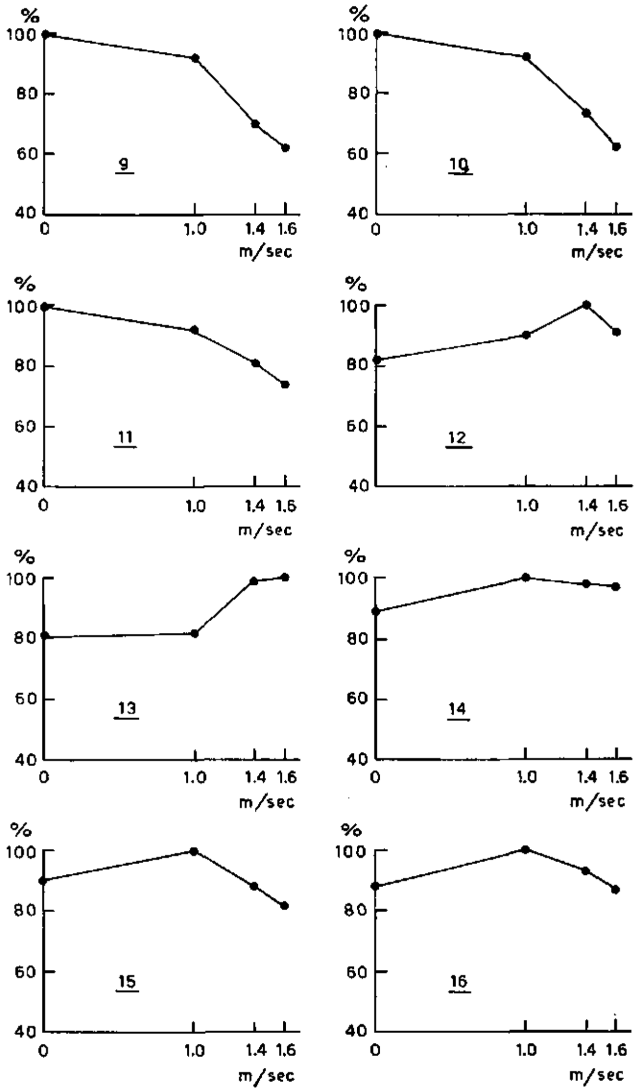

Figure 1b.

Curve 9: Increase in dry weight of roots.
Curve 10: Increase in fresh weight of total plant.
Curve 11: Increase in dry weight of total plant.
Curve 12: Top/root ratio for fresh weights.
Curve 13: Top/root ratio for dry weights.
Curve 14: Total water use per unit increase in fresh weight of the plant.
Curve 15: Total water use per unit increase in dry weight of the plant.
Curve 16: Total water use per unit final leaf area.

and morphogenesis (e.g. leaf size), in this case operate via effects on the water household and transpiration mechanisms. The present experiment, however, does not allow a final decision in this respect. With respect to other environmental factors which also affect both water household, production, and morphogenesis (e.g. light intensity, temperature, relative humidity), a direct action also on several other physiological processes (e.g. part of the photosynthetic and morphogenetic reaction chains) appears more probable.

4. Summary

The influence of wind speed on transpiration and growth of *Phaseolus vulgaris* L. has been investigated in an experiment of three weeks duration at 20°C air temperature, 70% relative air humidity, and a light intensity of 1.1×10^5 ergs/cm².sec from 120 Watt fluorescent daylight tubes (Philips, type TL MF 120 W/33 RS).

Increase in wind speed beyond 1.0 m/sec causes a decrease of total water use, and a corresponding retardation of growth. This results in relatively small differences in water use per gram increase in total fresh weight, per gram increase in total dry weight, and per cm² final leaf area. This differs from some results, reported in literature for short term observations. The reason may be that, in our experiment, the plants have adjusted themselves to the various conditions more than occurs in short term experiments.

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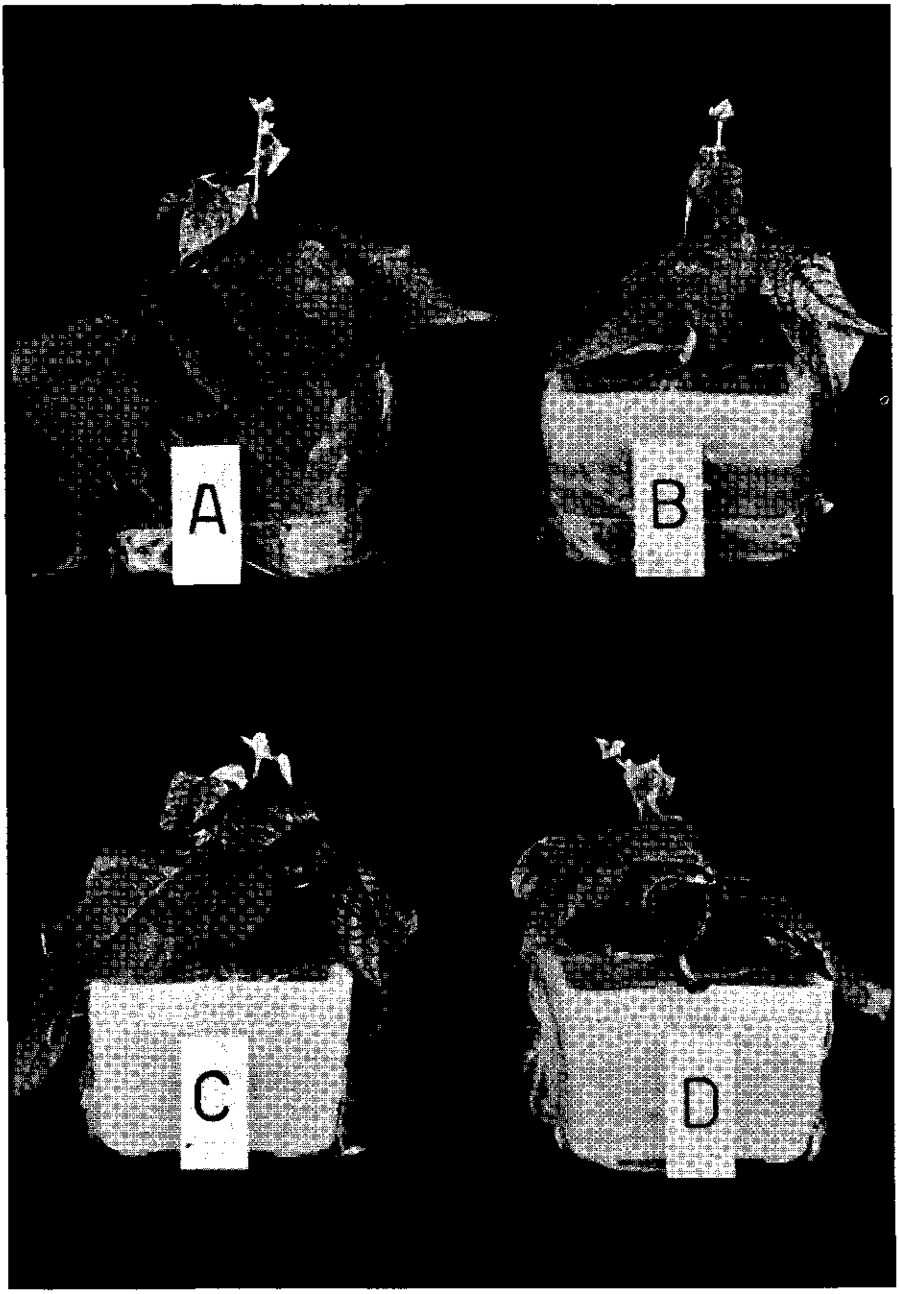

PLATE 1. Effect of wind speed on the growth of bean plants *(Phaseolus vulgaris* L.). Plants 4 weeks old; last 3 weeks submitted to different wind speeds (temperature 20°C, relative humidity 70%, light intensity 1.1×10^5 ergs/cm^2.sec). **A**: 0 m/sec, **B**: 1,0 m/sec, **C**: 1,4 m/sec, **D**: 1,6 m/sec.