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MEASURING LEAF-WATER POTENTIAL IN CHICKPEA WITH A PRESSURE CHAMBER†

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SUMMARY

The pressure-chamber technique has been used for the first time to measure leaf-water potentials in chickpea under field conditions. Available soil-water contents at different depths for irrigated and non-irrigated crops are presented along with the diurnal variation in leaf-water status, to show that pressure-chamber measurements correspond closely with available soil water. Leaf-water potential has also shown differences in leaf-water status among different cultivars. The rapidity and ease with which measurements can be made in the field make the technique suitable for quick measurements of leaf-water status for chickpea.

Chickpea (*Cicer arietinum* L.), one of the oldest and most widely used grain legumes in the Middle and Far East, is India's most important pulse crop, ranking fifth after rice, wheat, millets and sorghum in total acreage and second in the world after dry beans (Maesen, 1972). In India and Pakistan, chickpea is cultivated during the *rabi* (post-monsoon) season, on conserved soil moisture without supplemental irrigation, and at times suffers from moisture stress. The time-sequence of events is significant in assessing the overall effect of stress on a plant, and in attempting to understand the physical and biological mechanisms underlying plant responses, interactions and causal relations (Hsiao *et al.*, 1976). It is possible to record the sequence in which different degrees of water stress develop at different stages of crop growth by measuring plant-water stress at regular intervals. Such stress arises from the combined effects of soil-moisture stress in the root zone, resistance to water movement in the plant, stomatal control, and atmospheric evaporative demand. Measuring plant-water stress is of particular importance for chickpea since its growth and yield depend on residual moisture in the soil, but no such investigations have been reported so far.

Previous studies on the response of crops to drought have been hampered by lack of a simple and rapid technique for measuring plant-moisture stress, though water potential has been widely accepted as a fundamental measure of plant-water status. Scholander *et al.* (1965) reported the determination of leaf-water potential with a pressure chamber, which is by far the simplest and most rapid of the several methods which have been suggested for measuring plant-water stress. The technique has been used to measure leaf-water potential of tropical pulse crops such as soyabeans (Boyer, 1970; Boyer and Ghorashy, 1971; Sivakumar and Shaw, 1978a, b) and peas (Hiler *et al.*, 1972; Clark and Hiler, 1973). The present study deals with the measurement of leaf-water potential in chickpea and the results obtained in the field.

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MATERIALS AND METHODS

The experimental work in this study was carried out at ICRISAT (17° 27′ N, 78° 28′ E) during the *rabi* (post-rainy) season in 1977–78 on a deep vertisol, which is a very fine, clayey, montmorillonitic, calcareous, hyperthermic member of the family of typic Pallusterts. The upper limit of water availability, determined *in situ*, averaged 0·44 cm^3/cm^3 and the lower limit averaged 0·27 cm^3/cm^3 (Russell and Sardar Singh, 1979).

Experiment 1

The first experiment was laid out in a randomized block design with three replications, each consisting of two 10 × 20 m plots. One plot in each replication was irrigated on 17 November with 7 cm of water, and other experimental details have been given by Russell and Sardar Singh. Chickpea cv. JG-62 was sown in 30 cm rows on 10 October. A neutron probe was used throughout the growing season at 22, 37, 52, 67, 82, 97, 112, 142, 157, 172 and 187 cm depths, at four locations in each plot. Volumetric moisture contents were averaged over 12 neutron measurements. Gravimetric measurements were taken in the top 20 cm soil layer. Leaf-water potentials in the irrigated and unirrigated plots were measured with the pressure chamber (PMS Instruments, Corvallis, Oregon, USA), hourly from 0600 to 1800 on the observation days.

Experiment 2

Leaf-water potential measurements were also taken for nine chickpea cultivars in a more comprehensive experiment, laid out in a randomized block design with three replications, to evaluate differences in light interception. Each replicate consisted of nine 6 × 3·75 m plots. The cultivars were four local ones (P-436, JG-62, BEG-482, and P-234) and five Kabuli varieties (L-550, Rabat, GL-629, No. 501, and K-4), sown in 37·5 cm rows on 17 October 1977. Leaf-water potential measurements for each cultivar were taken diurnally on four different dates during the growing season, to show whether the pressure-chamber technique could be used effectively to study differences in leaf-water status.

Technique for measuring leaf-water potentials

The theory behind the use of the pressure-chamber technique has been discussed previously by Scholander *et al.* (1964, 1965) and Boyer (1969). A leaf or leafy twig is cut from a transpiring plant and sealed into the chamber with the cut surface open to the atmosphere. The pressure in the chamber is then increased until xylem sap just begins to exude from the cut surface. This balance point occurs when the applied pressure, P, is equal to the absolute value of the original (negative) hydrostatic pressure in the xylem vessels connected with the leaf cells. It is assumed that before pressure was applied the water potential of the xylem (Ψ_x) was equal to that in the cells of the leaf (Ψ_l). The former is the sum of two components, the hydrostatic pressure or pressure potential (ϕ) and the solute potential (Π) of the xylem sap. $\Psi_x = \phi + \Pi$, and initially $\Psi_x = \Psi_e$, but at the balance point $P = -\phi$, so that $P = -(\psi_l - \Pi)$. If Π is negligible, then at the balance point the applied pressure equals the absolute value of the water potential of the leaf.

Use of the technique to measure leaf-water potentials in chickpea is essentially similar to that for other legumes, such as soyabeans and peas. Chickpea is more or less branched from the base and secondarily branched at various levels; plants are semi-erect, erect or prostrate; and leaves are imparipinnate with 11–13 leaflets. The leaf petiole is very short, making it difficult to insert into the rubber stopper of the apparatus and it was found that a short upper branch, fully exposed to sunlight and bearing at least five to seven leaves, is more easily used to give quick and reliable measurements of leaf-water potentials.

Essential components for the preparation of a sample for measuring leaf-water potential are shown in Figure 1. The sample is inserted into the rubber stopper with the insertion tool (shown on the left) after it is cut from the plant with a sharp knife or razor blade. The insertion tool is inserted into the rubber stopper and the stem fed into the tool, which is then withdrawn, leaving the stem in the stopper.

The rubber stopper is then put into the chamber top after applying a thin film of petroleum jelly on top and around the stopper to prevent gas leakage. A close-up of the chamber top, ready for sealing into the pressure chamber, is shown in Figure 2. The top is then quickly sealed so that the cut stem surface protrudes above the metal, then pressure from the cylinder is applied by opening the main valve, and using the rate valve to apply pressure slowly and steadily, to avoid large temperature rises due to adiabatic compression. The cut surface is carefully observed through a low-power (20×) lens; when the meniscus of the xylem sap just returns to the cut surface, pressure is read on the gauge and the valve is turned off to facilitate recording the pressure, which is then released by turning the valve to 'exhaust'. The purpose of the work was comparative, to see whether reductions in water potential due to loss of water from the leaves after they had been cut from the plant would be similar for all samples.

It is normal practice to compare the xylem pressure thus obtained with the leaf-water potential measured with a thermocouple psychrometer, but Boyer and Ghorashy found that the former measurements are close to the latter for soyabeans and Boyer (1969) observed that the convenience of the pressure chamber would justify its use without determining xylem osmotic potentials. Indeed, field measurements often contain sources of variability which are larger than the discrepancies between the two methods.

RESULTS AND DISCUSSION

A summary of the meteorological data for the growing season (Table 1) shows that December, January and February were characteristically dry, with only

Table 1. *Meteorological conditions during the post-rainy season at ICRISAT, 1977*

Month	Average temp. Max. (°C)	Average temp. Min. (°C)	Total precipi-tation (cm)	Average 24 h wind run (km/h)	Average solar radiation (ly/day)	Average pan evaporation (cm/day)
20 Oct.	31·2	17·9	—	6·7	474	0·61
Nov.	29·1	20·5	2·78	9·4	346	0·45
Dec.	27·6	12·9	0·20	6·6	377	0·47
Jan.	27·9	15·8	0·07	8·9	240	0·48
6 Feb.	28·5	18·1	0·28	12·3	363	0·57

5 mm of rainfall, and non-irrigated plots experienced severe water stress, especially in January.

Experiment 1

Changes in available soil water at different levels during the growing season in non-irrigated and irrigated plots are shown (Figs 4a, b) where one irrigation of 7 cm was given on 17 November, 38 days after planting (DAP). Differences between the treatments are quite apparent. Non-irrigated chickpea showed rapid extraction of water, and by 43 DAP the top 20 cm of soil showed no available water as defined earlier. Water depletion was rapid in the next three layers (22–52, 52–82 and 82–112 cm) which showed much lower available water contents than those in the irrigated plots, but the 112–142 and 142–187 cm layers were similar in both non-irrigated and irrigated soils. Irrigated plots showed available water in the 0–22 cm soil layer until 59 DAP and up to about 75 DAP chickpea was able to extract water from the 22–112 cm layer, which

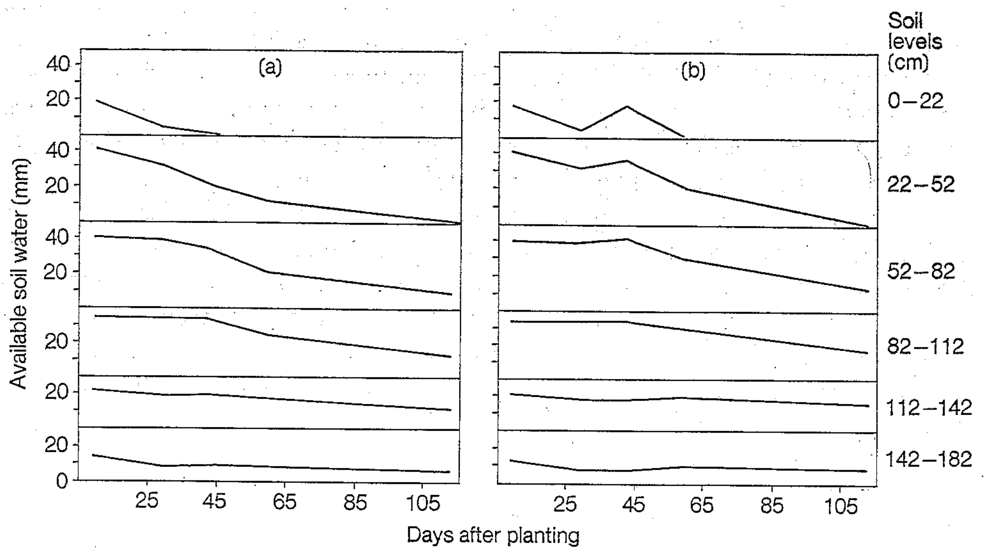

Fig. 4. Changes in available soil water at different levels during the growing season for (a) non-irrigated and (b) irrigated chickpea.

still had a high content of available water, after which soil moisture was fairly similar for both treatments.

Leaf-water potential measurements, taken hourly on ten chickpea plants in each treatment, showed diurnal variations for the two treatments on four different dates. Hourly variations on 25 November (46 DAP) are shown in Figure 5a after irrigation on 17 November. Irrigated chickpea plants were fairly turgid throughout the day, with a minimum potential of −7·5 bar at 1330 h in the irrigated chickpea, compared with −10·5 bar for the non-irrigated crop.

Another set of diurnal leaf-water potential measurements, taken on 2 December (Fig. 5b), showed a consistent difference of −2 to −3 bar in the diurnal pattern

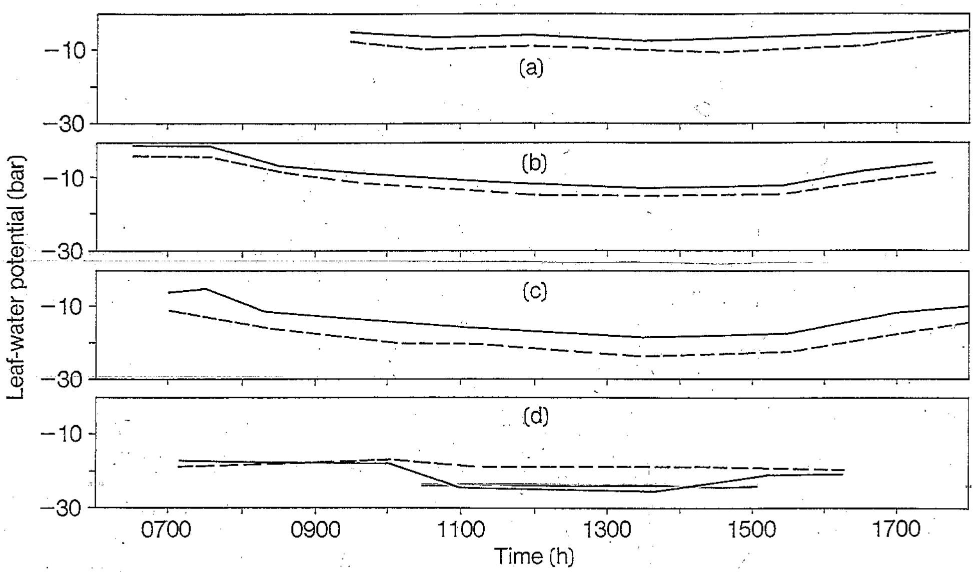

Fig. 5. Diurnal variation in the leaf-water potential of irrigated (——) and non-irrigated (– – –) chickpea on (a) 25 November 1977, (b) 2 December 1977, (c) 20 December 1977, (d) 4 January 1978.

between irrigated and non-irrigated plants, the former showing higher potentials, which might permit better photosynthetic activity than the non-irrigated ones. Leaf-water potentials were high early in the day but decreased up to 1300 h in both treatments with increasing evaporative demand, after which decreasing levels of irradiance produced some degree of recovery (though not complete) in leaf turgidity by 1700 h.

The period between 2 and 20 December was almost dry except for a small 2 mm shower on 3–4 December, and leaf-water potential measurements on 20 December reflect this increasing soil dryness. The diurnal pattern (Fig. 5c) is fairly similar to that observed earlier, on 2 December, and it is apparent that non-irrigated chickpea was under severe moisture stress, as reflected by the low potentials observed by 0800 h. A minimum leaf-water potential of −24 bar was recorded at 1330 h for non-irrigated plants against −18 bar for irrigated ones.

At 1700 h both treatments still showed leaf-water potentials lower than -10 bar, indicating that plants were suffering marked stress even in the irrigated treatment.

The last set of measurements was taken on 4 January, when there had been no rainfall since 20 December. Chickpea plants in both treatments were severely stressed (Fig. 5d) and those in the non-irrigated plots severely wilted. The loss in leaf turgidity is corroborated by the nearly constant values of leaf-water potentials, suggesting complete stomatal closure. The diurnal values show that the irrigated plants were still transpiring and showing changes in leaf-water

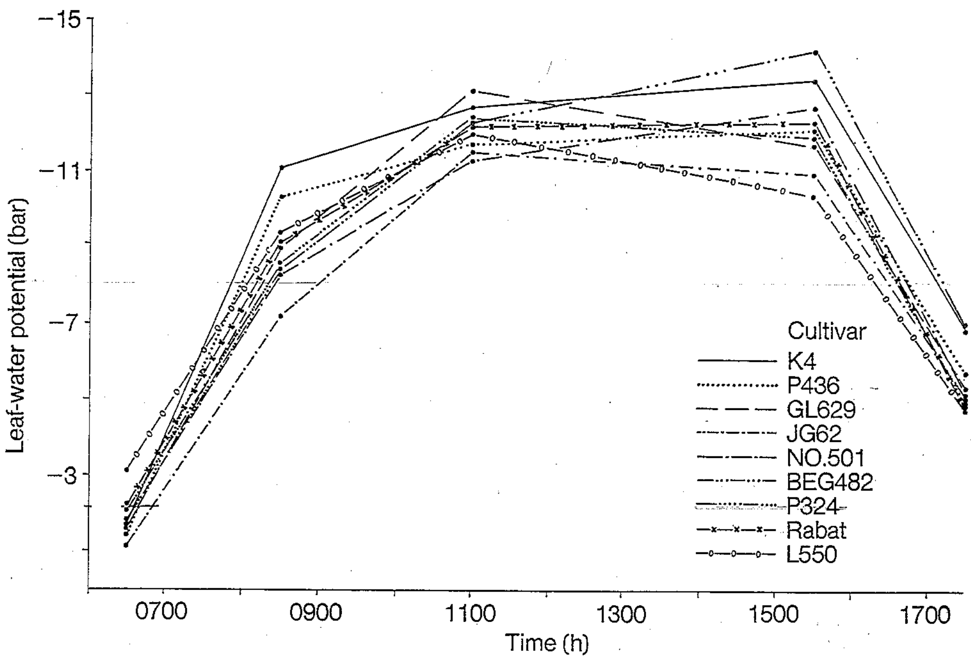

Fig. 6. Diurnal variation in leaf-water potential of nine chickpea cultivars on 1 December 1977.

potential with different evaporative demands. Available soil-water in the top 82 cm of soil was almost the same for the two treatments (Fig. 4), and plants were probably not able to extract water beyond the 82 cm soil layer.

Experiment 2

Although four sets of leaf-water potential measurements were taken in all, only the data for 1 December are presented here (Fig. 6), to delineate differences in the diurnal variation among the nine chickpea cultivars. Averaged over the entire day, cultivar JG-62 showed the maximum leaf-water potential, but cultivars differed by -2 to -4 bar in their leaf-water potentials.

It may be interesting to note that cv JG-62 which showed the maximum leaf-water potential, gave a final yield of 2652 kg/ha, whereas cv K-4 yielded 1649 kg/ha. It may not be justified to draw conclusions on cause-and-effect from such limited sets of data, but cv JG-62 showed consistently higher leaf-water potentials on each of the 4 days of measurement. Maintenance of higher plant turgidity could have facilitated stomatal opening for a longer duration, better expansion of leaves, and better movement of water and nutrients to various parts of the plant, resulting in higher production rates. Further experimentation is needed for conclusive proof, but these results show that the pressure-chamber technique could be used effectively to measure the leaf-water status of chickpea. In investigations on the moisture stress effects on crop growth, and on the performance of different crop cultivars, such measurements might find useful application.

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