SOME OBSERVATIONS ON THE RELATION BETWEEN TRANSPIRATION AND SOIL MOISTURE [1]

J. F. BIERHUIZEN

Institute for Land and Water Management Research, Wageningen, The Netherlands [2]

SUMMARY

Pot experiments on transpiration with kidney beans (*Phaseolus vulgaris*) were carried under controlled conditions of light intensity and temperature. Transpiration was measured by loss of weight. Measurements were taken at different moisture contents from the field capacity down to the wilting point. From the regularly recorded data on loss of weight the moisture content at each interval was calculated. The transpiration rate is greater at higher light intensities. It increases with the increase in the available moisture content from the wilting point and then becomes nearly constant at higher levels of moisture availability. At the highest light intensity it shows a maximum beyond which it slightly decreases. This may be explained by the deficiency of oxygen at higher moisture contents.

INTRODUCTION

Evidence regarding the availability of soil moisture between *field capacity* (maximum moisture content in equilibrium with the force of gravity) and *wilting point* is rather conflicting. In light and medium soils moisture appears to be equally available throughout this range (9). Other observations, however, indicate that deep rooted species on heavy soils may show a marked plant response to moisture deficit before the wilting point, as in stomatal behaviour, photosynthesis, respiration, transpiration, and starch accumulation. Growth is markedly influenced, particularly in plants grown in pots or containers (12). It has been assumed that water movement and root growth are more rapid in light and medium soils, and that this results in a fairly uniform depletion of soil moisture up to the wilting point. On the other hand, in heavy clay soils the upper zone together with the bulk of the roots may be depleted up to or below this percentage long before the lower zone, the average calculated availability still being high. It may be expected that plant species with sparse rootsystems will be more sensitive and respond earlier to drought than species with an intensive rootsystem.

The question as to whether or not soil moisture is equally available between field capacity and wilting point also depends upon the overall shape of the pF-curve, as has been shown by RICHARDS and WADLEIGH (8). It is evident from their figures that Olympic clay holds nearly 50 per cent of available water with a tension of one atmosphere and 25 per cent with a tension of three atmospheres, whereas Yolo clay loam holds 25 and 15 per cent respectively at these tensions. Many investigators have made experiments with plants in Yolo clay loam or similar soils in which the margin between the wilting point and the point at which soil moisture begins to be available is so narrow that it cannot be detected in field experiments.

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The difficulty of maintaining a constant moisture tension during an experiment is well-known. The use of drying cycles in which growth occurs at low tensions during relative long periods but still for short times at higher tensions tends to minimize plant response. HALKIAS *et al.* (3) observed a regular decrease in soil moisture down to the wilting point using various crops. They concluded that water is equally available throughout the whole range. It seems that this conclusion is not right since the exhaustion of water from the soil is controlled by the evaporative power of the atmosphere [MAKKINK and VAN HEEMST (5)] and also to the increase in leaf area.

Further evidence on factors affecting the relation between soil moisture and plant growth has been summarized by VEIHMEYER and HENDRICKSON (10), RICHARDS and WADLEIGH (8) and HAGAN (2). It is obvious that the contradictory data of transpiration obtained by different authors can be attributed to differences in experimental conditions. Experiments described in this paper were carried under controlled conditions of temperature and light intensity.

MATERIAL AND METHODS

Kidney beans (*Phaseolus vulgaris*) were cultivated in small white tins containing 1 kg of a light clay soil. This soil holds about half of its available water at a tension of one atmosphere (fig. 1), which, as mentioned above, is important for this kind of investigation. After sowing, the tins were placed in a growth cabinet at $20 \pm 2°$ C and illuminated for 12 hours a day by fluorescent daylight tubes at a light intensity of 2×10^4 ergs/sq.cm sec. The

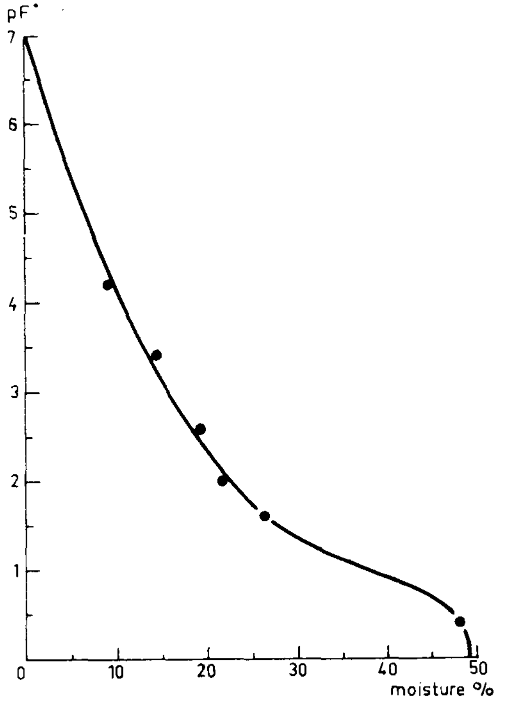

FIG. 1 THE MOISTURE CONTENT (WEIGHT PERCENT) VERSUS THE MOISTURE TENSION (pF) OF A LIGHT CLAY SOIL.

soil was kept at field capacity by sprinkling the tins every day if possible. This way ensures a rapid growth. After a period of three weeks when the leaf area was 100–130 sq.cm, the soil surface was covered with vaseline to prevent evaporation. Then, the tins were placed in thermostats for measuring transpiration under controlled conditions.

The four thermostats at 15°, 20°, 25° and 30° C can be kept at constant temperatures with an accuracy of 0.5° C by means of a thermorelay. The upper side of the thermostat was covered by a glasspanel above which fluorescent daylight tubes were placed. Various light intensities were obtained by placing different white paper screens on the glasspanel. The light intensities were measured with a photocell which had been calibrated against a large surface thermopile. The relative humidity was measured by means of an ASSMAN-psychrometer and recorded by a hygrograph. In this way transpiration was measured at four temperatures and four to five light intensities ranging from 0–4.5 $\times$ 10^4 ergs/sq.cm sec.

The tins were weighed on a balance every hour with an accuracy of 10 mg. The measurements were taken during the daytime until the moisture content of the soil reached the wilting point. This period ranges between 4 to 10 days depending on the intensity of transpiration. Then, soil samples were taken and dried at 105° C in order to determine the moisture content. From this percentage and the regularly obtained data of loss in weight the moisture content at each interval could be calculated. Leaf area was measured by squares on a natural size image.

EXPERIMENTS

The plants from the growth cabinet were selected according to equal leaf area and placed into the thermostats the night before the experiments started in order to establish an equilibrium between air and soil temperature.

Figure 2 shows the transpiration in gms/100 sq.cm hr versus the moisture percentage of the soil at various light intensities at 20° C and 40 per cent relative air humidity. The results obtained by VEIHMEYER and HENDRICKSON (11) using beans have also been plotted in the figure. It is evident that much higher transpiration rates were observed in our experiments. Obviously the curves represented tend to meet at the wilting point (moisture content $\pm$ 9%) where the transpiration rate is 0.3 gms/100 sq.cm hr. In another experiment carried by the author under lower evaporation conditions the transpiration rate was 0.15 which is nearly equal to that obtained by VEIHMEYER and HENDRICKSON. The latter authors concluded that soil moisture is equally available over the entire range studied due to the maintenance of the transpiration rate at a constant level. Examination of the results obtained in this paper shows that the transpiration rate is influenced by the change in the availability of moisture. At the highest light intensity of the order of 4.5 $\times$ 10^4 ergs/sq.cm sec the transpiration rate was 0.3 gms/100 sq.cm hr near the wilting point, then it increases gradually with the increase of the available moisture content until it attains a maximum of 1.2 gms/100 sq.cm hr at a moisture content of 16%. At a moisture content above 16% the transpiration rate exhibits a slight fall. The decrease in transpiration at low moisture tensions may be due to lack of oxygen, which strongly affectcs water absorption [Mc DERMOTT (5)]. At lower light intensities the curves show nearly the same trend but tend to flatten.

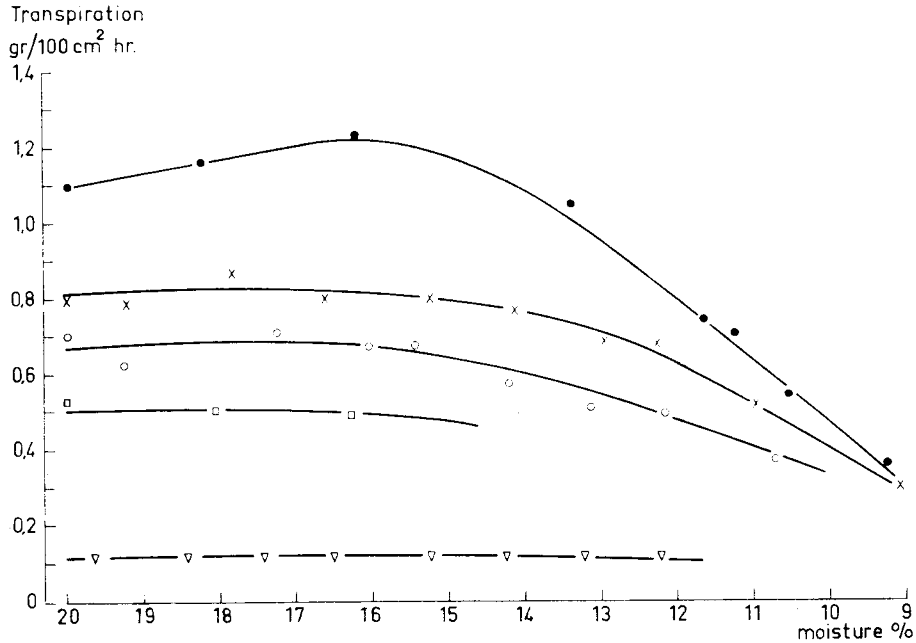

FIG. 2 THE TRANSPIRATION OF BEANS IN gms/100 sq.cm hr VERSUS THE MOISTURE PERCENTAGE OF THE SOIL, AT VARIOUS LIGHT INTENSITIES AT A TEMPERATURE OF 20° C AND A RELATIVE HUMIDITY OF 40%.
● light intensity 4.5 × 10^4 ergs/sq.cm sec
× light intensity 2.4 × 10^4 ergs/sq.cm sec
o light intensity 1.4 × 10^4 ergs/sq.cm sec
□ light intensity 0.66 × 10^4 ergs/sq.cm sec
▽ results from VEIHMEYER and HENDRICKSON (11).

Therefore it is evident that the transpiration rate shows a remarkable change with the variation in the soil moisture availability. The amplitude of this change becomes less pronounced at the lower light intensities. Comparable results were obtained at 15°, 25° and 30° C and other relative humidities. The effects of light intensity, temperature and saturation deficit on transpiration, however, will be dealt with in a subsequent paper.

MAKKINK and VAN HEEMST (5) draw a similar conclusion. They demonstrated that a decrease of the actual evapo-transpiration of grass with increasing moisture tensions only occurs at high evaporation conditions. At low evaporation conditions no such decrease was observed. The lack of the relation between transpiration rate and availability of soil moisture in VEIHMEYER and HENDRICKSON's results may be due to the fact that they carried their experiments under a limiting potential evapo-transpiration. Moreover since transpiration rates of 1–3 gms/100 sq.cm hr and under extreme conditions up to 6 gms/100 sq.cm ha have been recorded on many occasions and this is at least ten times the rate observed by these authors.

DISCUSSION

Various soil factors, for example shape of the moisture tension curve and root growth affect the results obtained in experiments on moisture availability, as has already been explained in the introduction. VAN DEN HONERT (4) treated water uptake, water movement through the plant and transpiration as a series of linked processes in which the overall rate is determined by the slowest process. This implies that investigations concerning the availability of moisture should be made under optimal atmospherical conditions. It has been shown (fig. 2) that the experiments with beans conducted by VEIHMEYER and HENDRICKSON (11) cannot serve as a general proof that soil moisture is equally available from field capacity to wilting point, since transpiration was only one tenth of that normally occurring in the field. On the other hand, the same authors arrived at a similar conclusion with sunflowers in a glasshouse. In this case atmospherical conditions were not limiting and a transpiration rate of roughly 40 gms/100 sq.cm day, or 4 mm/day was found. Examination of the figure obtained by the mentioned authors shows that the points indicating the transpiration rate at different moisture content are scattered. Moreover the total leaf area in the several containers varied from 450–1300 sq.cm. Transpiration was measured by using large plants in the wet region and small plants in the dry region. In representing transpiration per unit leaf area one assumes a linear relation between leaf surface and transpiration. However, BIALOGLOWSKI (1) and PARKER (7) showed that this relationship does not always exist and depends on other factors among which may be shading of the leaves and change in the top-root ratio. This ratio may be higher in small containers since root extension is limited by the walls whereas the transpiring leaves can occupy a larger surface especially when grown in the wet region as compared with a field vegetation. It is possible, therefore, that in VEIHMEYER and HENDRICKSON's (11) experiments with sunflowers the computed transpiration values per unit leaf area for the large plants in the wet region for this reason are relatively too low as compared with those for the considerably smaller plants in the dry region.

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