STUDIES ON PRODUCTIVITY OF COFFEE

II - EFFECT OF SOIL MOISTURE ON PHOTOSYNTHESIS AND TRANSPIRATION OF COFFEA ARABICA

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SUMMARY

A study was made on the effect of soil water stress on transpiration, photosynthesis, stomatal aperture and relative turgidity of coffee plants.

The decrease in turgidity as a consequence of soil moisture depletion was only small, due to the closing of stomatas and hence a decrease in transpiration. This means that an efficient water control is present in coffee plants. The reduction in photosynthesis, however, was much more pronounced than that in transpiration. This could be ascribed, apart from an increase in stomatal resistance, to the large effect of increasing leaf temperature on the internal CO_2 concentration. The diurnal variation in stomatal resistance and internal CO_2 concentration shows that at midday with a moderate soil moisture stress a closure of stomates results in a decrease in CO_2 internal. Net photosynthesis almost recovers in a period of five days when rewatering after drought.

1. INTRODUCTION

In a previous report (NUNES *c.s.* 1968) some results of the effects of light, temperature and external CO_2 concentration on photosynthesis, growth and transpiration of *Coffea arabica* were given. It was observed that below 24°C, the net photosynthesis increased linearly with light in the range studied (up to 0.3 cal cm^{-2} min^{-1}). The tangent was comparable to the one of annual plants under equal conditions. Above a temperature of 24°C, however, a rise of one degree results in a depression of about 10% in net photosynthesis. With these data the potential dry matter production of coffee plants can be estimated for various environmental conditions. The present paper concerns the effect of soil water content, being another important environmental factor.

Several studies on the influence of rainfall frequency and irrigation on growth and production of coffee have been made, also measurements of plant transpiration have been reported at different natural conditions (DEAN 1939; NUTMAN 1941; FRANCO 1951, 1952; FRANCO & INFORZATO 1950–1951). Generally speaking coffee plants seem to be rather resistant to drought although the growth may be depressed to a large extent (GUISCAFRE-ARRILAGA 1957; RINGOET 1952; SYLVAIN 1959). Research on the effect of soil moisture stress on plant turgidity, transpiration and photosynthesis under controlled environmental conditions, however, is scanty.

In general soil moisture depletion reduces the growth rate by cell enlargement, the transpiration and the photosynthesis in this order. A reduction in

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transpiration (latent heat) causes an increase in sensible heat transfer by increasing the leaf temperatures (SLATYER & BIERHUIZEN 1964). Such an increase in leaf temperature above 24°C, however, influences the internal CO_2 concentration and hence the carbon dioxide gradient in the coffee plants greatly. It therefore depends to a large extent on the various parameters involved, whether in the particular case of coffee plants the transpiration is more sensitive for drought than photosynthesis.

For this reason, experiments were performed, in which during a drying cycle, the trend in transpiration, photosynthesis, leaf turgidity and stomatal opening was observed. Measurements of these plant parameters were also made after rewatering in order to study the recovery of a coffee plant after drought.

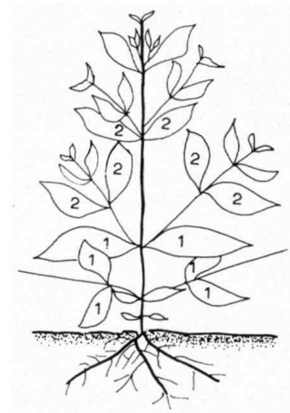
2. MATERIAL AND METHODS

Young cuttings of *Coffea arabica* of about 9 months old were obtained from the Department of Tropical Crop Husbandry of the Agricultural University at Wageningen. The plants were grown on plastic 10 liter pots on a soil, consisting of a mixture of clay, sand and old rotten leaves (2:1:1 by volume), the pF curve of which was known. The soil surface was covered with a 3 cm layer of gravel in order to reduce evaporation losses. The experiment was performed in natural daylight in a greenhouse with air temperature and relative humidity controlled (25/20°C day/night temperature and 70% R.H.).

Seven plants chosen at random were submitted to a drying cycle. Abundant water was given only once at the beginning of the experiment. Thereafter, due to water uptake by the plant, the moisture content of the soil decreased until a low and fairly constant value was reached after 2 to 3 weeks. The measurements of relative turgidity, photosynthesis and stomatal aperture were made at five different stages of soil water content. The photosynthesis was always measured in two plants, whereas the other plants were used one at a time for determining the relative turgidity and stomatal opening.

For the photosynthesis measurements a closed gas circuit was used. A detailed description of the method and the equipment used has been given previously by BIERHUIZEN *c.s.* (1968) and NUNES *c.s.* (1968). The turgidity of six leaves of the same physiological age was measured in old (nr. 1) and young leaves (nr. 2), as shown in *fig. 1*. The leaf discs were taken from one half of a leaf, the other half was used for infiltration tests and porometer readings. The relative turgidity was measured by means of leaf discs saturation on agar plates as described by CATSKY (1960). Values for stomatal aperture were obtained by means of infiltration techniques with various mixtures of isopropanol and water, according to WORMER (1965). Additional stomatal measurements were made with a porometer, according to BIERHUIZEN *c.s.* (1965). The porometer data are expressed in seconds for a pressure drop from 200 to 100 mm Hg. Daily transpiration rates were obtained by weighing the pots. The total leaf area of each plant was measured with a planimeter at the beginning and at the end of the experiment. Assuming that leaf growth was linear during this time interval, the total leaf area at any day could be estimated.

Fig. 1. Diagram of coffee plant to indicate the approximate site of the old (1) and young (2) leaves studied in this article.



3. RESULTS

In *fig. 2* the effect of soil moisture depletion on transpiration, photosynthesis, relative turgidity, and stomatal aperture (infiltration and porometer reading) is represented. The transpiration rate at field capacity (pF 2.0) was approximately 9 g H_2O dm^{-2} day^{-1}. The transpiration rate declines a little from pF 2.0 till pF 3.3 and very rapidly from pF 3.3 till pF 4.2.

The average rate of net photosynthesis at field capacity and at an air temperature of 27 °C was 8×10^{-6} cm^3 cm^{-2} sec^{-1}. It declined more progressively with a decrease in soil moisture content than the transpiration rate. At a pF of 3.3 the reduction in transpiration is for example approximately 20% and that of photosynthesis 40%. The net photosynthesis is almost negligible at a pF of 3.9, where the transpiration still remains at 45% of the amount at field capacity.

The relative turgidity decreases from 90 till approximately 80% when the soil moisture content decreases from field capacity (pF 2.0) to permanent wilting point (pF 4.2). The lowest value of 67% is obtained only after a severe desiccation of the soil below the wilting point. The effect of soil moisture content on relative turgidity shows a similar pattern for young as well as old leaves. The relative turgidity was far less affected by soil water stress than the photosynthesis or the transpiration. The stomatal opening, measured by infiltration and porometer, was larger at a low soil moisture content and became gradually smaller upon drying of the soil. The results of both methods demonstrate also that the stomates in young leaves are wider opened and more firmly closed under favourable respectively unfavourable soil moisture conditions.

The data of transpiration (T) and photosynthesis (P) were converted in grams per unit time and leaf area and expressed as a transpiration coefficient (T/P). At a high soil moisture content the transpiration coefficient is relatively low and in the order of 100 (g water transpired per g dry matter produced). With a depletion of soil moisture content the value of T/P rises due to a larger decrease in the rate of photosynthesis than in the rate transpiration.

In a previous publication (NUNES *c.s.* 1968) the photosynthesis has been

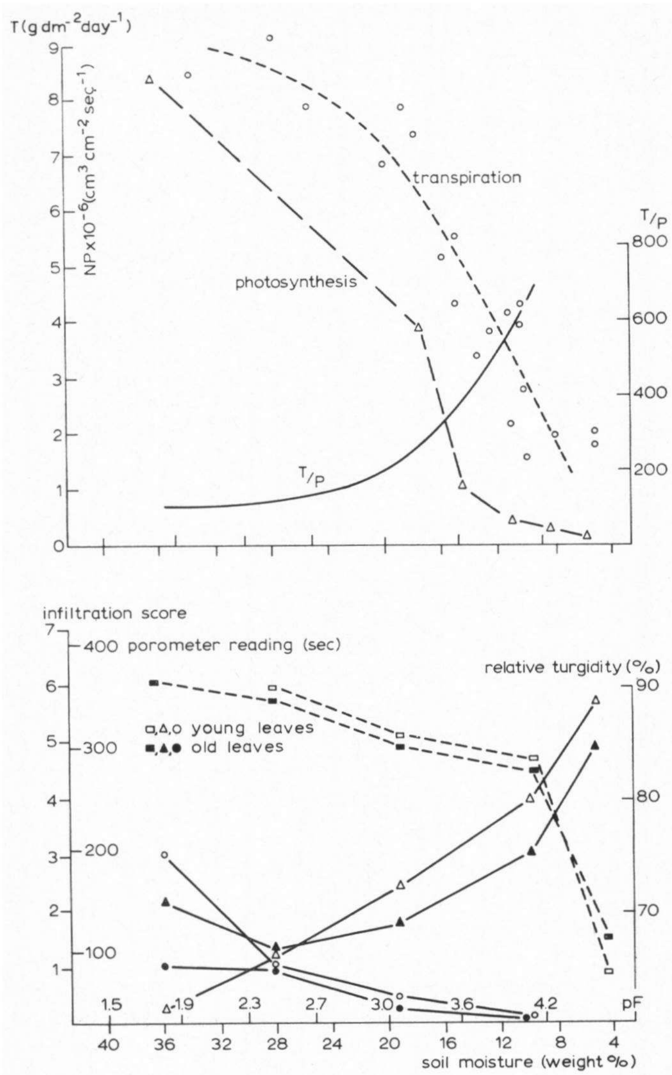


Fig. 2. The effect of water stress on transpiration (T), net photosynthesis (NP), transpiration coefficient (T/P), relative turgidity (□) and stomatal aperture of coffee (infiltration score ○ and porometer reading △).

described as controlled by a diffusive process, depending on a carbon dioxide gradient and a total resistance in the carbon dioxide pathway. Calculations were made of the internal CO_2 concentration and the total resistance, at various moments during the day, and various levels of soil moisture stress. Only those data were calculated where the light intensity level was higher than 0.1 cal cm^{-2} min^{-1} at an air temperature of 27 °C (see *fig. 3*). At these intensities, light saturation of photosynthesis in coffee plants can be expected (NUNES *c.s.* 1968).

It is evident from this figure, that the total resistance at a moisture content of 37.0% (pF 1.8) remains low during the course of the day and is in the order of 30 sec cm^{-1}. The internal CO_2 concentration remains low as well but shows an increase at the end of the day. At a lower soil moisture content (14.8%), the total resistance rises gradually during the course of the day from 50 to 120 sec cm^{-1}. The internal CO_2 concentration has also increased to a large extent and seems to show a maximum in the middle of the day. At the lower soil moisture contents of 11.4, 9.0 and 6.5%, the total resistance rises from a relatively low value early in the morning to a high one a few hours later. At a soil moisture content of 11.4% it declines at the end of the day, but remains high at soil moisture contents of 9.0 and 6.5%. The internal CO_2 concentration was initially high but it showed a minimum in the middle of the day.

In *fig. 4* the rate of recovery in resistance, CO_2 internal and net photosynthesis are shown after rewatering. The resistance decreases rapidly the first day after rewatering, next gradually and was after five days nearly equal to the one of the control. The CO_2 internal of the tissues remained high during the first day and also approached the control after five days. Both these parameters contribute in this way that the net photosynthesis increases almost linearly in this time interval. After 5 days, however, it still reaches only approximately 65% of that of the control.

4. DISCUSSION

The curves of transpiration, stomatal aperture and relative turgidity (*fig. 2*) clearly demonstrate that stomatas efficiently control the water loss when soil moisture depletion occurs, which means that the water balance of the plant as measured by relative turgidity is not much affected. The relative turgidity decreased between field capacity and wilting point from 92 to only 80%. Moreover, at a depletion of twothirds of the available water in the soil till pF 3.2, the turgidity is 85%, whereas the net photosynthesis has already been depressed to 60% of the initial value. An important consequence is that the turgidity measurements should therefore not be applied as a control for irrigation requirements. These results are in agreement with the common statement that coffee plants are fairly drought tolerant but that the growth reduction is large with a deficient water supply. The average transpiration rate measured under full light conditions was 9.0 g dm^{-2} day^{-1} with a light period of 15 hours, which value is in the same order of magnitude as those found by NUTMAN (1941) and FRANCO & INFORZATO (1950) in field experiments.

It was evident from previous results that the leaf temperature determines to a large extent the maximum net photosynthesis rate via the internal CO_2 concentration of the tissues (NUNES *c.s.* 1968). With a shortage of soil moisture causing stomatal closure, an increase in leaf temperature has to be expected. The results of CO_2 internal measurements presented in *fig. 3b* confirm this assumption and explain together with the increase in resistance (*fig. 3a*) the observed large depression in photosynthesis (*fig. 2*). It is obvious therefore,

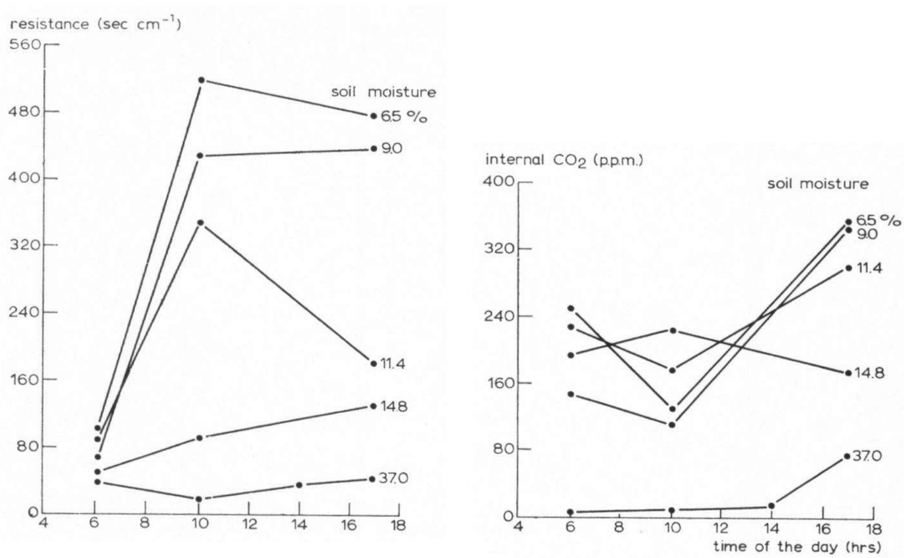


Fig. 3. The variation in stomatal resistance and CO_2 internal at various water stress levels during the day.

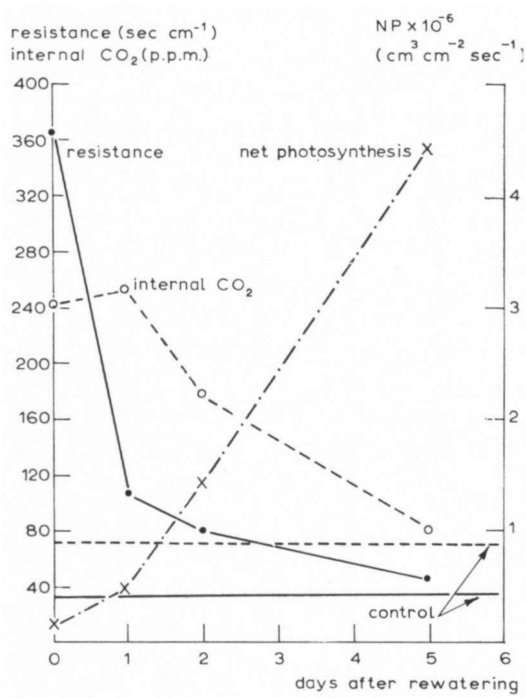


Fig. 4. The effect of rewatering after a drought period on recovery of CO_2 internal, stomatal resistance and net photosynthesis.

that photosynthesis is more sensitive to drought than transpiration, which results in a rise in transpiration coefficient with soil moisture depletion (*fig. 2*). Theoretically (BIERHUIZEN & SLATYER 1965; HOLMGREN *c.s.* 1965), the reverse should have been expected in the first instance, because of the smaller contribution to the total resistance of the CO_2 transport as compared with that of the water vapour. On these considerations the application of antitranspirants is based (SLATYER & BIERHUIZEN 1964). In the case of coffee, however, increase in leaf temperature and the large increase in CO_2 internal, counterbalance a larger decrease in transpiration than in photosynthesis.

The effect of water stress on the diurnal variation in resistance demonstrates that the stomates are partly opened in the beginning of the morning after a recovery in turgidity during night and closed at midday. At the end of the day a decrease in stomatal resistance occurs when soil moisture stress is not very high. The variation in CO_2 content of the tissues is in agreement with the changes in stomatal resistance.

Apart from the fact that dry matter production (net photosynthesis) is sensitive to soil moisture depletion, irrigation after a drought period shows that the recovery in net photosynthesis is fairly long and in the order of at least five days (*fig. 4*).

It is evident from the given results that coffee, as would be expected of a shade loving subtropical crop, is very sensitive to climatic and soil conditions causing high leaf temperatures. This is of special practical importance when a decision is to be made to alter the growing conditions as for example by removing the shade trees in coffee plantations in tropical countries on soils with low moisture content.

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