The use of certain plant parameters to determine the profile available water capacity of durum wheat at different growth stages

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Abstract

The profile available water capacity (PAWC) for durum wheat was determined at different growth stages on a soil of the Limpopo series near Cradock. In previous studies some problems were experienced with pre-dawn leaf water potential (PLWP) as an indicator of first material stress (FMS) and other parameters had to be used. It was decided to use the stem elongation rate (SER) to indicate FMS in durum wheat plants during young growth stages. SER proved to be a reliable parameter during the early growth stages, while PLWP could indicate FMS in mature plants. It was also found that young plants were more sensitive to reductions in PLWP. During young growth stages FMS was clearly identified when PLWP decreased to about -800 kPa. In mature plants FMS was detected when PLWP reached a value of -1 500 kPa. The difference in leaf water potential value of mature and immature leaves stressed the importance of standardising the method for PLWP measurements. PAWC values for durum wheat ranged from 85 mm at a young growth stage to 125 mm at flowering stage.

Introduction

Hensley and De Jager (1982) defined "profile available water capacity" for a specific crop and soil under a certain evaporative demand as "the amount of water which is held in the effective root zone between field capacity and first material stress". The lower limit of PAWC (first material stress) was defined as: "the quantity of water in the soil profile at the degree of crop water stress at which the next irrigation should be applied if optimum yield is to be obtained". This definition was later changed to: "First material stress can be defined as the soil water content at which plant physiological processes have been reduced by 25% of their normal rate" (Hensley, 1984). Hensley and De Jager (1982) defined field capacity (upper limit of PAWC) as the amount of water retained in a soil profile when free drainage has materially ceased.

The techniques used by Hensley and De Jager (1982) to detect FMS were visual symptoms, leaf diffusive resistance, leaf water potential and the ratio of actual evapotranspiration to pan evaporation. No parameters directly linked to plant performance such as growth or yield were used. Because the use of these parameters will probably lead to a very accurate definition of the lower limit of PAWC, they were extensively used in the study by Vanassche and Laker (1989).

The concept of PAWC as defined by Hensley and De Jager was tested on several crops at full canopy development on a variety of soils and reproducible results were obtained. From their data, Laker (1982) compiled a first simple equation to predict the PAWC for different irrigated (soil-evaporative demand) systems for maize. This led to a follow-up project with the aim of developing PAWC models.

The development of PAWC models was studied by Boedt and Laker (1985) in a research project in the Department of Soil Science at the University of Fort Hare. Their research consisted of the determination of PAWC for a selection of important crops on a variety of soils under different evaporative demands in the Ciskei and at the Vaalharts and Loskop irrigation schemes. They experienced problems with the interpretation of PLWP as a parameter to indicate FMS in crops under very high evaporative demand. Visual symptoms as described by Mallett and De Jager (1971) and Hensley and De Jager (1982) could also not be used since the plants wilted fairly early in the morning even in soils at field capacity under these conditions. Eventually Boedt and Laker (1985) resorted to the use of early morning wilting (at 09:00) as indicator of FMS. Again this emphasises the importance of the use of parameters which are directly linked to plant performance. The obtained results were used to compile equations to estimate the PAWC and the profile extractable water (PEW) for wheat and maize, using the physical and chemical properties of the soils combined with the effective rooting depth and the depths at which specific pedogenetic horizons occur.

Irrigation scheduling experiments were carried out in order to test the PAWC concept. The effect of irrigation, at extraction of different fractions of PAWC, on seasonal water use, yield and water-use efficiency was studied. Boedt and Laker (1985) concluded that the PAWC concept seemed to provide a consistent basis on which to base irrigation scheduling. The results showed that beyond a certain threshold value of extracted water, yields dropped to economically unacceptable levels and hence indicated the necessity to improve identification of the lower limit of PAWC. This could possibly be done by comparing plant performance related parameters with the previously used PLWP and wilting parameters.

Until now PAWC determinations and related studies have always been conducted at the full canopy phase or flowering stage (Hensley and De Jager, 1982; Boedt and Laker, 1985). A need still existed for studying PAWC at different young growth stages and its evolution as plants grow towards maturity. This was, therefore, the first objective of this study. A second objective was to improve identification of FMS, the lower limit of PAWC, in view of the unsatisfactory results found by Boedt and Laker (1985) with PLWP and visual symptoms under conditions of high evaporative demand.

Materials and methods

This paper uses experimental data reported by Vanassche and Laker (1989). The research was conducted at the Cradock Experimental Station of the Department of Agriculture and Water Supply near Cradock in the Eastern Cape Province, Republic of

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Received 26 July 1990; accepted in revised form 16 October 1990.

TABLE 1
GROWTH STAGE AT WHICH DRYING CYCLES FOR DURUM WHEAT WERE STARTED

Plot	Phenological growth stage	Days after planting
a	Tillering	45
b	Leaf sheaths erected	65
c	Flag leaves appear	80
f	Flowering	100
e	Well-watered control plot	

South Africa. Cradock (32° 08'S, 25° 37'E; altitude 660 m) is situated about 250 km north of Port Elizabeth at the eastern border of the Great Karoo, a large semi-arid region in the central part of South Africa. The soil is young, of alluvial origin, and is classified according to the South African Binomial Soil Classification System (MacVicar *et al.,* 1977) as an Oakleaf (Limpopo series). According to Soil Taxonomy (USDA, 1975) the soil is classified as a Mollic Ustifluvent.

Five plots of 5 m by 5 m were laid out for the experiment. An aluminium neutron hydroprobe access tube was inserted in each plot to a depth of 1 500 mm. The plants were protected against animals by a fence of strong netting and against rain by movable rain-sheds. Flood irrigation was used, and a centrifugal pump, which was calibrated at regular time intervals, was used to pump the water from the furrow to the plots. To prevent soil erosion in the plots the water was pumped into a small basin adjacent to the plot. The cultivar was Moni, the sowing date was 22/06/1987 and the sowing rate was 100 kg seed per hectare. The standard recommendations of the Cradock Research Station were followed for fertiliser applications, planting densities and pest and weed control treatments.

Soil water measurements to a depth of 1 500 mm were done by means of a Campbell Pacific Nuclear neutron hydroprobe (model CPN 503). The instrument was calibrated against different soil water contents determined gravimetrically at depth intervals of 150 mm. A small plot was irrigated several times to ensure complete wetting of the profile. When drainage had effectively stopped, the measured volumetric soil water content was taken as the field capacity value.

Pre-dawn leaf water potential (PLWP) measurements were done by means of a pressure chamber similar to the one described by Scholander *et al.* (1964). The method of sampling, as well as the measuring itself and the sequence of measuring, were done according to a standardised procedure in order to obtain representative and reproducible values (Vanassche and Laker, 1989).

Stem elongation measurements were done at regular time intervals on ten randomly selected plants in each plot.

The different growth stages of durum wheat at which the different drying cycles were started are listed in Table 1. Before the drying cycles were started, the plots were irrigated to ensure a complete wetting of the profile. PLWP measurements were started two days after irrigation and continued until severe water stress was observed. Soil water content was monitored on a daily basis.

Results and discussion

Stem elongation and PLWP patterns

During the experiments it was found that PLWP patterns of young, immature leaves were constantly lower than those of mature leaves. In some cases they had very low values, apparently indicating FMS, while no signs of stress could be detected in the mature leaves. This confirms the statement of Boedt and Laker (1985) that it is very important to standardise on the plant part used for PLWP determinations. For durum wheat it is clearly very important to use mature leaves and the readings, therefore, were

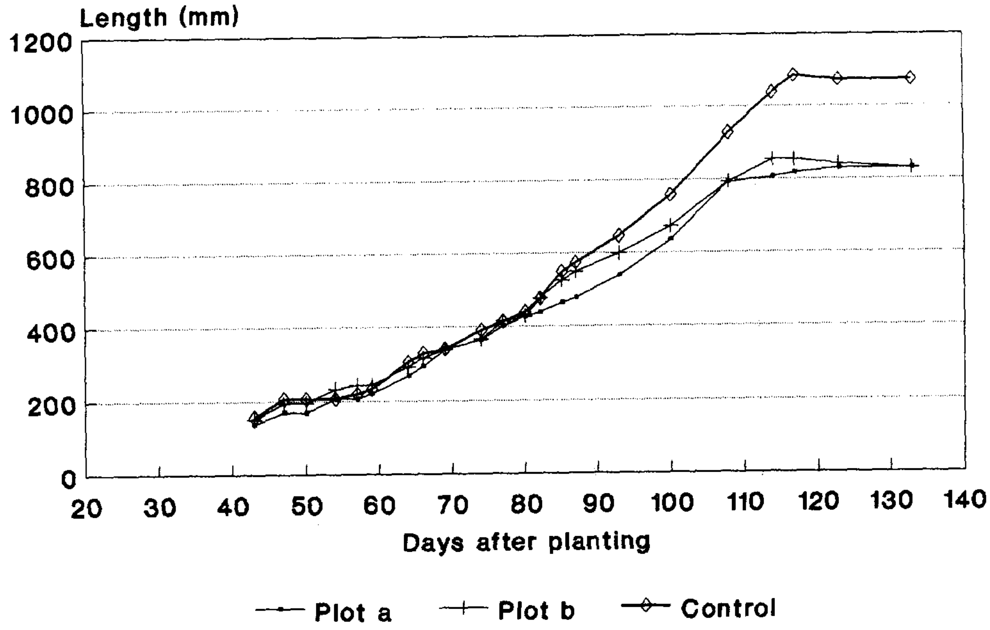

Figure 1A
Cumulative stem elongation of durum wheat on Plots a, b and Control

always done on the youngest mature leaf. The results of the determinations done on immature leaves are also indicated in Fig. 2A and illustrate the discrepancies between immature and mature leaves. Similar tests done on wheat showed no difference between the values for immature and those of mature leaves.

The stem elongation patterns of Plots a and Control were similar until day 80 (i.e. day 35 after the start of the drying cycle). However, the stem elongation rate (SER) on Plot a decreased already on day 69, 24 d after the start of the drying cycle (Fig. 1A). From day 69 until day 80 the cumulative stem elongation on Plot a decreased slightly relative to that of the Control plot. After day 80, a gap between the two cumulative stem elongation lines started to widen very quickly, indicating severe water stress. During the first nineteen days of the drying cycle PLWP values were quite stable around -200 kPa (Fig. 2A). During the next ten days PLWP readings fluctuated around an average of -500 kPa and a minimum value of -750 kPa was measured on day 24 of the drying cycle, indicating FMS. Normally, only PLWP values below a certain value (-1 000 kPa) are considered to be an indication of FMS. However, it was found that younger plants seem to be more sensitive to reductions in PLWP caused by water stress (Vanassche and Laker, 1989). As a result of a decrease in air temperature from 27°C to 10,5°C on days 24 and 28 of the drying cycle, PLWP values increased again to about -400 kPa. After day 29 of the drying cycle PLWP dropped very sharply and stayed below -1 000 kPa with slightly fluctuating values (Fig. 2A).

The cumulative stem elongation on Plot b was similar to that observed on the control plot until 86 d after planting, i.e. day 21 of the drying cycle. At that time the growth rate of the plants on Plot b started to decrease relative to that of the control plot, indicating FMS. The gap between the stem elongation lines of Plots b and Control gradually widened (Fig. 1A). In Fig. 2B a drop in PLWP was observed 25 d after the final irrigation, i.e. four days after the stem elongation started decreasing. The values dropped overnight from -300 kPa to -1 300 kPa, whereas the values for the control plot remained above -500 kPa.

The stem elongation pattern of the plants on Plot c could not clearly indicate FMS. Only a small decrease in stem elongation rate relative to that of the Control plot was observed on day 108. As the plants were nearly fully grown (appearance of the ears), soil water stress had very little effect on the vegetative growth and a difference in cumulative stem elongation of only 40 mm between the plants of Plot c and those of the Control plot was measured (Fig. 1B). The PLWP pattern indicated FMS on day 29 of the drying cycle (Fig. 2C). The values dropped very sharply from -350 kPa to -1 250 kPa and stayed below -1 000 kPa until the plot was irrigated again.

The drying cycle on Plot f (flowering) was started 100 d after planting, when the ears started appearing. The stem elongation patterns could not indicate FMS because the vegetative growth stage had ended at the time when water stress was induced (grain filling stage). At the end of the expriment no difference in height between the plants of Plot f and those of the Control plot was measured (Fig. 1B). PLWP on Plot f decreased gradually until day 19 of the drying cycle, after which a clear drop to far below -1 000 kPa occurred. The PLWP pattern, therefore, indicated FMS on day 20 of the drying cycle (Fig. 2F). The period to reach FMS on Plot f was shorter relative to the other plots because of the peak demands during the drying cycle as a result of the advanced growth stage and also because of the higher evaporative demand as a result of the relatively high temperatures (28°C to 32°C during the second half of the drying cycle).

The number of days to reach FMS and the parameter which indicated FMS for durum wheat for the different growth stages are summarised in Table 2.

Soil water extraction patterns and PAWC values

The extraction patterns shown in Fig. 3 represent soil water contents at the point in time when FMS was reached for the various drying cycles. All patterns show the same basic fan shape similar to the one found for wheat (Vanassche and Laker, 1989). However,

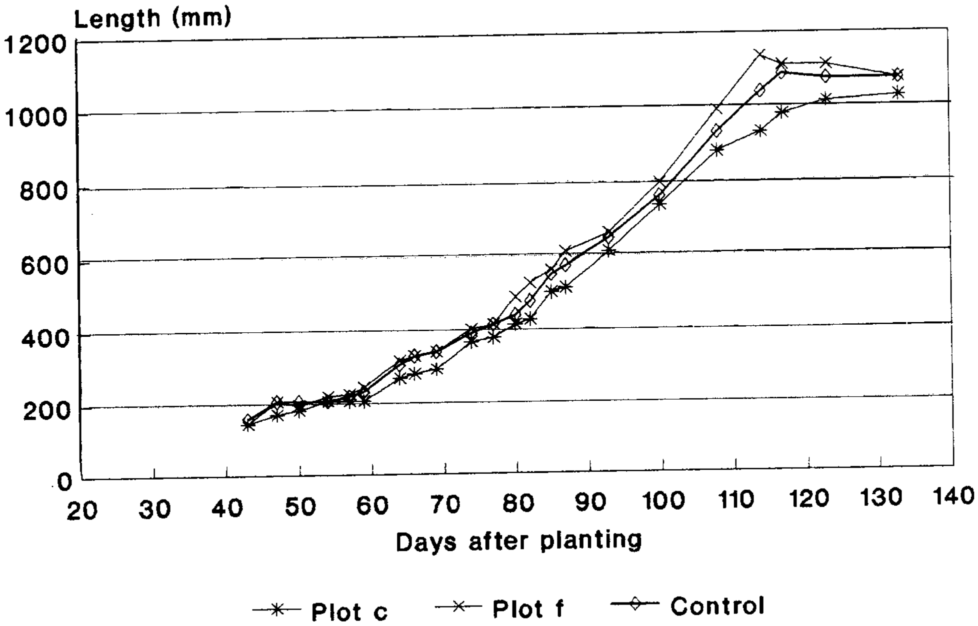

Figure 1B
Cumulative stem elongation of durum wheat on Plots c, f and Control.

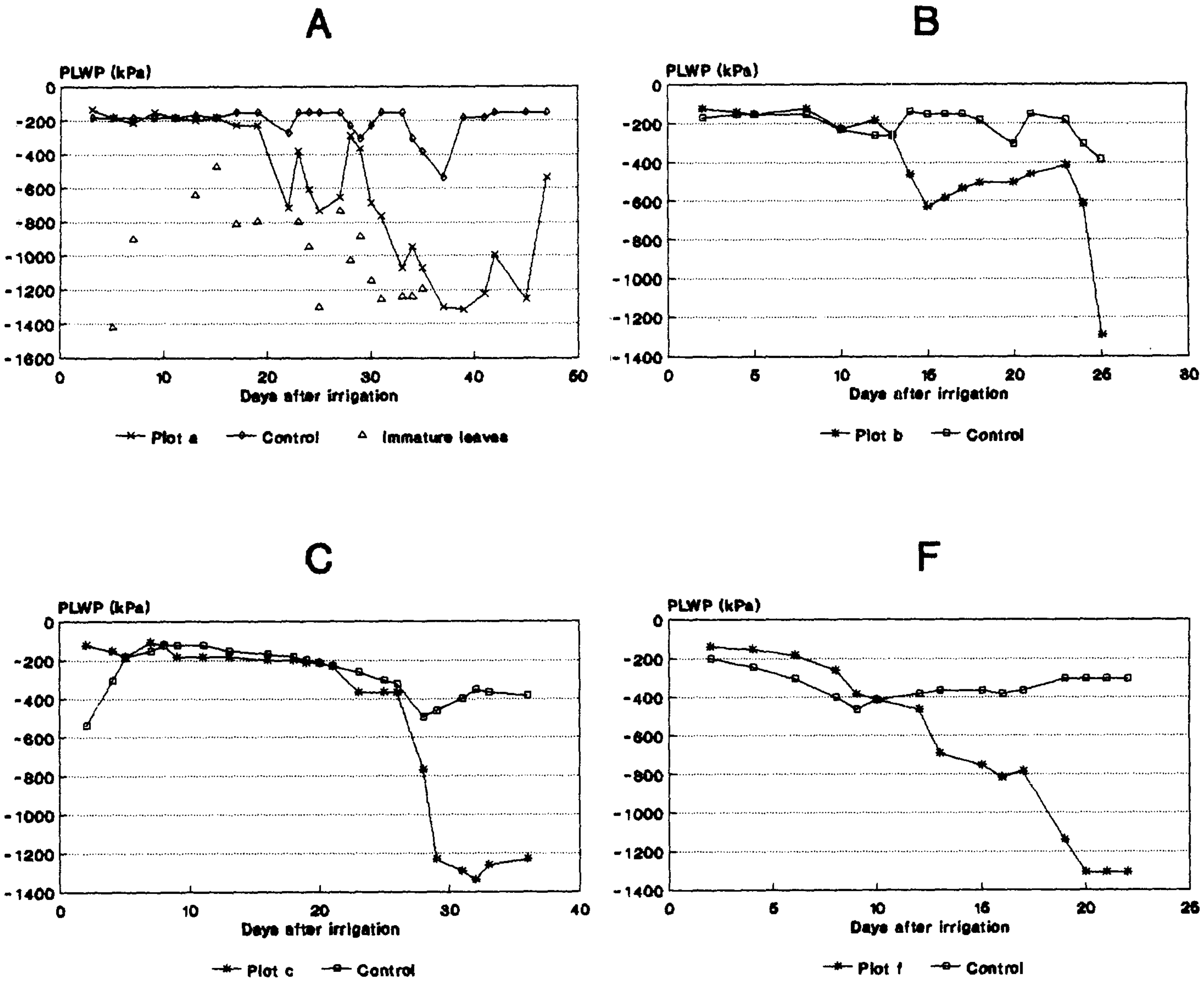

Figure 2

Pre-dawn leaf water potential patterns of durum wheat.

TABLE 2
NUMBER OF DAYS TO REACH FMS AND PARAMETERS USED TO IDENTIFY FMS IN DURUM WHEAT AT DIFFERENT GROWTH STAGES

Plot	Days to FMS	Parameter
a	24	PLWP* and SER
b	25	PLWP and SER
c	29	PLWP
f	20	PLWP

PLWP: pre-dawn leaf water potential.
PLWP*: at -800 kPa.
SER: stem elongation rate.

the PAWC values for durum wheat were lower than those for wheat which ranged from 72 mm to 140 mm at different growth stages (Vanassche and Laker, 1989). As the plants grew older, more soil water was extracted from soil layers between 400 mm and 600 mm depth and not from layers deeper in the profile. This was caused by the presence of a compacted B horizon at 650 mm depth which impeded root growth and penetration. The presence of this restricting layer is clearly illustrated in the soil water extraction patterns. A first indication is the high apparent field capacity value above the restricting layer. The true field capacity value for this part of the profile is much lower (28% by volume). The higher value is a result of partial waterlogging. However, this water was also available to the plants and must be taken into account when calculating PAWC. A second characteristic is drying out of the soil above this layer (FMS lines bulging to the left) which is probably indicative of a concentration of roots.

Table 3 shows the quantities of soil water extracted at different

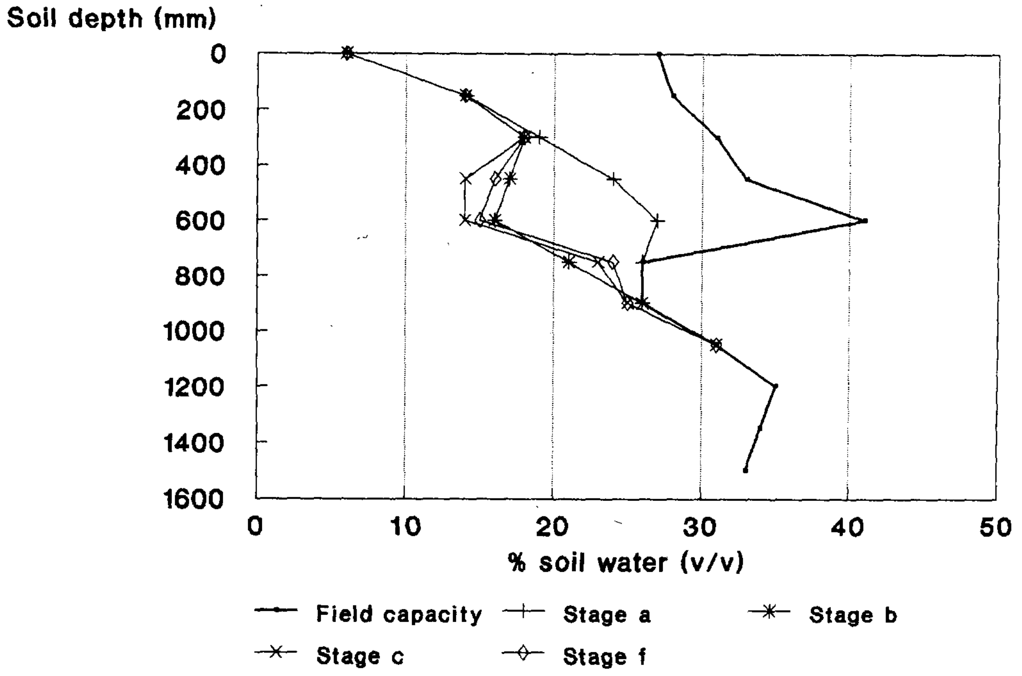

Figure 3
Soil water extraction patterns of durum wheat at different growth stages.

TABLE 3
QUANTITIES OF SOIL WATER EXTRACTED BY DURUM WHEAT AT DIFFERENT SOIL DEPTHS AND PAWC VALUES FOR EACH GROWTH STAGE

	water extracted (mm)			
Depth (mm)	a	b	c	f
0 - 100	17,0	18,0	16,8	18,0
100 - 200	12,5	13,0	11,7	13,5
200 - 300	12,0	12,0	11,5	12,8
300 - 400	11,8	16,8	18,5	17,0
400 - 500	12,5	21,0	24,0	22,0
500 - 600	14,7	25,5	28,0	28,0
600 - 700	5,0	11,5	10,0	9,7
800 - 900		3,5	1,5	1,8
900 - 1000			1,0	1,5
1000 - 1100				0,5
PAWC	85,5	121,3	123,0	124,8

soil depths and the PAWC values for the four growth stages. The extraction of soil water from layers between 400 mm and 700 mm depth at Stage f (flowering) was twice the amount measured at Stage a (leaf sheaths erected) in this part of the profile. The PAWC determined at flowering stage (Stage f) was already reached at Stage b (appearance of flag leaves).

Conclusions

Both stem elongation rate (SER) and PWLP were very good indicators of FMS in young plants. At later growth stages (appearance of flag leaf) SER failed to indicate FMS, but PLWP indicated it very clearly. Single PLWP values could not be used as an indication of FMS. When PLWP is used as an indicator of FMS, a long-term intensive pattern, starting as soon as possible after irrigation with daily measurements, has to be studied. PLWP measurements on plants of a well-watered Control plot made identification of FMS easier as climatic influences could be eliminated. PLWP indicated FMS in young plants (Plot a) as soon as the values dropped to -800 kPa.

Great care has to be taken in the selection of leaves for leaf water potential measurements. Tests have shown that young, immature leaves have lower PLWP values which could mistakenly be interpreted as an indication of FMS. It is, therefore, very important to standardise the procedure of leaf water potential measurements even to the point of leaf selection. This statement was also made by Boedt and Laker (1985) as a consequence of the results obtained during their research on PAWC for different crops in a variety of soils. During this experiment the youngest, mature leaves were selected for PLWP determinations.

PLWP and SER indicated FMS simulataneously during the young growth stages (until the end of tillering stage, Plot a). At this stage PLWP indicated FMS when values dropped to -800 kPa. During more advanced vegetative growth stages (from the end of tillering onwards) SER indicated FMS before PLWP did. It is therefore recommendable to use both parameters when determining onset of FMS in durum wheat during vegetative growth stages. After the appearance of the flag leaves, SER failed to indicate FMS. PLWP gave a very good indication of FMS at these growing stages when values dropped sharply below -1 200 kPa.

The PAWC values determined at the different growth stages indicated that the maximum PAWC value (value at flowering stage) is already reached quite some time before flowering. During this experiment it was found that the maximum PAWC of 125 mm was already reached when the flag leaf started to appear (121 mm at Stage b). This means that the PAWC value determined at flowering stage can be used for irrigation scheduling purposes already at the end of tillering stage (50 d after planting). Before that time a PAWC value of 70% of the PAWC at flowering can be used.

Acknowledgement

The research reported here was supported by a grant from the Water Research Commission.

References

BOEDT, LJJ and LAKER, MC (1985) The development of profile available water capacity models. WRC Report No 98/1/85, Pretoria.

HENSLEY, M (1984) The determination of profile available water capacities of soils. Ph.D dissertation. University of the Orange Free State, Bloemfontein.

HENSLEY, M and DE JAGER, JM (1982) The determination of the profile available water capacities of soils. University of Fort Hare, Alice.

LAKER, MC (1982) A provisional simple model for predicting PAWC for maize on certain Ciskeian soils. In: *The determination of the profile available water capacities of soils.* Edited by Hensley and De Jager. University of Fort Hare, Alice.

MacVICAR, CN, DE VILLIERS, JM, LOXTON, RF, VERSTER, E, LAMBRECHTS, JJN, MERRYWEATHER, FR, LE ROUX, J, VAN ROOYEN, TH and HARMSE, HJ VON M (1977) Soil Classification. A Binomial System for South Africa. Dept. of Agriculture, Pretoria.

MALLETT, JB and DE JAGER, JM (1971) Effect of a moisture stress day upon maize performance. *Agroplantae* **3** 15-20.

SCHOLANDER, PF, HAMMEL, HT, HEMMINGSEN, EA and BRADSTREET, ED (1964) Hydrostatic pressure and osmotic potential in leaves of mangrove and some other plants. *Pro. Nat. Acad. Sci. U.S.A.* **52** 119-125.

SOIL SURVEY STAFF (1975) Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. *USDA Handbook* 436. Government Printer, Washington DC.

VANASSCHE, FMG and LAKER, MC (1989) Studies on irrigation management based on PAWC and soil water monitoring. WRC Report No. 166/1/89, Pretoria.