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Review article

AN OVERVIEW ON ROLE OF PHOSPHORUS AND WATER DEFICITS ON GROWTH, YIELD AND QUALITY OF GROUNDNUT (*ARACHIS HYPOGAEA* L.)

S. Hemalatha[1], V. Praveen Rao[2], J. Padmaja[3] and K. Suresh[4]
[1]Farmers' Call Centre, ANGR Agricultural University, Hyderabad-500061; AP, India,
[2]Water Technology Centre, ANGR Agricultural University, Hyderabad-500030, AP, India;
[3]Dept. of Agronomy, College of Agriculture, Rajendranagar, Hyderabad-500030, AP, India
[4]Agricultural Polytechnic, ANGR Agricultural University, Garikapadu-521175, AP, India

Fertilizer application in crop plants normally result in enhanced crop yields up to certain levels. Each of these major and minor nutrients have specific role in producing growth and yield enhancement in agricultural crops. However, the exact time and dose of fertilizer application in the given crop schedule is also of paramount importance for successfully exploiting the crop's potentiality in terms of yield. Groundnut is an important oilseed crop in the tropics and semi-arid tropics. Yield and often quality of oil in groundnut is sizeably dependent on proper application of different nutrients that have a direct say on these attributes. Phosphorus application in groundnut has tremendous impact on growth and development in groundnut. Further, the effect of phosphorus on yield and yield attributes is also well established. Another important factor determining crop growth and yields in groundnut is water. During periods of unpredictable water shortages, within season adjustments of water scheduling must be made in relation to the difference in the yield sensitivity to water deficits on groundnut and its individual growth periods. Thus management of limited water supplies for increased crop production requires studies on water production function of groundnut. This paper reviews information on phosphorus fertilization studies in groundnut and also in identifying moisture sensitive periods in groundnut for limited water management.

PHOSPHORUS NUTRITION IN GROUNDNUT

The total amount of phosphorus taken up by groundnut crop is relatively small amounting to 0.4 kg available phosphorus to produce 100 kg of pods (Reid and Cox, 1973). Though the amount of phosphorus required is small, large quantity of fertilizer has to be applied as the efficiency of phosphorus uptake from fertilizers is very low. Further, because of low phosphorus requirement of groundnut, response to application of phosphatic fertilizers has not been conspicuous, unless available phosphorus level in the soil is low (less than 10 kg available phosphorus ha^{-1}) and previous application is limited (Reid and Cox, 1973). The other possible reason for poor response of groundnut to phosphorus application even in low phosphorus soils might be the ability of groundnut to utilize phosphorus at the lowest levels than the most other crops, probably because of the formation of mycorrhizal association of the roots with soil fungi or due to phosphobacteria in the rhizosphere of the plant making unavailable phosphorus available to groundnut plant (Reddy, 1988).

Growth and Development

In groundnut, phosphorus deficiency is known to reduce flower production, size of pods and adversely affect the formation of root nodules (Seshadri, 1962). Phosphorus promoted shoot growth and a more extensive root system thus widening the root-shoot ratio which enable the plants to extract more moisture and nutrients from deeper depths (Arnon, 1975; Ahlawat and Saraf, 1982). The overall improvement in crop growth with P application seems to be on account of its significant role in early formation of roots, their proliferation and increased microbial activity in the root nodules. This has been shown to improve the effective utilization of soil nutrients by the crop and greater biological N fixation through enhancement in nitrogenase activity (Venkateswarlu *et al.,* 1988). These results are in line with those of Gupta et al. (1998).

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Application of phosphorus to groundnut was found to increase growth ancillaries due to cell division and rapid development of meristematic tissue resulting in a greater plant height, more number of branches and leaves per plant (Bhosale *et al.*, 1982; Sankar *et al.*, 1984; Juan *et al.*, 1986; Saradhi, 1988; Rao, 1989; Zalawadia and Patel, 1983). Kumar and Sreekumaran (1992) reported an increased plant height from 25.65 cm to 29.63 cm due to P application from 40 to 120 kg P_2O_5 kg ha^{-1}. Application of phosphorus brought significant improvement in LAI. At harvest, phosphorus deficiency decreased shoot length, number of leaves (Basha and Rao, 1980) and its presence is important for Lecithin (Miller, 1938), a compound in which edible oils occur in plants. Dry matter accumulation in groundnut is a result of leaf and stems growth during the vegetative phase and a combination of pod and kernel growth concurrent with shifts in leaf and stem mass during reproductive phase. Dry matter accumulation due to 40 and 80 kg ha^{-1} P levels was 10.0 and 9.8 per cent respectively more over no P. The increase in dry matter due to P could be mainly due to active involvement of P in carbohydrate metabolism which helps in putting more vegetative growth (Shrivastava and Verma, 1982; Patel *et al.*, 1990; Saradhi, 1988; and Deshmukh *et al.*, 1995). Signficant increase in dry matter production due to phosphorus application at 40 kg P_2O_5 ha^{-1} (Reddy, 1988; Satyanarayana, 1984; Saradhi, 1988; Thanzuala and Dahiphale, 1988; and Prasad *et al.*, 1996), at 60 kg P_2O_5 ha^{-1} (Juan *et al.*, 1986; Sebale and Khuspe, 1986; Intodia *et al.*, 1995; Kaushik, 1987) and even up to 90 kg P_2O_5 ha^{-1} (Sankar *et al.,* 1984) was noticed during rabi season.

Yield attributes

Significant increase in mature pods $plant^{-1}$, test weight and shelling percentage due to phosphorus application at varied levels against no phosphorus application was observed by several workers. The response was up to 40 kg P_2O_5 ha^{-1} (Vishnumurthy and Rao, 1986; Thanzuala and Dahiphale, 1988; Lal and Saran, 1988; Saradhi, 1988; Dimree and Dwivedi, 1994; Tomar *et al.,* 1996), up to 60 kg P2O5 ha^{-1} (Rao *et al.,* 1984a; Singh and Ahuja, 1985; Venkateswarlu and Nath, 1989; Chitkala and Reddy, 1991; Dimree *et al.,* 1993; Intodia *et al.,* 1995; Patra *et al.,* 1995; Raghavaiah *et al.,* 1995; Patel and Thakur, 1995; Deshmukh *et al.,* 1995; Yadav *et al.,* 1998) and up to 75-80 kg P_2O_5 ha^{-1} (Kumar and Sreekumaran, 1992; Rath *et al.,* 2000). On the other hand, Saini and Tripathi (1974), Shinde et al. (1981) and Reddy (1984), Akbari *et al* (1998) could not observe significant effect of P even at 60 or 90 kg P_2O_5 ha^{-1} on yield attributes of groundnut.

Yield

Groundnut required about 10 kg of P to produce a 1 tonne kernel yield (Tandon, 1987). Positive response of groundnut pod yield to phosphorus application was emphasized by many research workers. However, recommended levels of phosphorus to maximize the pod yield of groundnut exhibited a wide range (30-150 kg P_2O_5 ha^{-1}). This disparity evidently existed due to initial phosphorus status of the soil, moisture regime and response of crop to applied phosphorus under such environments. Significant increase in pod yield with phosphorus application ranging from 20 (Maliwal *et al.,* 1988) to 150 kg P_2O_5 ha^{-1} (Singh and Chaudhari, 1996) was observed depending upon the initial soil phosphorus status. Significant improvement in pod yield due to phosphorus application was noticed up to 40 kg P2O5 ha^{-1} (Vishnumurthy and Rao, 1986; Thanzuala and Dahiphale, 1988; Lal and Saran, 1988; Reddy and Giri, 1989; Saradhi, 1988; Dimree and Dwivedi, 1994; Prasad *et al.*, 1996; Tomar *et al.*, 1996; Vasisht and Pandey, 1999) and up to 50 kg P_2O_5 ha^{-1} (Konde *et al.,* 2001). Likewise response of groundnut to P application was evident up to 75 kg P_2O_5 ha^{-1} (Rath *et al.,* 2000), up to 90 kg P_2O_5 ha^{-1} (Singh and Ahuja, 1985), up to 120 kg P2O5 ha^{-1} (Kumar and Sreekumaran, 1992). Contrary to the above, positive influence of P application was not observed in increasing the pod yield of groundnut (Akbari *et al.,* 1998).

Quality

Influence of phosphatic fertilization on groundnut quality was studied by many workers who have observed significant differences in the effect of this nutrient on oil and protein content (Zalawadia and Patel, 1983; Rao and Singh, 1985; Lal and Saron, 1988; Dimree and Dwivedi, 1994; Intodia *et al.*, 1995; Patel *et al.*, 1995; Gupta *et al.*, 1998; Rath *et al.*, 2000). Contrary to the above, Reddy (1984) and Raghavaiah et al. (1995) reported that phosphorus levels could not bring about discernible variations in the oil content of groundnut kernels. Nair and Sadanandan (1981) reported decrease in oil content with increase in phosphorus dose from 50 to 100 kg P_2O_5 ha^{-1}. According to Prasad et al. (1996), any increase in phosphorus quantity above 40 kg P2O5 ha^{-1} had detrimental consequences on quality of groundnut due to the mechanism of fixation of phosphate at higher levels of P application.

Nutrient uptake

Significant increase in NPK contents (%) and NPK uptake was noticed with P application up to 60 kg P2O5 ha^{-1} (Dubey and Shinde, 1986; Khamparia, 1996; Lakshmamma *et al.*, 1996) and up to 75 kg P_2O_5 ha^{-1} (Deshmukh *et al.*, 1995).

WATER DEFICIT EFFECTS ON CROP GROWTH IN GROUNDNUT

Plant height

Plant height of groundnut is a product of the number of nodes and intermodal length. Soil water deficits at vegetative period in groundnut caused reduction in intermodal length more drastically than node number (Ochs and Wormer, 1959) although rate of node development was also reduced (Boote and Hammond, 1981). Stem morphology was altered by water deficit. Main axis and cotyledonary branches were shorter for water stressed groundnut plants (Lin *et al.*, 1963; Su *et al.*, 1964; Gorbet and Rhoads, 1975; Boote and Hammond, 1981; Babu, 1975; Lakshminarasimham *et al.*, 1977; Mathew *et al.*, 1983). Maximum stem elongation was registered when water applied was equivalent to that lost in either pan evaporation (Desai *et al.*, 1985) or crop evapo-transpiration (Reddy, 1988).

Leaf area index

Water deficits have been shown to inhibit leaf expansion through its reduction of relative leaf turgidity (Slatyer, 1955; Allen *et al.*, 1976; Vivekanandan and Gunasena, 1976) or leaf turgor potential (Rodrigues, 1984; Ong *et al.*, 1985). Water deficits also caused reduction in the rate of daily leaf production (Ochs and Wormer, 1959; Billaz and Ochs, 1961; Vivekanandan and Gunasena, 1976; Boote and Hammond, 1981; Ong *et al.*, 1985). Rate of leaf production showed progressive reduction (0.3 to 0.23 leaves day^{-1}) as soil water deficit increased (Boote and Hammond, 1981; and Ong *et al.*, 1985) although the total number of leaves was generally reduced more than number of leaves on the main axis thus indicating reduced branching (Ong *et al.*, 1985). Based on reductions in LAI, leaf size was reduced even more by soil water deficit than was the number of leaves (Ong et al. 1985). Leaf longevity and leaf area duration were reduced by decreasing soil water potential. Pandey et al. (1984a) reported that leaf area expansion rate, leaf area duration and LAI were progressively reduced as soil water deficit was intensified. Leaf morphology was altered by water stress. Continuous soil water deficit caused fewer and smaller leaves which had smaller and more compact cells (Il'ina, 1958; and Lin *et al.*, 1963) and greater specific leaf weight (Pandey *et al.*, 1984b). The xeromorphic leaf structure was retained even after adequate water was supplied, although new leaf development would apparently be normal.

Dry matter accumulation

Dry matter accumulations in groundnut is a result of leaf and stem growth during the vegetative phase and a combination of pod and kernel growth concurrent with shifts in leaf and stem mass during reproductive phase. Water deficit has significantly reduced dry matter production of all vegetative components (Fourrier and Prevot, 1958; Ochs and Wormer, 1959; Su *et al.*, 1964; Lenka and Misra, 1973; Vivekanandan and Gunasena, 1976; Pallas *et al.*, 1979; Ong, 1984; Sivakumar and Sarma, 1986; Sridhara *et al.*, 1995; Reddy *et al.*, 1996;) as well as crop growth rates (Slatyer, 1955; and Pandey *et al.*, 1984b). Shelke and Khuspe (1980) reported that water deficits at flowering and pod development periods reduced dry matter significantly. Total dry matter accumulation and dry weight was unaffected by mild stress at vegetative period (Rao *et al.*, 1985; Sivakumar and Sarma, 1986; and Reddy *et al.*, 1996). Increase in pod shoot ratio with short periodic water deficits was reported by Boote (1982).

Water deficit effects on yield attributes

Flowering

Reproductive growth of groundnut consists of three distinct stages viz., production of flowers, and development of pegs that carry the ovary below ground and the subsequent formation and filling of pods (Wright and Rao, 1994).

Moderate soil water deficit has been shown to delay flowering by 1 to 2 days and reduced the total number of flowers (Lenka and Misra, 1973). Continuous soil water deficit (soil maintained at or drier than 35 per cent of field capacity) was shown to delay flower initiation by 7 days and caused flowering to be inhibited (Il'na, 1958). Flowering is most severely affected by water deficits at or just before flowering (Fourier and Prevot, 1958; and Su *et al.*, 1964). Billaz and Ochs (1961) found that water deficit from 50-80 DAS on a short season groundnut reduced flowering and pegging and produced a greater yield reduction than stress at any other period. Possible causes for reduced flowering include reduced photosynthate supply, reduced turgor and low relative humidity. Low relative humidity which often accompanies water deficit has been shown to reduce the rate of flowering (Lee *et al.*, 1972; Ong *et al.*, 1985). Bolthuis et al. (1965) reported that low humidities increased the occurrence of flowers with short styles probably due to reduced turgor. This abnormally lowered the rate of fertilization and varied with cultivar. Not only flowering, but number of pegs (Ong *et al.*, 1985) and the rate of peg elongation (Lee *et al.*, 1972) were reduced by low humidity. This effect could be an important impediment to pod initiation and addition in arid environment (with less dew and lower humidity).

Pegging and pods per plant

Soil water deficit during pegging, pod initiation and formation period primarily reduced the number of pods plant^{-1} while scarcely affecting weight per pod (Matlock *et al.*, 1961; Skelton and Shear, 1971; Underwood *et al.*, 1971; Lenka and Misra, 1973; Ono *et al.*, 1974; Boote *et al.*, 1976; Vivekanandan and Gunasena, 1976; Pallas *et al.*, 1979; Rao *et al.*, 1985; Sivakumar and Sarma, 1986; Rao *et al.*, 1988; Wright and Rao, 1994). Soil water status in the top centimeter or two of soil is critical to peg entrance into the soil (Cox, 1962; Sivakumar and Sarma, 1986). Underwood et al. (1971) and Sivakumar and Sarma (1986) observed that pegs frequently failed to penetrate effectively into air dry soil, thus preventing pod growth. Boote et al. (1976) reported that within 4-day of with-holding of water in the field, the soil surface became too dry for peg entrance. Ono et al. (1974) observed that adequate pegging zone moisture was critical for development of pegs into pods and that adequate soil water in the root zone could not compensate for lack of pegging zone water for the first 30 days of peg development. After 30 days of adequate pegging zone moisture, pods could continue normal growth in dry soil if roots had adequate moisture. Thirty day old pods are usually fully expanded, have a rigid shell and have begun seed growth (Schenk, 1961). Stern (1968) and Sivakumar and Sarma (1986) reported that seed growth could continue after full pod expansion with root supplied water even if surface moisture was inadequate. Insufficient water in the pod zone can also depress Ca uptake by developing pods and cause more pops (unfilled pods), fewer double loculed pods (Skelton and Shear, 1971; Cox *et al.*, 1976). Pod initiation was also delayed due to water stress (Stirling and Black, 1991). On the other hand, several workers have reported that adequate water supply significantly increased total and filled pods plant^{-1} (Reddy *et al.*, 1980; Reddy *et al.*, 1982; Mathew *et al.*, 1983; Desai *et al.*, 1985; Katre *et al.*, 1988; Lakshmi, 1990).

Hundred-Kernel weight

Water deficits during pod fill or kernel growth period have been reported to reduce weight per seed (Gorbet and Rhoads, 1975; Varnell *et al.*, 1976; Pallas *et al.*, 1977; and 1979; Pandey *et al.*, 1984a; Sivakumar and Sarma, 1986; Rao *et al.*, 1988; Reddy *et al.*, 1996) and weight per pod (Underwood *et al.*, 1971; and Lenka and Misra, 1973). There is often a decrease in the percentage of extra large kernels (Stansell *et al.* 1976) and an increase in the per centage of damaged or shriveled kernel (Pallas *et al.*, 1979; Sivakumar and Sarma, 1986). Moisture stress from flowering to pod filling period caused 22 per cent reduction in 100-kernel weight (Pathak *et al.*, 1988). Likewise, Yao *et al* (1982) observed 24.7, 25.1 and 14.7 per cent reduction in 100-kernel weight due to water deficits at flowering, pod filling and ripening periods respectively. A number of researchers have reported significant increase in 100-kernel weight by maintaining adequate water at kernel growth or pod filling period (Khan and Datta, 1982; Lakshmi, 1990; Ramachandrappa *et al.*, 1992; Reddy *et al.*, 1996).

Shelling percentage

The shelling percentage or per cent sound mature kernels was found to be several units lower for water stressed groundnuts (Stansell *et al.*, 1976; Vivekanandan and Gunasena, 1976; Reddy *et al.*, 1978; Boote and Hammond, 1981). Water deficit from 36 to 70 DAS and from 71 to 105 DAS also caused an increase in immature pods and reduced shelling percentage to 73.4 and 69.7 per cent respectively compared to 76.5 per cent of the irrigated check (Stansell and Pallas, 1985).

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However, a 35 day water deficit during late pod fill period (105-140 DAS) actually increased shelling percentage because the late stress eliminated the addition of young immature pods (Stansell and Pallas, 1985). Reduction in shelling percentage was 28 per cent when stress was imposed during pod filling period when compared to fully irrigated control (Pathak *et al.,* 1988).

Harvest index

Excessive irrigation may promote vegetative growth at the expense of reproductive growth (Sivakumar and Sarma, 1986). High soil water potential has been reported to cause greater LAI and excessive vegetative growth, but no increase in pod yield resulting in reduced harvest index (Vivekanandan and Gunasena, 1976). An increased ratio of pods to vegetative growth under small periodic water deficits may be a natural and important mechanism of groundnut adaptation to drought conditions, except where pod formation is considerably restricted by the water deficit of long duration during reproductive growth. Ong (1986) found that the rate of peg production was less sensitive to declining plant water potential than was leaf area expansion. The particular influence of water deficit on harvest index depends on the timing and severity of the water deficit relative to fruit set. Moderate water deficits from planting to the start of peg initiation (0-51 DAS) had no effect on total biomass, but increased the yield by 12-19%, primarily via the effect on harvest index. The harvest index was 0.5 for fully irrigated groundnuts, as high as 0.57 for stress during 0-51 DAS, and as low as 0.24 for prolonged water deficit during the pod-fill phase. By contrast, water deficit during pod formation (50-80 DAS) was reported to cause significant reduction in harvest index (Billaz and Ochs, 1961; Reddy, 1988).

Oil content

Studies on quality aspects of groundnut revealed an increase in oil content with increase in soil moisture availability (Mehrotra *et al.,* 1968; Saini and Sandhu, 1973; and Rasve *et al.,* 1983), while Singh and Sandhu (1968), Singh *et al* (1968), Lingam (1969), Sharma and Singh (1987) observed no significant effect of regular supply of moisture on oil content. Yao et al. (1982) and Sharma and Singh (1987) reported that water deficits at flowering had no effect on oil content. However, water deficits at kernel growth or pod filling period significantly reduced the oil content. Likewise Sarma (1984) reported that imposition of early water deficits from emergence to peg initiation increased oil content, but when stress was imposed from flowering to start of kernel growth resulted in decreased oil content.

Water deficit effects on pod yield

To effectively irrigate groundnut, one must consider the stage of growth and development of the crop. For example, water extraction depth is influenced by rooting length and density, and crop ET is influence by canopy cover. Furthermore, pegging and pod formation have additional requirements for adequate moisture in the pod zone. Fourrier and Prevot (1958) reported that water deficits at any growth period from 35-60, 60-85 and 85-110 DAE caused significant yield reduction. Billaz and Ochs (1961) found that water deficits between 10-30, 30-50, 50-80 and 80-120 DAE caused 21.6 18.0, 46.0 and 27.0 per cent yield reduction. On the other hand, several researchers have reported that water deficits that occur only during early vegetative growth caused minor reductions in yield (Il'ina, 1958; Su *et al.*, 1964; Stansell *et al.,* 1976; Reddy and Reddy, 1977; Pallas *et al.,* 1977; Rao *et al.,* 1985; Thorat *et al.,* 1988; Reddy *et al.,* 1996; Ghatak *et al.,* 1997). Likewise, less frequent irrigations and irrigation at greater soil water depletion has its least detrimental effects on pod yield if applied prior to pegging and pod formation (Subramanian *et al.*, 1975; Reddy *et al.*, 1996). As the reproductive growth commences 5-6 weeks after sowing, water deficits during the first 35 DAS should reduce primarily vegetative growth, since few flowers and pegs are present. Further, since vegetative growth is frequently excessive in wet regimes (Gorbet and Rhoads, 1975; Vivekanandan and Gunasena, 1976; Sivakumar and Sarma, 1986) pod harvest index may be improved by moderate water deficits prior to pegging (Rao et al, 1985) and minor effects on final pod yield are expected if water deficit is relieved by 35 DAS (Sivakumar and Sarma, 1986; and Reddy *et al.*, 1996). Water deficits during vegetative growth were less damaging because ground cover and LAI are incomplete. Thus, less water was consumed in Eta and irrigation amounts and frequently can be reduced during the phase. Moreover, early vegetative growth may continue by using stored soil water as root extension progresses (Srinivasan and Anjuman, 1987). Obviously, irrigation should be used to ensure germination and emergence and to relieve extreme stress if irrigation water is available (Sarma, 1984; Rao *et al.*, 1988).

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Water deficits are more detrimental to pod yield if they occur while pegging (Newman, 1976) and pod initiation and addition (Rao *et al.*, 1974). In terms of groundnut growth stages of a short season variety (100-110 days) this period starts when the peg tips first begin to swell (40-45 DAS) and ends when a full pod load has been established (80 DAS) and vegetative growth begins to slow down. The greater sensitivity of crop yield to water deficits during this phase may be partly related to the fact that crop reaches its peak water use and Eta during this time (Doorenbos and Kassam, 1979). Additionally, this was the period during which a full pod load is set. Therefore, soil water deficit during this period can limit the final yield potential significantly (Hang *et al.*, 1984; Patil and Gangavane, 1990; Reddy, 1991; Reddy and Reddy, 1993). After the full pod load is set (by about 80 DAS), water deficit reduced pod yield initially by causing smaller and younger pods to terminate growth and eventually by reducing the growth rate of olde pods (Rao *et al.*, 1985). Stansell and Pallas (1985) reported that water deficit during pod filling period (105-140 DAS) caused less yield reduction than 35 day deficit periods from 36-70 DAS or from 71-105 DAS coinciding with pegging, pod initiation and addition period. Likewise, several workers have observed that moderate water deficits (IW/CPE ration of 0.5 or Eta/Etm=0.6) during pod filling period were tolerable by the crop and minor effects were noticed on pod yield (Patil and Gangavane, 1990; Reddy and Reddy, 1993; Reddy *et al.*, 1996; Babu *et al.*, 1996). Thus irrigation can be managed more conservatively during the last 30 days period. Significant increase in pod yields were reported by application of water equivalent to that lost in pan evaporation (Kachot *et al.*, 1984; Rao and Singh, 1985; Chavan *et al.*, 1988; Thorat *et al.* 1988; Desai *et al.*, 1989; Rao, 1989; Muktha *et al.*, 1996; Sujith *et al.*, 2000). Critical crop-growth sub-periods for moisture supply identified by several workers for groundnut under different agro-climatic conditions are summarized in Table 1. Perusal of Table 1 suggests that there was no complete agreement on the stages of sensitivity to soil water deficit as probably due to contrasting varieties of different duration, variable soil-water and climatic conditions in which they were grown.

Water deficit effects on crop water requirement.

The seasonal water use (Eta) by a groundnut crop is controlled by climatic, agronomic and varietal factors. A summary of the reported seasonal Eta values of groundnut is given in Table 2. The range of seasonal Eta values given reflects the variable agroclimatic conditions under which the crop is grown and varieties used. Under high evaporative demand in Israel, daily Eta of improved Virginia bunch averaged 6.9 mm day^{-1} 53 to 83 days after sowing (Mantell and Goldin, 1964). Ishag *et al* (1985) reported peak Eta rates of 7 to 8 mm day^{-1} at 75 to 85 semi-spreading Virginia type cultivar in Sudan. Soil water deficits reduced both evaporation and transpiration (Sarma, 1984; Sivakumar and Sarma, 1986; Ramachandrappa and Kulkarni, 1992; Reddy and Reddy, 1993). Metochis (1993) revealed that daily Eta rates under optimum soil moisture conditions increased from 1.5 to 2.0 mm day^{-1} at the beginning of growing season to 7.0 to 7.5 mm day^{-1} at full crop development and then decreased to 2 to 3.0 mm day^{-1} by the end of the season. There is evidence that the Eta/ETo ratio during the season can be increased by more frequent irrigations (Mantell and Goldin, 1964; Goldberg *et al.*, 1967; Karunasagar, 1993). The seasonal pattern in ET of groundnut is substantially related to the pattern of canopy development and establishment of LAI. The crop coefficients (ET/ETo ratio) were reported to increase linearly from 0.3 to 1.0 as the percentage ground cover increased from 0 to 100 per cent and as the LAI increased during groundnut growth (Goldberg *et al.*, 1967; Kassam *et al.*,1975; Yayock and Owonubi, 1986). Kassam et al. (1975) reported that peak ET occurred shortly before peak LAI was achieved. After full foliage development and ground cover, daily ET gradually declined from the maximum value until the plants reached maturity. This decline may be due in part to plant senescence (both loss in LAI and leaf conductance) and to seasonal decrease in evaporative demand. Dancette and Forest (1986) in Senegal reported crop coefficient for short seasons groundnut peaked slightly above 1.0 between 50 to 70 DAS.

Water use efficiency

Water use efficiency (WUE) is defined as pod yield per hectare per unit depth of water used in Eta reflects whether irrigation schedule followed was successful in conserving water, but it does not define the point of greatest economic yield. Highest WUE will frequently occur in relatively dry treatments having less than the highest economic yields. Water deficits during vegetative period (emergence to peg initiation) significantly improved the WUE of groundnut due to saving in water without any reduction in yield (Sarma, 1984; Patil and Gangavane, 1990; Reddy, 1991; Reddy and Reddy, 1993).

Highest WUE of 83.91 kg ha^{-1} mm^{-1} was reported by Ramachandrappa and Kulkarni (1992) when irrigations were scheduled at an IW/CPE ratio of 0.5 from 10-70 DAS and at an IW/CPE ratio of 0.75 from 70 days to harvest in sandy loam soil of Bangalore during summer season. Likewise, WUE was found to be higher (7.44 and 7.09 kg ha^{-1} cm^{-1}) by scheduling irrigations either at 50 per cent DASM or 50 mm CPE (Babalad and Kulkarni, 1993).

Depth of water extraction

One of the important consideration in the availability of soil water to groundnut plants is the rooting depth under normal conditions to fully exploit the profile water. Although the rooting depth of the groundnut plant is reported to extend up to 150 cm (Metelerkamp, 1975) and even up to 200 cm (Robertson *et al.*,1980), a majority of the roots are in the surface soil layers. The fraction of water extracted from various soil layers depends on rooting length density in the respective zones and the pattern of water application to the soil (Hillel, 1980). With frequent rains or irrigations more of the water will be extracted from the upper soil layers (Sivakumar and Sarma, 1986). Mantell and Goldin (1964) reported that under adequate water supply as under irrigated conditions, groundnut extracted up to 48 per cent of the water from the upper 30 cm, 23 per cent from 30-60 cm, 15 per cent from 60-90 cm, 9 per cent from 90-120 cm and 5 per cent from 120-150 cm soil depth. Under limited water situations, more water extraction occurred from the 90-150 cm soil layer (Reddy, 1988; Ramachandra Reddy, 1991; Sivakumar and Sarma, 1986; Patel and Patel, 1995). Hammond and Boote (1981), Avasarmal et al. (1982) and Desai et al. (1989) also concluded that maximum water extraction occurred from 30-45 cm soil layer. Stansell *et al* (1976) observed water extraction below 60 cm depth only 75 DAS.

Crop water production functions

The .functional relationship between crop yield and water use is defined as crop water production function. Water input can be either on a seasonal basis or on a critical growth period basis. The corresponding functions are named as seasonal and dated water production functions (Yaron, 1971). Knowledge of the relationship between crop production and water use would greatly contribute in a) Planning of strategies for water supply at farm and project level., b) Evaluation of alternate cropping patterns in relation to the availability and utilization of water resources, c) Economic analysis of irrigation projects, design and management criteria, d) Allocation of water for given cropping pattern among crops under conditions of water shortage. The temporal distribution of irrigation water and randomly incidental precipitation interact with other soil characteristics to affect plant water status/ stress and yield. If soil moisture is not limiting, maximum crop growth would presumably occur under the abundance of other factors essential for plant growth. Given an initial moisture or irrigation regime, crop response to water will depend on when water is applied again, how much is applied and how much time elapses in the growing season until next irrigation was made (Hexam and Heady, 1978). For groundnut, timing and amounts of irrigation for satisfactory yields were shown to be very important (Mantell and Goldin, 1964; Gorbet and Rhoads, 1975; Stansell *et al.* 1976; Pallas *et al.*, 1977; Hammond *et al.*, 1978; Rao *et al.*, 1985; Stansell and Pallas, 1985). Yield response to water (Eta) was measured under carefully controlled lysimetric conditions by Stansell *et al* (1976), Pallas et al. (1977), Hammond *et al* (1978) and Boote *et al* (1982). The highest yield occurred when seasonal water use was 60 cm or more. The yield response was curvilinear between 40 and 60 cm, but yield declined linearly to zero as Eta declined from 40 to 10 cm. In the linear range of yield response to Eta (up to 50 cm) yield increased at 93 kg ha^{-1} for each additional centimeter of water evapo-transpired. Under field conditions, where <50 cm of rainfall plus irrigation was received, yield response was 76 kg ha^{-1} per cm of Eta (Reddy and Reddy, 1977; Boote *et al.*, 1982). Likewise, Shinde and Pawar (1982) observed a curvilinear response in yield to Eta with an R^2 value of 0.67. Rao *et al* (1985) reported that yield response to seasonal Eta is highly dependent on the stage of growth at which the Eta deficits occurred. In a narrow range of nearly the same Eta (50 -60 cm), there were several different lines describing yield response to Eta, each for different stage of growth when water deficits occurred. Data of Stansell and Pallas (1985) also indicated different yields obtained at the same seasonal Eta, also caused by timing of Eta deficit. Yield was reduced linearly for a given seasonal water use, when deficit at pod development period. Similar observations were made by Patil and Gangavane (1990), Ramachandra Reddy (1991) and Jain *et al* (1997).

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