Lysimetric studies on the effect of soil moisture tension on growth and yield of maize (Zea mays L.)

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INTRODUCTION

The dry zone comprises nearly 3/5 of the total extent of Sri Lanka and offers the gratest potential for the cultivation of arable crops. Except in the Jaffna peninsula where water is available for year round cultivation, the scarcity of water is the factor limiting the cultivation of arable crops in the rest of the dry zone. The cropping seasons are therefore demarcated according to rainfall season and most of the cropping is carried out in the wet season (October-January). In the dry season (Mid March—June) erratic and scanty showers rarely provide adequate water for the cultivation of most arable crops.

The provision of supplementary irrigation to evolve a system of settled farming therefore needs no emphasis. With this in view a series of field experiments were conducted to investigate the water requirement of some important field crops and this paper reports the effect of different moisture tensions on the growth and yield of maize.

MATERIALS AND METHODS

The experiment was carried out in catchment 'C' at the Agricultural Research Station, Maha Illuppalama during May-August (Yala season) 1969. The soil belonged to the great soil group of Reddish Brown Earths and has been described by Panabokke, 1968.

The treatments consisted of 3 soil moisture regimes approximating to 33, 53 and 73 millibars (mb) of soil moisture tension and these moisture tensions refer to the maximum extent to which the plants in different treatments were stressed.

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All treatments were arranged in a 3 x 3 Latin Square. Each plot measured 9.5 m^2 and lysimeters were installed at the centre of each plot. The lysimeters consisted of cubicular tanks made of 16 gauge galvanised iron and measured 1.22 m. The interior as well as the exterior of these tanks were coated with bituminous paint to minimise corrosion. The bottom of the lysimeter had a sloping cemented surface to facilitate drainage of water to one of its corners termed a " collection well ", to which was fitted a pipe for the removal of drainage water. Above the cement floor was a layer of pebbles 20 cm. high, over which was a layer of cement and coarse grit in the ratio of 1 : 8 for the purpose of free flow of drainage water. Above this the soil removed from the same location was repacked in the same order to maintain a similar soil level both in and outside the lysimeter. The lysimeters were irrigated uniformly through a flexible plastic tubing bent into several loops and the quantity of water applied on each occasion was measured.

When the soil in the lysimeters reached the pre-determined moisture tensions as indicated by the two tensiometers placed in the lysimeter, the soil was irrigated slightly in excess of the estimated evapotranspiration from a free water surface, measured by using a standard U.S. Weather Bureau Class ' A ' pan to bring it up to field capacity. Thus a wetting and a drying cycle as practiced in normal irrigation was followed. Rainfall receipts during the stress period were considered as additional water applied at the prevoius irrigation. Irrigation for the plot surrounding the lysimeter was by gravitational flow through open furrows.

After land preparation ridges were made 60 cm. apart and 3 seeds of the maize variety T 48 were dibbled per hill on the top of the ridge as a spacing of 30 cm. on 11 May, 1969.

All plots received a basal dressing of concentrated super phosphate (42% P_2O_5) and muriate of potash (50% K_2O) at the rate of 40 and 30 kg/ha respectively. Nitrogen as amonium sulphate (20% N) was applied at the rate of 70 kg/ha, of which 40 kg/ha was applied at the final stage of land preparation and the remainder was applied 5 weeks after sowing.

The crop was sequentially sampled at 10 day intervals commencing from the day of complete emergence and the sampling procedure adapted was as follows : At each sampling 10 plants from 5 randomly selected hills from each plot were removed, and plant height, dry matter yield and leaf area were estimated.

Measurement of stomatal opening was made by the infiltration technique using mixtures of kerosene and medical paraffin in different proportions. Kerosene being the least viscous liquid penetrated the leaf (as shown by a change in leaf colour to dark green) when the stomata were least open, followed by more viscous solutions as stomata progressively opened. Eleven graded solutions were prepared with a 10 per cent increase in concentration of kerosene to paraffin. The fully emerged unshaded 3rd and 4th leaf from the top was selected for the measurement of stomatal opening (Vivekanandan, unpublished) and measurements were made only on clear bright days.

Relative turgidity, defined as the ratio of the moisture content of the leaf at any time to the maximum that the leaf could contain under fully turgid conditions, expressed as a percentage (Weatherly, 1951), was measured at the same times of the day when the stomatal opening measurements were made as follows: about 25-30 leaf discs having an area of 2.05 cm^2 were punched using a cork borer and their fresh weights were recorded. They were then floated in distilled water for four hours and the turgid weights were recorded. Subsequently they were dried in an oven and the relative turgidity was determined.

Leaf area was estimated by the leaf length × maximum leaf width method (Vivekanandan *et at,* 1971).

Climatic data : Climatic data are given in Table 1. During the growing season the crop received very little rain and generally the weather conditions were similar to that of any dry (yala) season in the dry zone.

RESULTS AND DISCUSSION

The results have been subjected to a detailed analysis of variance. The least significant differences refer to a probability level of 0.05. In figures the L. S. D's are represented by vertical straight lines.

The cumulative evapotranspiration (Et) increased with a decrease in soil moisture tension and at the final harvest (110 days) Et for the wet, intermediate and dry moisture regimes (33, 53 and 73 mb) were 596, 508 and 438 mm respectively. This could be attributed to a greater limitation of available water under increased moisture tensions due to the high potential evaporation which exceeded 6 mm on hot sunny days during April-Sept. ; low available water capacity of Reddish Brown Earths which approximated to 3.6 cm per 30 cm of soil depth and the unique energy-moisture relationship of the soil where a 50 per cent depletion of available moisture occured at 33 mb soil moisture tension. Such strong dependence of total water use on prevailling weather conditions makes generalisation of water use by maize extremely difficult. Robins and Rhodes (1958) and Doss *et al* (1962) have reported similarly.

In this experiment under all soil moisture regimes, Et per day was higher only around the 60th day after sowing and gradually decreased until final harvest. Similar to that cumulative Et, the rate of daily Et increased at lower soil moisture tensions, however, considerable differences in daily Et existed between treatments. The daily Et in the initial growth stage was 4.0-4.5 mm and this lower daily Et persisted for about 30 days from crop emergence in the dry (73 mb) soil moisture regime. The period of persistance of low levels of daily Et was comparatively less in the wetter treatments. This might be due to a sparse crop cover that existed early in the season and to effects of surface sealing of the soil. This supports Penman's (1948) contention that evaporation from a wet bare soil will be about the same as evapotranspiration from a crop covered surface but once a shallow surface layer becomes dry, evaporation from the soil approaches zero. The soil evaporation was reduced with irrigations made at higher tensions. With the phenomena of surface sealing limiting Et, the increase in leaf area was slower at higher soil moisture regimes. The peak period of water use in all treatments were between 50-65 days from emergence and during this period daily Et exceeded the potential evaporation (Eo) in the wet (33mb) treatment. The period of peak water use is important in irrigation in the determination of the size of channels and rate of flow or the pump capacity that is required in planning an irrigation system.

Denmead & Shaw (1959) and Doss *et al* (1962) observed a similar peak in the pattern of daily Et in maize while the findings of Stanhill (1962) indicate a plateau rather than a peak where the daily Et and Eo remained high for nearly 40 days. The pattern of daily Eo did not resemble that of daily Et. This would mean that the variations in daily Et during different stages of growth of the crop was influenced by factors other than potential evaporation. As indicated earlier, surface sealing effects during the early stages of growth together with changes in leaf area and stomatal regulation may have caused significant changes in daily Et, besides the effects of potential evaporation. The duration of the peak period of water use will no doubt depend largely on how rapidly the crop achieves complete leaf cover and the duration of leaves thereafter. This had been emphasised by Laing (1965) who found a similarity in the pattern between leaf area index and Et/Eo ratio of soybean.

Estimates of open water evaporation (Eo) as an index of crop evaporation has been widely used to determine irrigation requirements both under limiting and non-limiting soil moisture conditions. (Hudson 1962, Monteith, 1961) Sivanayagam (1971) also observed in a maize crop grown in a green house under non-limiting soil moisture conditions a great reliability of the dependance of Et upon Eo. However, in the present experiment where maize was grown under field conditions no such relationship was obtained. It may be that a relationship is unlikely under very adverse conditions where the atmospheric demand is very high, storage of available moisture in the root zone is extremely low and when the moisture is released at extremely low tensions ; This could be due to a greater dependance of daily Et on such factors as soil, leaf area and stomatal regulation.

Under all moisture regimes stomata remained closed at 6.00 a.m. Then they gradually opened until a maximum was reached between 8.00-9.00 am. This was followed by a decrease until a maximal mid-day closure was reached between 12.00 noon-1.00 p.m. Thereafter, the stomatal opening increased up to 3.00-4.00 p.m. followed by a rapid closure at 6.00 p.m. stomata remained completely closed. The diurnal pattern of relative turgidity during the hours 8.00 a.m.-4.00 p.m. was similar to that of stomatal opening. However, during the very early hours (6.00 a.m.-8.00 a.m.) increase in openness of stomata was associated with an increase in the relative turgidity.

Over the period 8.00 a.m.-4.00 p.m. there was a similarity in the diurnal pattern between the relative turgidity and stomatal opening due to the lower availability of water resulting in the development of plant water stress. Although such characteristic pattern of relative turgidity and stomatal opening during the growing season has been observed by (Slatyer, 1955 and Weatherley, 1951 Glover, 1959 and Offir *et al,* 1968) little work has been done to study both factors in perspective. Though differences in stomatal opening and relative turgidity were caused by different soil moisture tensions, no differences in the response of these two factors were observed within the range of 0—25 mb soil moisture tension. Offir *et al* (1968) found no stomatal response until soil moisture was depleted by $\frac{1}{3}$ of available water. Even though the reasons for this phenomenon is not clearly understood, it could possibly be due to the manifestation of different soil and plant resistances dominating at lower and higher moisture tensions.

It is interesting to note that both relative turgidity as well as stomatal opening decreased under the comparable soil moisture tensions as the age of the crop advanced. This would indicate that the soil moisture tension at which irrigation should be made would differ at different stages of growth. However, the measurements made on 81st day indicated that in spite of the fact that stomatal opening continued to decrease, relative turgidity increased. A similar phenomenon had been observed by Denmead & Shaw (1960) and had been attributed to reduced physiological activity associated with senescence.

Significant differences in leaf area index (L) were recorded at samplings made on 40, 70 and 100 days after sowing ($P = 0.01$).

The maximum values of L recorded at 70 days from emergence were 4.45, 3.32 and 2.45 for the wet, intermediate and dry treatments respectively. Thereafter L declined, the rate of decline being faster with each increment of moisture tension. Hence, leaf persistence was greater at lower soil moisture tensions in comparison with higher moisture tensions and at the final harvest, the wet treatment recorded an increase of over 100% L compared with other treatments. At low leaf water potentials, the rate of leaf enlargement was reduced in maize and a minimum turgor was required for rapid cell enlargement (Boyer, 1970). In this investigation also marked differences in leaf area were associated with small differences in relative turgidity.

The effect of soil moisture tension in leaf area duration (D) was similar to that of (L) and (D) was reduced by increasing moisture tension. The intermediate and dry treatments reduced D by 57% respectively in comparison with the wet treatment.

Dry matter yield increased up to the final harvest (110 days after emergence) for all treatments. Dry matter and grain yield decreased with increasing soil moisture tension. At high moisture tensions cob size and grains per cob were also reduced. The highest rate of dry-matter accumulation was recorded between 40-60 days during which period the rate of dry matter accumulation was 5.0, 4.3 and 3.2 g/day for wet, intermediate and dry treatments respectively. At the final harvest, intermediate and dry treatments reduced dry matter yield by 21% and 36% compared with the wet treatment.

SUMMARY

The effect of three different soil moisture tensions, on water use, growth and yield of maize was studied. Small differences in soil moisture tension did not show significant differences in the daily water

use up to 45-50 days from emergence whereas during the subsequent period this effect was reversed. At all soil moisture tensions highest daily water use was recorded between 50-60 days after crop emergence. The differences in daily water use over the different growth stages could be attributed mainly to the surface sealing of the soil, changes in leaf area and stomatal behaviour rather than to the direct effect of evapotranspiration. The soil moisture stress decreased grain yield and total dry matter. The reduction in grain yield at higher soil moisture tensions was due to a reduction in grain number per cob through a reduction in cob size.

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REFERENCES

BOYER, J. S. (1968). Relationship of water potential to growth of leaves. *Pl. Physiol.* 43 : 1056-1062.

DENMEAD, O. T. and SHAW, R. H. (1959). Evaporation in relation to development of the corn crop. *Agron. J.* 51 : 725-726.

DOSS, B. D., BENNET, O. L. and ASHLY, D. A. (1962). Evapotranspiration by irrigated corn. *Agron. J.* 54 : 497-498.

GLOVER, J. (1959). The apparent behaviour of maize and sorghum stomata during and after drought. *Agron.* J. 53 : 412-416.

HUDSON, J. P. (1962). Water requirement of tomato crop. XVIth *Int. Hort.* Cong. Belgium. II. 253-258.

MONTEITH, J. L. (1961). Research in crop evaporation in Isreal. U. N. Comm. Tech. Ass. Rep. TAO/ISR/30.

OFFIR, M., SHAMNELI, E. and MORESHET, S. (1968). Stomatal infiltration measurements as an indicator of water requirement and timing of irrigation for cotton. *Exp. Agric.* 4 : 325-337.

PANABOKKE, C. R. (1968). A study of some soils in the dry zone of Ceylon. *Soil Sci.*

PENNMAN, H. L. (1948). Natural evaporation from open water, bare soil and grass. *Proc. Royal. Soc.* (Lond). A. 193 : 120-145.

ROBINS, J. S. and *RHODES*, H.F. (1958). Irrigation of field corn in the west. USDA Leaflet No. 440.

SIVANAYAGAM, T. (1971). Responses of *Zea mays* towater regimes. Ph.D. Thesis, University of Nottingham.

SLATYER, R. O. (1955). Studies in water relations in crop plants grown under natural rainfall in Northern Australia. *J. Agric. Res.* 6 : 365-377.

STANHILL, G. (1962). Control of field irrigation practices for measurements of evaporation. *Israel J. Agric. Rec.* 12 : 51-62.

VIVEKANANDAN, A. S., GUNASENA, H. P. M. and SIVANAYAGAM, T. (1971). Statistical evaluation of three techniques used in estimating leaf area of crop plants. *Indian J. Agric. Sci.* (9) 857-860.

WEATHERLY, P. E. (1951). Studies in the water relations of the cotton plant II. Diurnal and seasonal variation in relative turgidity and environmental factors. *New Phytal.* SD : 36-51.

TABLE 1

Climatic Data — 1969

Period		*Temperature (F°)*		*Relative humidity%*	*Sunshine hours*	*Total rainfall inches*	*Radiation/ Cal/cm day*
		Mini.	*Max.*				
May	11–15	76·9	90·5	72·3	7·9	—	—
	16–20	77·7	90·1	71·5	7·6	—	—
	21–25	78·6	89·8	73·3	5·1	—	—
	26–30	77·5	90·2	72·4	8·7	0·15	—
	31–04	77·9	90·5	71·6	8·2	0·15	400
June	05–09	77·5	91·6	65·9	9·5	—	360
	10–14	77·1	90·5	66·0	7·9	—	275
	15–19	77·1	91·6	66·7	7·7	—	300
	20–24	76·2	91·2	65·9	9·5	—	410
	25–29	77 1	92·1	66·7	10·2	0·05	380
	30–04	76·8	92·1	62·7	9·7	—	450
July	05–09	77·4	95·3	62·3	8·8	0·25	400
	10–14	76 9	90·3	65·2	5·6	—	350
	15–19	76·2	91·9	61·4	7·0	—	365
	20–24	75·4	91·1	63·9	6·1	—	350
	25–29	76·1	90·5	63·2	5·7	—	400
	30–03	76·4	92·1	58·5	10·0	—	470
August	04–08	77·0	93·6	59·2	10 0	—	460
	09–13	76·8	95·1	55·5	9·5	0·28	450
	14–18	73·3	90 7	72·4	6·9	6·43	350
	19–23	72·2	90·6	70·1	8·1	1·88	360
	24–28	72·8	89·9	71·5	7·3	4·37	400
	29–02	75·6	88·3	70·3	7·9	0·10	350