Water Table Gradient Effects on the Performance of Diverse Cowpea Cultivars

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Water Table Gradient Effects on the Performance of Diverse Cowpea Cultivars

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ABSTRACT

Cowpea sown in tropical monsoon climates is often constrained by soil saturation and a high water table during growth. We hypothesized that a strong interaction exists between cowpea maturity class and the soil water table depth regime experienced during the growing season, and that the occurrence of shallow water table depths in the dry-wet transition period before rice and the rapid decline in water table depth in the wet-dry post-rice period favor early maturing cultivars. The effects of three water table regimes on the performance of 24 diverse cowpea [*Vigna unguiculat* (L.) Walp] cultivars was studied on a Typic Tropudalf toposequence. The water table depths in the shallow (SWT), medium (MWT), and deep (DWT) water table regimes varied between 0.06 to 0.54 m, 0.28 to 0.96 m, and 0.68 to 1.44 m in the 2 yr of dry season (DS) experiments. In the wet season (WS), the three regimes were 0 to 0.27 m, 0.30 to 0.60 m, and 0.55 to 1.05 m. Most of the early maturing cultivars exhibited their best performance in the DWT regime, but the medium maturing cultivars were superior in seed yields in all water table regimes. The mean yields of the early maturing cultivars were reduced by 49% (1986-1987 DS) and 57% (1987-1988 DS) in SWT compared to DWT. They were reduced by 50% in the 1987 wet season. The mean yield reductions for the medium maturing cultivars were 40%, 54%, and 51%, respectively, in SWT compared to DWT. Pods per plant was the yield component most affected by excess moisture. Flowering in the SWT was delayed by 4 vs 5 d (DS) and 5 vs 7 d (WS) between the early and medium maturing cultivar groups, respectively. The superiority of the medium maturing cultivars was consistent among sites with a water table within the root zone for a major portion of the crop season.

INCREASING CROP INTENSITY by growing cowpea after rice is a promising system for improving productivity in the South and Southeast Asian rice growing region. However, cowpeas planted after rice are often constrained by soil saturation and a shallow water table in the root zone, resulting in waterlogging stress. Subsequently when the water table declines below the root zone, the crop suffers from water stress. Such contrasting water table regimes, along with unfavorable edaphic factors in the root zone, seriously restrict cowpea growth and yield. Different cultivars of a species may react quite differently to a range in water table regimes (Moorman et al. 1977; Mambani and Lal, 1983; Stoop, 1986; Van Staveren and Stoop, 1985; Hulugalle and Lal, 1986). Pandey et al. (1986) also observed cultivar differences of cowpeas to varying water table depth.

Shallow water tables are recognized as a potential source for meeting part of the crop water requirement (Namkem et al. 1969; Stewart et al. 1969; Williamson and Kriz, 1970; Follett et al. 1974; Stuff and Dale, 1978; Wallender et al. 1979; Hundal and De Datta, 1984). Although many of these studies did not specify the contribution of water table through capillary upward flux, some studies have clearly indicated that capillary rise from a shallow water table plays an important role in supplying water to the crop (Ragab and Amer, 1986). On the other hand, a constant shallow water table or intermittent flooding reduces leaf number, leaf width and length, root and shoot growth, nutrient uptake, and grain yield of several crops (Joshi and Dastane, 1966; Lal and Taylor, 1969; Herrera and Zandstra, 1979; Campbell and Drew, 1983). Stanley et al. (1980) reported yield reductions in soybean under a shallow water table.

Table 1. Physical and chemical properties of soil at the experimental site.

Parameter	Shallow water table (SWT)	Medium water table (MWT)	Deep water table (DWT)
Physical Properties			
0- to 0.2-m soil depth			
Bulk density	1.21	1.22	1.26
Soil texture	Clay loam	Silty clay loam	Silty clay loam
Saturated hydraulic conductivity (cm d^{-1})	5.0	28.7	75.0
0.2- to 0.4-m soil depth			
Bulk density	1.19	1.26	1.28
Texture	Silty clay	Clay	Clay loam
Saturated hydraulic conductivity (cm d^{-1})	2.3	5.3	1.8
Chemical Properties			
0- to 0.2-m soil depth			
Organic C (g kg^{-1})	11.5	12.4	11.8
Total N (g kg^{-1})	1.2	1.3	1.3
Olsen available P (mg kg^{-1})	19.0	14.0	19.0
Exchangeable K (cmol kg^{-1})	0.39	0.57	0.78
CEC (cmol kg^{-1})	29.8	29.5	28.7
pH	5.8	5.6	5.5
0.2- to 0.4-m Soil depth			
Organic C (g kg^{-1})	9.4	8.8	12.0
Total N (g kg^{-1})	0.9	1.0	1.2
Olsen available P (mg kg^{-1})	19.0	9.3	11.0
Exchangeable K (cmol kg^{-1})	0.28	0.27	0.56
CEC (cmol kg^{-1})	31.8	31.7	29.0
pH	5.8	5.8	5.4

The above studies suggest that for every crop species, and possibly, for every cultivar of a species, there is an optimum water table that maximizes the crop water uptake thereby maximizing yield. These studies further suggest that if rainfall is limited, and flooding is not a hazard, water stress can be minimized and yields maximized in crops grown in soils with a high water table.

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Abbreviations: SWT, MWT, and DWT, shallow, medium, and deep water table, respectively; DS and WS, dry and wet season; and DAE, days after emergence.

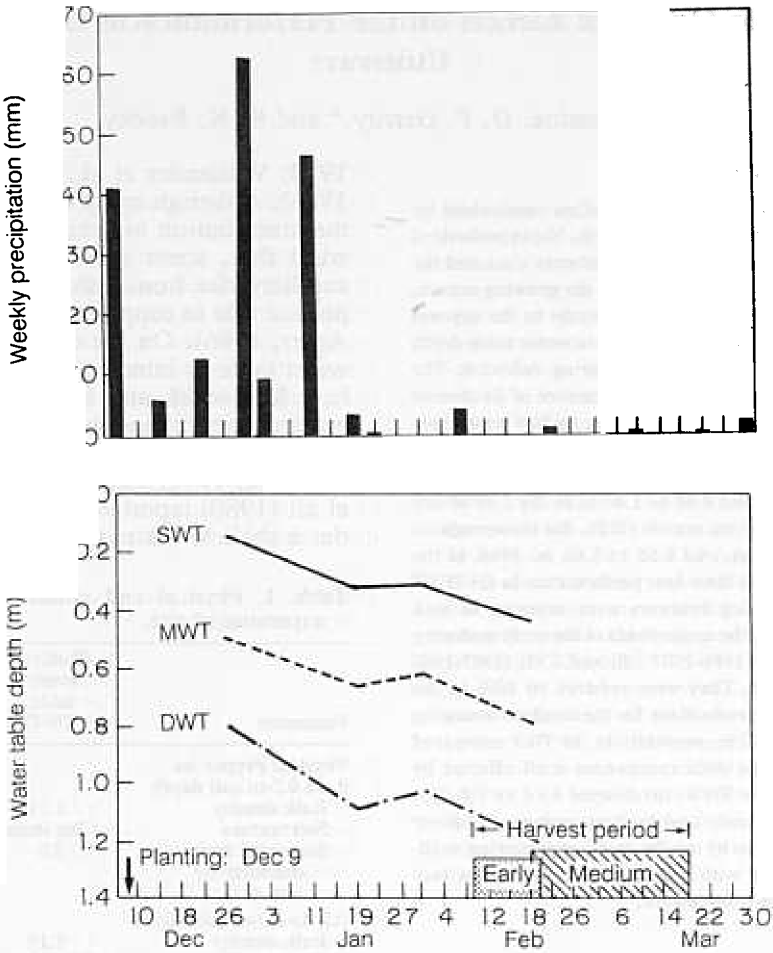

Fig. 1. Variation of water table depth and precipitation with time during the growing season (1986-1987 dry season)

There is almost no literature for cowpeas concerning the influence of water tables that is relevant to the culture of the crop in rice-based systems in the Asian monsoon tropics. We hypothesized that a strong interaction exists between cowpea maturity class and the soil water table depth regime experienced during the growing season, specifically, that early maturing cultivars are favored by the occurrence of shallow water table depths in the dry-wet transition period before rice and by the rapid decline in water table depth in the wet-dry post-rice period. The studies were conducted to guide the development of improved cultivars, and the extrapolation of cowpea management systems, for tropical ricelands. The yield and yield components of cultivar response are discussed in this paper. Shoot growth, root growth, and plant water relations of a selected group of these cultivars is reported in a companion paper (Timsina et al., 1993).

MATERIALS AND METHODS

Field experiments were conducted during the dry seasons 1986-1987 and 1987-1988, and in wet season 1987 on a naturally occurring sloping field (medium deep Typic Tropudalf) at the International Rice Research Institute (IRRI) (14° 11′N, 121° 15′E, 23 m elevation), Los Baños, Laguna, Philippines.

Twenty-four diverse cowpea cultivars were evaluated under different water table depths on the toposequence in the 1986-1987 DS and the 1987 WS. The cultivars were grouped into four classes: early maturing grain and vegetable-types, and medium-maturing grain and dual-purpose (ie. grain and fodder) types. The mean number of days from emergence to flower of each class is approximately 36, 39, 42, and 48 d, respectively. Under an unirrigated moisture regime, the maturity of early maturing grain and vegetable type cultivars ranges from 58 to 68 d and that of the medium-maturing grain and dual purpose types ranges from 67 to 78 d (Timsina, 1989). Based on the performance of cultivars in the first two experiments (1986-1987 DS and 1987 WS), four cultivars (TVX3236-01G—a medium-maturing grain type, TVX3410-02J—a medium-maturing dual-purpose type, BS6 [(LBBS#1 × CO1) 4-1-1-2]—an early maturing vegetable-type, and IT82D-892—an early maturing grain type) were selected for a subsequent study in the 1987-1988 DS on the same toposequence.

A toposequence provides a continuum of edaphic and hydrologic conditions from dryland to hydromorphic, and offers the possibility of evaluating the differential response of cultivars to a gradient of water table depth, from very deep to quite shallow (Stoop, 1986). In a toposequence, the soils in the higher stratum (i.e. higher position on the slope) are often subjected to drought and the soils in the lower stratum (or bottomland) are subjected to excess moisture due to slower drainage, surface and subsurface lateral flow of water, and a shallow water table depth (Moorman et al., 1977; Hanna et al., 1982). Different water table regimes along a toposequence system provide a basis for screening crop species and cultivars for drought and excess moisture. The system employed con-

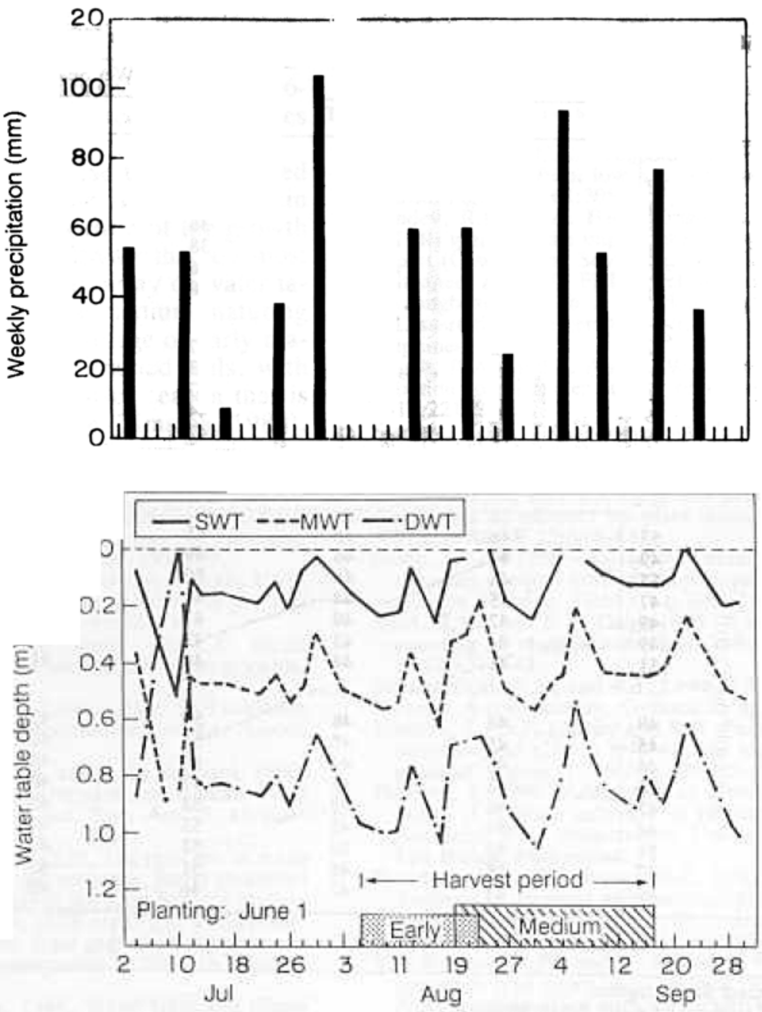

Fig. 2. Variation of water table depth and precipitation with time during the growing season (1987 wet season).

sisted of continuous plots of each cultivar sown parallel to the slope.

The 40 m long sloping toposequence was divided into three equal parts (each 12 m long) representing three water table regimes. The lowest stratum was designated as having a SWT, the middle as MWT, and the uppermost as DWT. Each plot (3 by 40 m) of a cultivar was subdivided into three subplots (3 by 12 m) representing the three water table regimes. Cultivars were the vertical factor while the water table regimes were the horizontal factor of a strip plot design. Since the water table sites could not be randomized, the statistical analysis as proposed by Hanks et al. (1980) was used.

Table 1 gives the soil physical and chemical properties for 0-to 0.4-m soil depth in the three water table regimes. Soil texture, bulk density, saturated hydraulic conductivity, and exchangeable K varied among levels, but most other parameters were similar.

The field was plowed once and rotovated once. Fertilizer at the rate of 30-13-25 N-P-K kg ha^{-1} was uniformly broadcast on the field before planting. Cowpea seeds were treated with a fungicide Brassicol (Pentachloronitrobenzene) at the recommended rate. The seeds were planted with a 0.50-m row spacing with an IRRI-designed Inverted-T planter on 9 Dec. 1986, and on 1 June 1987, for the first two screening experiments, and on 9 February, 1988 for the subsequent detailed study. Seedling density was maintained at 200 000 plants ha^{-1} in each experiment. Stand establishment was good in all experiments. Monocrotophos (dimethyl phosphate ester with (E)-3-hydroxy-*N*-methylcrotonamide) was used for insect control and was applied at approximately 15 d intervals. Deltamethrin [(S) -α-cyano-3-phenoxybenzyl- (1R)-*cis*-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropane carboxylate a.i. 2.5 EC] was sprayed fortnightly at the rate of 480 ml ha^{-1} to control thrips [*Megalurothrips sjostedti* (Trybom)] and pod borers [*Maruca testulalis* (Geyer)] in all experiments. Two handweedings (20 and 35 DAE) were done to control weeds, providing excellent weed control in all experiments.

Water table measurements were made with observation wells (0.05 by 1.50-m perforated polyvinylchloride pipes) in all experiments. In the 1987-1988 experiment, tensiometers and a neutron probe were used for soil moisture monitoring. The observation wells were installed in the center of each water table site in three replications for daily monitoring of the seasonal fluctuation in water table depths. Tensiometers were installed at 0.1- and 4.0-m soil depths in the three water table sites in two replications. The variation in soil matric potential was determined daily. Soil water contents were monitored weekly using the neutron moderation technique (Campbell Nuclear Pacific Hydroprobe Model 503 neutron moisture meter; Pacheco, CA). Seasonal variation in air-filled porosity for 0- to 0.2-m depth was determined every 2 to 3 d from moisture content and bulk density data. The particle density was assumed to be 2.65 Mg/m^3.

Seed yields were obtained from all experiments, whereas yield components were obtained only from 1987 WS and the 1987-1988 DS experiments. Seeds were harvested from the middle 6-m row segment in 1986-1987 DS and 1987 WS experiments, and from the center two 6-m row segments in the

Table 2. Number of days to 50% flowering of 24 cowpea cultivars in three water table sites (1986–1987 DS and 1987 wet season).

Cultivars	Dry Season (1986-87)			Wet Season (1987)			Mean
	SWT	MWT	DWT	SWT	MWT	DWT	
Early Maturing (Grain)							
IT82E-18	43	40	39	48	40	37	41
IT82E-16	41	39	38	42	40	41	40
IT82-889	38	37	36	36	32	32	35
CES41-6	41	39	38	38	36	36	38
IT82D-892	40	38	37	36	33	33	36
$\bar{X}$	41	39	38	40	36	36	38
Early Maturing (Vegetable)							
IT81D-1228-10	44	39	39	37	36	36	38
IT81D-1228-13	44	38	38	53	43	42	43
IT81D-1228-15	46	41	41	47	44	42	43
Farve 13	49	46	43	44	46	39	44
LBBS 1	49	41	41	42	36	34	40
BS 6	42	41	40	40	35	33	38
$\bar{X}$	46	41	40	44	40	38	41
Medium Maturing (Grain)							
TVX3236-01G	55	46	46	45	41	41	46
TVX2907-02D	49	47	46	49	43	43	46
Vita 4	55	46	45	50	45	43	47
IT82D-716	47	45	44	41	38	38	42
IT81D-1205-174	49	42	40	47	42	42	44
All Season	49	44	43	42	36	36	42
$\bar{X}$	51	45	44	46	41	40	44
Medium Maturing (Dual)							
TVX2724-01F	48	48	46	54	43	42	47
TVX1948-01F	45	45	45	51	42	42	45
TVX3381-02F	46	45	44	48	44	42	45
TVX3410-02J	49	46	45	47	40	40	45
TVX3871-02F	47	46	49	53	45	43	47
TVX289-4G	44	39	42	53	47	46	45
TVX1948-012F	51	49	50	52	43	44	48
$\bar{X}$	47	45	46	51	43	43	46
Grand mean	46	43	42	46	40	39	43
SE: (Between Cultivars)† = 1							
(Between WT × Cultivars)‡ = 1				2			

† Between cultivars within a water depth regime.
‡ Between any combination of cultivar by water depth regime.

Table 3. Effect of different water table depth on number of days to flowering and to maturity of four cowpea cultivars in three water table sites (1987–1988 dry season).

Cultivars	Flowering			Maturity		
	SWT	MWT	DWT	SWT	MWT	DWT
TVX3236-01G	51	48	47	88	78	76
TVX3410-02J	51	40	40	84	74	75
BS6	43	35	34	66	62	57
IT82D-892	43	34	34	71	66	64
SE: Between Cultivars† = 1				3		
Between WT × Cultivars‡ = 1				3		

† Between cultivars within a water depth regime.
‡ Between any combination of cultivar by water depth regime.

1987-1988 DS experiment. Pods were harvested when 95% were matured. Early maturing grain and vegetable-type cultivars were harvested in one or two pickings while the medium maturing types were harvested in two to three pickings. Pods were threshed and seeds were dried in an oven at 60 °C for 48 hr and all yields adjusted to 140 g kg^{-1} moisture content. A subsample of plants in a 1.0-m row segment was harvested for analysis of yield components in the 1987 WS and the 1987-1988 DS experiments.

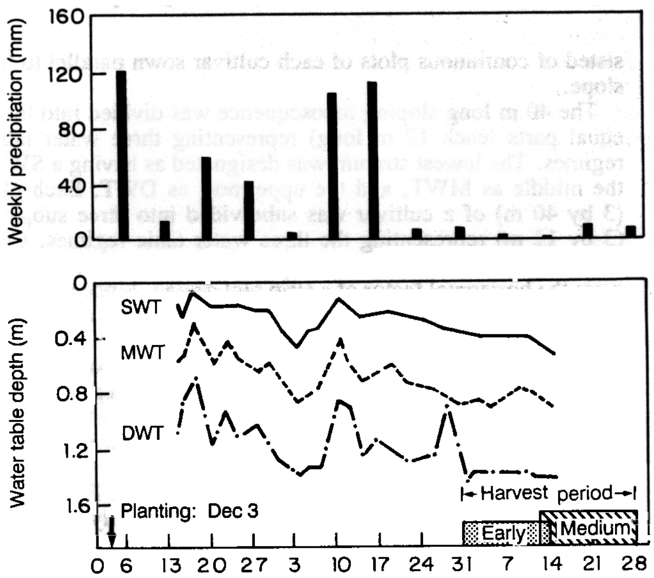

Fig. 3. Variation of water table depth and precipitation with time during the growing season (1987-1988 dry season).

RESULTS

Crop Environment

Rainfall and the fluctuation in water table depths in the different strata of the toposequence at four dates (28 December, 20 January, 1 February, and 20 February) during 1986-1987 DS experiment are shown in Fig. 1. There was a substantial amount of rainfall during the vegetative stage (from 3 December–11 January) and negligible rainfall during the reproductive stage of the crop,

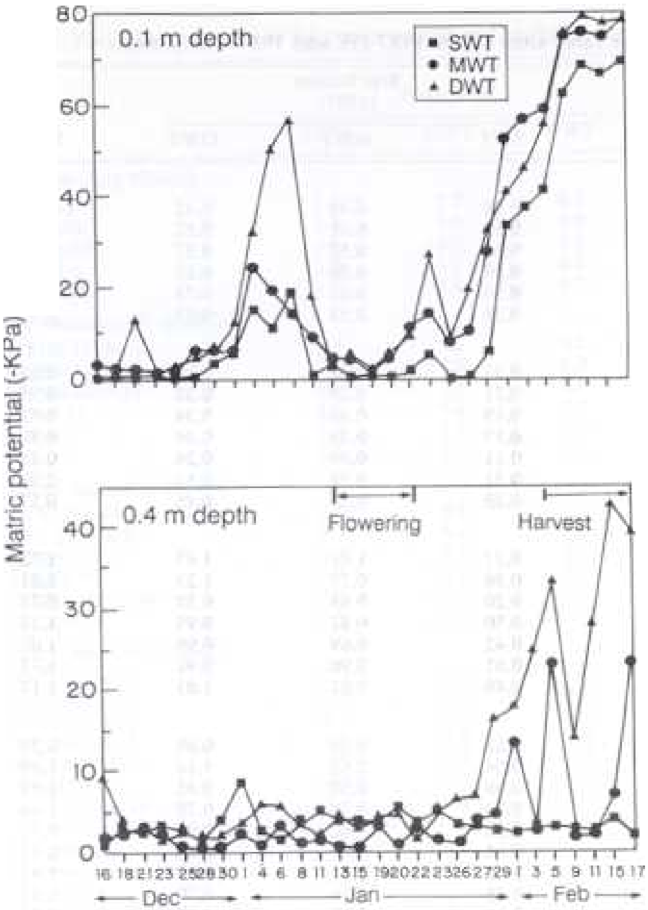

Fig. 4. Seasonal changes in soil matric potential (−kPa) at 0.1- and 0.4-m soil depths in three water table sites (each point is the mean of eight measurements (1987–1988 dry season).

as is common in the wet-dry transition period in SE Asian monsoonal climates. Water table depths in the SWT, MWT, DWT sites, ranged from 0.15 to 0.45, 0.50 to 0.80, and 0.80 to 1.20 m from soil surface, respectively. Daily average maximum and minimum temperatures during the vegetative stage were 29.9 °C and 21.9 °C respectively (average for 11 December–15 January). Daily average maximum and minimum temperatures during the reproductive stage were 29.5 °C and 21.0 °C respectively (average for 16 January–28 February).

The rainfall and the fluctuations in water table depths in the different strata of the toposequence during the 1987 WS experiment are shown in Fig. 2. There was very high rainfall during the vegetative stage (259 mm from 30 June–10 August) as well as the reproductive stage (292 mm from 11 August–15 September), totaling 551 mm rainfall. Evaporation during the crop growth period was only 334 mm.

The cultivars experienced severe waterlogging stress from intense rainfall and high water table throughout the crop growth period. During the growing season, the water table depths fluctuated from 0 to 0.27 m, 0.30 to 0.60 m, and 0.55 to 1.05 m, respectively in the SWT, MWT, and DWT regimes. Daily average maximum and minimum temperatures during the vegetative stage were 31.9 °C and 24.0 °C respectively (average for 30 June–10 August). Daily average maximum and minimum temperatures during the reproductive stage were 31.7 °C and 24.3 °C respectively (average for 11 August–15 September).

In the 1987-1988 DS experiment, there was abundant rainfall during the crop growing season, especially during the first 40 days after planting (Fig. 3). The water table depths in the shallow, medium, and deep water tables sites fluctuated from 0.06 to 0.54 m, 0.28 to 0.96 m, and 0.68 to 1.44 m from the soil surface, respectively. Water tables in all sites during the vegetative period were higher than during the reproductive period. Daily average maximum and minimum temperatures during the vegetative stage were 29.1 °C and 23.1 °C respectively (average for 1 December–15 January). Daily average maximum and minimum temperatures during the reproductive stage were 31.2 °C and 23.1 °C respectively (average for 16 January–15 February).

Seasonal fluctuations in soil matric potentials for the 0.1- and 0.4-m soil depths in the three water table sites in 1987-1988 experiment is presented in Fig. 4. The shallow water table maintained the top 0.10 m soil at near saturation until the end of January. From the beginning of February, soil moisture tension increased in all water table sites and reached nearly 80 KPa. Data were not recorded after 17 February since as of that date the mercury columns were broken and readings became unreliable. All the cultivars were physiologically mature by this time. At the 0.4-m soil depth in all sites, the soil matric potential was maintained near zero until the end of January. After 1 February, soil moisture tension increased in the MWT and DWT sites and reached nearly 45 KPa, but in SWT site, the matric potential was maintained near saturation even up to 17 February.

Seasonal fluctuation in air-filled porosity for the 0- to 0.2-m soil depth in three sites is presented in Fig. 5.Air filled porosity was consistently higher in the DWT site as compared to SWT site. The cowpea cultivars in the SWT site experienced excess moisture in the root zone throughout their growth. The soil matric potential at 0.4-m depth was continuously close to zero. In the MWT and DWT sites, the cultivars experienced waterlogging stress during the vegetative stage since the soil was nearly saturated at this time.

Phenology

The flowering of all cultivars was delayed in the SWT site as compared to MWT and DWT in both the dry season of 1986-87 and the wet season of 1987 (Table 2). The range in number of days to flower among the early-maturing vegetable and grain-type cultivars in the dry season trial was 38 to 56 and 36 to 51 DAE, respectively, under SWT and DWT sites, whereas in the wet season, this range was 36 to 53 and 32 to 42 DAE, respectively. The range for the medium maturing grain and dual purpose cultivars was 44 to 65 and 42 to 50 DAE, respectively under SWT and DWT sites in dry season. In the wet season, this range was 41 to 53 and 36 to 46 DAE, respectively under SWT and DWT sites. The shallow water table also delayed flowering and maturity of all cultivars in 1987–1988 DS (Table 3).

Seed Yield

There was a substantial response in seed yields to water table depth among cowpea cultivars in all experiments.