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VALIDATION OF PNUTGRO MODEL FOR MOISTURE STRESS EFFECTS ON RAINFED GROUNDNUT IN MAJOR CROP GROWING AREAS OF ANDHRA PRADESH, INDIA - A CRITICAL REVIEW

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INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is an important oilseed crop grown in our country. Majority of crop is under rainfed conditions and as a post rainy season (Rabi) crop in Andhra Pradesh. Several models are available to predict the phenology, growth and yield of groundnut crop. However, no precise models are available to validate the effects of moisture stress on groundnut and their subsequent impacts on yields. This paper reviews critically a PNUTGRO model for predicting moisture stress effects in rainfed groundnut and their ultimate impact on other biometric characteristics of the crop. Detailed account on different aspects relating to the effects of the specified model under study on various aspects of plant growth was studied. Major factors that were under elucidated in the present paper include moisture stress, different dates of sowing, effect of varieties and interaction effect of sowing dates and varieties and crop simulation modelling. The following is a detailed account on Validation of PNUTGRO model under different heads.

1. EFFECT OF MOISTURE STRESS

Moisture stress during crop growth has been reported to adversely influence water relations and thereby the translocation of photosynthates and other nutrients (Babu and Rao, 1983), photosynthesis (Bhagsari *et al.,* 1976), mineral nutrition, metabolism, growth and yield of groundnut (Suther and Patel, 1992). The work cited by Reddy (1988) suggests that the period of maximum sensitivity to drought occurs between 50-80 days after sowing. Balasubramanian and Yayock (1981) observed that the adverse effect of moisture deficit was more severe on pod and kernel yield than the production of Haulm and total dry matter.

1.1. Moisture sensitive stages

Though the crop is reputed as drought tolerant, the available information on most sensitive of different phenol phases to moisture is contradictory. (Billaz and Ochs.,1961; Martin and Cox., 1977; Rao *et al.,* 1985). Flowering and pegging stages were considered as most sensitive ones (Reddy, 1976 and Doorenbos and Pruitt 1979). Roy *et al.* (1988) observed that the period of late flowering and pod formation was most sensitive to moisture. They further reported that moisture stress during late flowering and pod formation and filling reduced yields more than stress in early, full flowering, late flowering and pod formation stages. Majority of reports reveal that pod development stage is the most sensitive to moisture (Meisner, 1991 and Ramachandrappa *et al.,* 1992) during which the demand of photosynthetic products for active sinks (pods) is higher.

1.1.1. Vegetative phase

Shinde and Pawar (1984) reported that after relief of the water stress, the crop recovered in its vegetative growth. Jayarami Reddy and Rao (1968) concluded that the vegetative growth and yield were reduced progressively as soil moisture was not available from field capacity to apparent drying stage and that the effect of water stress on shoot and root growth was not uniform.

Kulkarni *et al.* (1988) observed that water deficit reduced the pod yields of Spanish type groundnuts (cv. J-11 and GG-2) at all the stages (vegetative, flowering and pod development). They also made an observation that water deficits during vegetative stage had less effect on plant dry matter, number of pods per plant and pod yield.

Kulkarni *et al.* (1988) observed that water deficits reduced the pod yields of Spanish type groundnut (cv J-11 and GG-2) at all the stages (vegetative, flowering and pod development). They also made an observation that water deficits during vegetative stage had less effect on pod yield than water stress at later developmental stages. Jayarami Reddy and Rao (1968) in an experiment on TMV 2 groundnut found that there was considerable reduction in yield of pods and kernel weight due to stress at time of flowering. Gowda and Hegde (1986) revealed that there was a reduction of 4.7 per cent in pod yield when TMV 2 plants were stressed between 30-45 days after sowing groundnut. Dhopate *et al.* (1992) reported that water stress imposed during flowering and pegging stage produced the greatest reduction in groundnut (cv JL-24) pod yield followed by water stress at early pod stage, late pod stage than vegetative stage.

1.1.2. Reproductive phase

Dhopate *et al.* (1992) reported that water stress during reproductive stage caused yield reduction of 32.1 per cent in JL-24 and 46.7 per cent in TAG-24. Sansayavichai *et al.* (1989) reported from green house experiment in Thailand that water stress only during the early or late period of growth did not reduced pod yields substantially, but water stress between 40 and 80 DAS was most harmful to groundnuts (Patil and Gangavane, 1990). Water stress imposed during flowering and pegging stage produced the greatest reduction in groundnut (cv.JL.-24) pod yield followed by water stress at early pod stage, late pod stage and vegetative stages. The deviation is probably due to less duration of flowering in JL-24. (Naveen *et al.,*1992).

Lenka and Misra (1973) noted productive efficiency of flowers to vary with availability of water and the percentage of unproductive flowers that did not peg to form pods increased with delayed irrigation. Pot Pimpanit *et al.* (1988) conducted an experiment at the Kalasin Field Crops Experiment Station, Thailand to investigate effects of stopping irrigation at different crop growth stages on yield of groundnut cultivar Tainam 9, and reported that drought stress during pegging and early pod forming stages would cause greatest yield reduction. Sarma and Sivakumar (1989) reported the importance of drought stress imposed from flowering to start of seed growth for yield and quality. Shinde and Pawar, (1984) found that flowering, pegging and pod formation to pod maturity stages are sensitive to water stress and any stress during these stages affect the yield. Similar observations were also made by Subramanian *et al.* (1974).

1.1.3. Pod filling or pod development phase

Billaz and Ochs (1961) found variability in susceptibility to drought during different periods of growth and reported yield reduction due to drought, 46 per cent between 50-80 DAS, 27 per cent between 80-120 DAS, 21 per cent 10-30 days after it, and 18 per cent between 30-50 DAS.

1.2. Varietal response

High variation in response to drought stress was observed in different genotypes. Ramana Rao (1994) reported that in groundnut when moisture stress was imposed from 40-75 days after sowing CVICG 2738 showed greatest reduction by 44.9 per cent in total dry weight and CVICG 1697 showed the least reduction (8.9 per cent). The mechanism of drought resistance in groundnut genotypes was mainly due to early vigorous growth, high dry matter production and remobilization of dry matter from vegetative parts to reproductive parts (Wright and Rao, 1994).

Variety JL-24 showed more reduction in dry matter production due to water stress than many other varieties (Anjaneyulu, 1988). Koti *et al.* (1994) reported that genotype DH 3-30 was tolerant to drought compared with TMV-2 and had the least transpiration rate with maximum diffusive resistance when stress was imposed by withholding irrigation for 7 days during summer season. Duncan *et al.* (1978) found that most of the yield variations among cultivars was due to the difference in the partitioning of assimilates between vegetative and reproductive parts.

In general, sensitivity of a genotype to drought increases with yield potential. Variation also exists in the proportion of the dry matter that is stored in pods. Large variation in the response of genotypes to mid season droughts are due to recovery differences after drought is relieved (Williams *et al.,* 1986). Arjunan *et al.* (1997) observed more dry matter accumulation in VG-77 and JL-24 under normal irrigated conditions and that the dry matter accumulation in stress conditions was more in JLM-6, followed by VG-76 and VG-75.

1.3. Influence on crop phenology

1.3.1. Flowering

Under most of the situations, the start of flowering is not delayed by drought stress (Roy *et al.,* 1988, Boote and Ketring, 1990). Rate of flower production is reduced by drought stress during flowering but total number of flowers per plant are not affected due to increase in duration of flowering (Gowda and Hegde, 1986: Janamatti *et al.,* 1986: Meisner and Karnok, 1992). A significant burst in flowering on alleviation of stress is the unique feature in the pattern of flowering under moisture stress, particularly where it is imposed just prior to reproduction stage (Janamatti *et al.,* 1986).The first flush of flowers produced up to 45 days do not form pegs when stress is imposed during 30 to 45 days after sowing. Flowers produced after stress relief, compensated for the loss (Gowda and Hegde, 1986).

1.3.2.Pegging

Peg elongation, which is turgor dependent is delayed due to drought stress (Boote and Ketring, 1990). Soil water status of soil surface is critical to peg penetration. Pegs fail to penetrate effectively into hard and dry soil, especially in crusted soils. It is likely that within a few days of withholding water the soil surface becomes too dry for peg penetration. Skelton and Shear (1971) reported that adequate moisture in the root zone will keep pegs alive until moisture content in the pegging zone is sufficient to allow penetration and initiation of pod development.

Stress at flowering and pegging was more injurious to crop growth, followed by stress at early pod stage, since the soil water deficit in the root zone at these physiological stages restricted not only the penetration of pegs into hard soil but also the well developed roots to absorb required nutrients from the rhizosphere (Naveen *et al.,* 1992). Reddy *et al*., (1980) reported that moisture stress at flowering decreased the biomass more than at pegging (or) pod formation stages in groundnut crop. Ramesh Babu *et al.* (1984) reported that moisture stress during early pod development phase (55 to 67 days after sowing) affected maximum loss (34.7 per cent) in biomass accumulation, while peak flowering and pegging (36 and 48 DAS) was the least affected phenophase.

1.3.3 Pod formation

Once pegs are in the soil, adequate moisture and darkness are needed for pod development. Adequate moisture in the pod zone is critical for development of pegs into pods and adequate soil water in pod zone for the first 30 days of peg development. After 30 days of adequate moisture in the pod zone, pods can continue normal growth in dry soil if roots have adequate moisture (Wright, 1989). Bennet *et al.* (1990) reported that pod formation was affected by dry pod zone.

Pod development and kernel development are progressively inhibited by drought stress due to insufficient plant turgor and lack of assimilates, soil water in the pod zone (Boote and Ketring, 1990; Stirling and Black 1991). Naveen *et al*. (1992) found that stress at early pod formation results in lower seed number. Samsukumar (1991) reported the moisture stress at flowering, pod formation and pod maturity stages in groundnut reduced the 100 pod and 100 kernel weight. Nautiyal *et al.* (2002) reported that per cent reduction in total biomass under stress during flowering and pod development ranged between 6 and 25%, where reduction in total biomass was mainly due to the reduction in pod mass rather than the vegetative mass. Panda *et al.* (2003) reported that any soil water stress during critical stages of growth such as flowering, pegging, pod formation had serious effect on yield reduction.

Sexton *et al.* (1990) reported that dry pegging zone soil delayed pod seed development and seed growth rates by approximately 30%.Extending the pod growth period by 10 days marginally increased the pod yield in favourable year and did not influence during drought year. But haulm yield was significantly increased by extending pod growth period by 10 days (Reddy *et al.,* 2000). Reduction in soil water content has a dual effect on peg and pod development. On one hand root zone water content directly effect the plant water status, photosynthesis and hence the assimilate supply to the developing pegs to pods. On the other hand water content in pegging and podding depth (5cm) could effect reproductive growth independent of root zone moisture content (Wright and Rao, 1994). Reddy*,* 1988 reported that moisture stress at pegging and pod development stages drastically reduced the yield and yield attributes of groundnut both under rainfed and irrigated conditions.

Pod initiation was delayed due to water stress (Stirling and Black, 1991). Pod development and kernel development are progressively inhibited by drought stress due to insufficient plant turgor and lack of assimilates. These stages can also be delayed by lack of soil water in the pod zone (Boote and Ketring, 1990; Stirling and Black, 1991).

1.4. Influence on crop growth

1.4.1.Plant height

Plants grow taller under moisture stress free conditions because, the plant growth depends on cell division and cell expansion for which adequate water supply is essential (Simhachalam 1981 and Naidu 1992). The results of research reported by Jayarami Reddy and Rao (1968) indicated that vegetative growth and shoot growth of groundnut were progressively reduced due to stress and entirely depended upon the availability of soil water to the plants. Lenka and Misra (1973) also showed reduced plant height due to increase in stress.

Boote and Hammond (1981) reported that when there was moistures stress in early pegging and pod formation in groundnut there was reduced vegetative growth by reducing the rate of node formation and reducing elongation between nodes. Shinde and Pawar (1984) reported that moisture stress had significant effect on plant height in groundnut. Ike (1986) reported that in Spanish peanut variety when subjected to stress at early flowering there was great reduction in plant height compared to pod formation stage.

1.4.2. Leaf Area Index (LAI)

Soil water deficit was known to inhibit leaf expansion and stem elongation (Vivekanandan and Gunasena 1976). Cell division and cell expansion was inhibited by soil water deficit (Allen *et al.*, 1976). Samsukumar (1991) stated that stress at flowering, pod formation and pod maturity stages reduced the leaf area per plant in groundnut which was due to reduction in leaf number and leaf expansion. Water stress reduced the leaf area and number of leaves. (Ferreira *et al*.,1992). Matthews *et al*., (1988) reported that when drought became severe, functional radiation interception was reduced by folding of leaves, with little decrease in LAI.

Sammons *et al*., (1978) reported that leaf area was reduced due to moisture stress in soybean plants. Moisture stress during flower initiation phase and commencement of flowering (22 to 32 DAS) reduced canopy area by 47 per cent but attained normal (37.5 per cent recovery) ground cover over in next 40 days (Reddy *et al*.,1980) Boote and Hammond (1981) indicated that vegetative growth in groundnut was reduced due to drought during early pegging and pod formation.

Ramesh (1983) observed that LAI was reduced by the moisture stress in all the varieties. Patel and Vaishnav (1980) and Ramesh Babu *et al.* (1984) reported that moisture stress decreased leaf area index in groundnut. Similar findings were also made in JL-11 and GG-2 varieties by Golakiya and Patel (1992).

According to Sivakumar and Sarma (1986) plants exhibited continuous loss of crop cover (62.4 per cent) when stressed beyond the early pod development phase (55 days). Ravindra *et al.* (1990) stated that water stress during flowering and pod development was highly detrimental to leaf area development compared with stress during vegetative phase. Soil moisture stress at flowering and pod development phase decreased leaf area compared to stress at vegetative phase. (Nautiyal *et al*.,1991). Ramana Rao (1994) reported that in groundnut plants stressed from 40-75 DAS leaf area index values ranged from 1.4 to 3.3 among genotypes. Rao *et al*. (1993) reported that mean LAI of 3.5 maintained at 95 DAS got reduced to 3.0 by 113 DAS when drought was imposed between 83 and 113 DAS.

1.4.3. SPAD Chlorophyll meter reading (SCMR)

Drought stress influences the chlorophyll content in leaves of groundnut. (Reddy *et al.,* 1980) reported that higher chlorophyll content in some varieties of groundnut under stress was presumably due to less reduction in leaf water potential under stress. Mohan and Rao (1989) in a pot experiment on groundnut cv. JL-24 found that water stress reduced the total chlorophyll content. Patil and Patil (1993) are of the view that water stress decreased total chlorophyll content of groundnut. SPAD chlorophyll meter reading has been used to quantify chlorophyll concentration, leaf N and leaf photosynthesis in various crops. SPAD chlorolophyll meter reading is a useful tool for improved photosynthetic capacity under water deficit conditions. (Talwar *et al.,* 2009).

SPAD Chlorophyll meter readings not only respond to crop N-status, but can also be effected by crop water status and availability of other nutrients. (Schepers *et al*., 1996) SCMR is indication of leaf nitrogen status since specific leaf nitrogen determines the differences in WUE. It can be used to reflect the differences in WUE during moisture stress (Rao *et al*., 2001). Nigam *et al.* (2008) opined that SCMR observations can be recorded after 60 days of crop growth under moisture deficit conditions and observed a significant increase in SCMR during partial imposed mid-season drought. Increase in total chlorophyll content under moisture stress in some groundnut varieties has been reported by several workers (Reddy 1991; Ramesh Babu *et al*.,1984). The genotypes with lower specific leaf area had more photosynthetic machinery (Rao and Wright, 1994). SCMR is also correlated with pod yield in groundnut (Reddy *et al.,* 2004).

1.4.4. Dry matter accumulation

It is reported that a positive association is observed between drymatter accumulation and pod yield under moisture stress conditions (Arjunan *et al*., 1997). Drymatter accumulation of peanut was reduced due to stress (Slatyer, 1955). Stansell *et al.* (1979) reported decrease in drymatter production due to drought in groundnut. Rao and Singh (1985) reported that there was a close relationship between total drymatter production and transpiration with an average production of 3 mg drymatter g^{-1} water. They also noted that the amount of drymatter accumulated by a crop was closely related to the water transpired. Sivakumar and Sarma (1986) reported that there was no recovery of total drymatter in groundnut when stress was imposed at start of seed growth, while recovery of total drymatter was found when stress was imposed from emergence to start of flowering and emergence to start of pegging.

Venkateswar Rao *et al.* (1986) reported that the total phytomass production in groundnut was reduced a greater extent due to moisture stress at flowering compared with stress at pegging and pod formation stages, total dry weight in groundnut plants was reduced under stress conditions over stress free conditions (Srinivasan *et al*., 1987). Kulkarni *et al.* (1988) reported that plant biomass in groundnut was reduced to 50 per cent when stress was created after 30 and 45 days growth. They also reported that plant biomass was reduced in all the stress treatments. Moisture stress during flowering and pod development was highly detrimental to drymatter production compared with stress during vegetative phase. Growth recovery after the stress was better at the vegetative phase than at later growth phases (Ravindra *et al*., 1990). Samsukumar *et al.* (1991) reported that moisture stress during flowering in groundnut decreased total dry matter.

Moisture stress at flowering and pod development phase decreased dry matter accumulation compared to stress at vegetative stage (Nautiyal *et al*., 1991). Polaria *et al.* (1991) from the pot trials, reported that dry matter accumulation during 0-25, 25-75 and 75-105 DAS (vegetative, reproductive and pod development stages respectively) was 4.8, 43.8 and 51.4 per cent of the total dry matter accumulation respectively and that dry matter synthesis and accumulation of nutrients were interrelated. Murthy and Rao (2002) reported that drought reduced the drymatter accumulation to varying degrees depending on its duration and phenophases affected. Wright and Rao (1994) reported that due to water stress, more amount of photosynthates in the leaves and stem got locked up under stress as reduction in the soil water content affected the water status and less assimilates supply to pods. Drymatter partitioning among various plant parts varied significantly under water deficit (Nautiyal *et al*., 2002).

1.5 Pod Yield

Pod yield in groundnut is a function of many plant and environmental factors which are often interrelated. The stage at which moisture stress occurred plays a major role in the final yield of the crop. The final yield in the crop plants was the result of complementary functioning and relation of source and sink components (Sinha and Khanna Renu, 1975). Studies of Murty and Rao (1986) at Tirupati revealed that high vigour of seedlings in the initial stages of crop growth (up to pod filling), maintenance of high leaf area duration from pod filling to maturity and an efficient translocation of photosynthates are major physiological parameters responsible for high pod yield in early sowings.

Billaz and Ochs (1961) reported that the most susceptible period to drought in groundnut was 50 to 80 days causing 46 per cent yield reduction. Groundnut pod yield was severely reduced due to moisture stress at flowering than at other stages (Reddy *et al*., 1980). Yield was drastically reduced in groundnut due to moisture stress at 9 to 13 weeks after sowing coinciding with peg and pod development (Balasubramanian and Yayock, 1981). In groundnut moisture stress during emergence to peg initiation (ICRISAT Annual report, 1982 and 1983) is very critical. Pandey *et al.* (2001) reported that in groundnut the most sensitive phase to kernel yield was the seed filling phase. Rao and Singh (1985) reported that when stress was imposed at seed filling phase yield reduction of groundnut was greatest.

Venkaiah *et al.* (1983)reported that pod yield was not effected due to moisture stress at peak flowering, pod development and pod maturation stages in 17,24,30 July sown crops at Tirupati, compared to August sown crops in which moisture stress has coincided with vegetative growth, commencement of flowering, peg penetration and pod development stages of crop growth.

Ike (1986) reported that there was reduction in yield when peanut plants were stressed during early flowering and pod formation stages. According to Sivakumar and Sarma (1986) reduction in pod yields of groundnut were larger due to stress at seed growth to maturity followed by stress at start of flowering to start of seed growth.

Venkateswara Rao *et al.* (1986) reported that moisture stress at flowering severely reduced the pod yield by limiting the number of mature pods per unit area. Gangamma (1987) noted that both early and mid season stress decreased the productivity in groundnut the later being more detrimental. Srinivasan and Arjunan (1987) reported that mid season water stress especially at pod formation to maturity stage caused yield reduction to a greater extent. Patel and Golakiya (1988) reported that the reduction in yield due to stress at pod development stage was attributed to the decrease in seed size, whereas that during pod formation primarily to reduction in number of seed per pod.

Anjaneyulu (1988) found pod development stage to be most sensitive to moisture stress than early growth stage (Peak flowering). Pathak *et al.* (1988) found that the highest reduction in pod yield (62.7 per cent) occurred when watering was withheld during the period of pod development. Roy *et al.* (1988) reported that there was yield reduction to a large extent due to imposition of stress at late flowering, pod formation and pod filling stages. Pot Pimpanit (1988) reported that drought stress during pegging and early pod forming stages would cause greatest yield reduction. Parmar *et al.* (1989) observed from an experiment with groundnut that moisture stress during vegetative phase reduced pod yield by 16 per cent only whereas stress during late vegetative and flowering stages resulted in 19 and 36 per cent yield reduction in comparison to control.

Sansayavichai *et al.* (1989) reported that the moisture stress at pod development stage caused the greatest yield reduction. Yield reduction was greatest with stress imposed during the period between pegging and pod development and lowest with stress imposed from pod development to maturation (Jana *et al*., 1989).

Stirling *et al.* (1989) identified that pod sink activity was negligible in the late stressed stand but increased markedly when early season stress was released. Water stress only during the early period of growth did not reduce pod yields but water stress between 40 and 80 DAS was most harmful to groundnuts (Patil and Gangavane, 1990). Wright *et al.* (1991) are of the view that variation in pod yield among groundnut cultivars was large due to differences in harvest characteristics.

Yield was significantly reduced by stress treatments between 50-80 DAS (reproductive) and between 80-110 DAS (pod filling) (Meisner, 1991). Patel and Golakiya (1991) reported the greatest yield reduction when water stress was imposed during pod development stage. Terminal drought reduced pod yield primarily by decreasing the duration of pod development phase (Stirling and Black, 1991). Ramachandrappa *et al.* (1992) reported that the groundnut crop was more susceptible to moisture stress from 70 days to harvest (pod initiation to maturity) than at 40-70 DAS. Pod dry weights are significantly reduced by a 30 days water stress during pod development stage (Meisner and Karnok, 1992). Golakiya and Patel (1992) reported that water stress at flowering, pegging, pod development and pod maturation stages reduced the pod yields by 26.6, 44.7, 56.3 and 6.0 per cent, respectively in J-11 and 12.6, 15.0, 38.3 and 5.8 per cent, respectively in GAUG -10 groundnut cultivar.

1.5.1. Influence on Haulm yield

Shinde and Pawar (1984) reported significant reduction in haulm yield when water stress is given at seeding to flowering and pegging to pod formation stage compared to stress at pod formation to pod maturity.

1.5.2. Influence on yield attributes

Moisture stress can adversely influence yield attributes like number of mature pods per plant, 100-pod weight, 100- kernel weight, shelling percent and harvest index

1.5.2.1. Filled and ill-filled pods

Reddy *et al*. (1988) reported that moisture stress at flowering and pod formation stages reduced number of full pods due to suppression of flower production and inadequate pod filling.

Balasubramanian and Yayock (1981) reported that moisture stress at 9 to 13 weeks after sowing, coinciding with the period of peg and pod development lowered nitrogen uptake and increased the proportion of unfilled pods. Boote and Hammond (1981) observed a delay in pod maturity by 10 to 11 days and reduction in pods by 51 per cent, when the groundnut crop had experienced stress for a period of 42 days after sowing). Moisture stress at late pod development stage (76 to 88 days after sowing) lowered filled pod number significantly and thereby increasing unfilled pods (Ramesh Babu *et al*., 1984). Venkateswar Rao *et al.* (1986) reported that moisture stress reduced the total number of pods per square meter. In the groundnut variety J-11, moisture stress at flowering, pegging and pod formation stages reduced pod number by 44.85, 20.00 and 27.87 per cent, respectively over control. Patel and Golakiya (1988) reported that water stress at pegging to pod development reduced number of matured pods per plant.

Total number of pods as well as filled pods per plant were highest due to no soil moisture stress throughout the crop period (Reddy, 1988) Selvam *et al*. (1989) reported reduced number of filled pods per plant due to moisture stress. Reddy (1991) opined that moderate (or) severe stress at pod formation stage drastically reduced the total and filled pods per plant. Patel and Golakiya (1991) stated that water stress during pod development stage increased the percentage of ill filled pods and finally reduced pod yield.

1.5.2.2. Hundred -pod weight

Jayarami Reddy and Rao (1968) observed reduced pod weight in an experiment after imposing stress on groundnut variety TMV-2. Ramesh Babu *et al*. (1984) reported that 100 kernel weight was reduced significantly due to moisture stress at pod development stage in groundnut. Venkateswara Rao *et al*. (1986) reported that moisture stress at flowering in groundnut increased 100 kernel weight while at pegging reduced 100 kernel weight compared to control. Water deficits during kernel or seed development reduced the weight of kernel (Janamatti *et al.,* 1986). Srinivasan *et al.* (1987) reported that pod weight of groundnut decreased due to water stress. A reduction of 21.9 per cent in 100 seed weight was observed due to the stress imposed during flowering compared with control (Pathak *et al.,* 1988).

Nautiyal *et al.* (1991) subjected groundnut cultivars to soil moisture stress at different growth stages and reported that the moisture stress during early vegetative phase resulted in an increase in 100 seed weight. Hundred seed weight was reduced greatly due to the moisture stress at pod development stage (Patel and Golakiya, 1991). Pathak *et al.* (1988) reported that plants subjected to drought during flowering stage resulted biggest reduction (29 per cent) in 100 pod weight compared with control. Ramana Rao (1994) and Babitha (1996) stated that there was decrease in 100 kernel weight and 100 pod weight due to moisture stress in simulated drought treatments compared to adequately irrigated control.

1.5.2.3. Shelling percentage

Ramesh Babu *et al.* (1984) reported that moisture stress at pod development phase decreased shelling percent more significantly than at other stages. Patel and Golakiya (1988) reported that shelling percentage was decreased due to stress at pegging to pod development stage. Ramana Rao (1994) reported that shelling percentage was reduced comparatively compared to adequately irrigated treatment. Balasubramanian and Yayock (1981) observed moisture stress resulting in increased proportion of unfilled pods with reduced shelling percentage and the ratio of kernel to total dry matter.

1.5.2.4. Harvest Index

Pandey *et al.* (1984) reported that water stress affected the seed formation more than the total dry matter, yield and hence harvest index declined. Ramesh babu *et al*. (1984) reported that moisture stress at pod development period in groundnut decreased harvest index significantly. Venksateswara Rao *et al.* (1986) reported that moisture stress reduced harvest index in groundnut.

Samsukumar *et al.* (1991) reported that water stress at pod filling and pod maturity stages reduced harvest index of all genotypes significantly. Wright *et al*., (1991) reported significant differences in the pod yield of 4 groundnut cultivars viz., MC Cubbin, Red Spanish, Virginia and Q-18801 by 17 to 25 per cent and variation in pod yield was largely as a results of differences in harvest index.

2. EFFECT OF DATE OF SOWING

Optimum date of sowing of any crop is an important non-monitory factor influencing phenology, productivity and water use efficiency. Optimum date of sowing provides favourable environmental conditions for growth, development and yield of crops through optimum utilization of available natural resources. Sowing dates studies for groundnut have been performed in most of the groundnut growing countries throughout the world (Bell 1986; Mozingo *et al.*, 1991; Banterng *et al.*, 2003).
Reddy *et al.* (1990) while assessing the flowering and reproductive efficiency of 28 genotypes during *kharif* under normal (8th July) and late (26th July) sown conditions observed that under normal sowing two peak flowerings were recorded which had greater reproductive efficiently than that of the late sown conditions. Subbaiah *et al.* (1974) reported that plant height was not influenced by dates of sowing. Lenka and Misra (1973) from Junagadh reported that the plants were shorter in drought year than the normal year but less plant height was compensated by more number of branches. The plant height and number of branches plant^{-1} were significantly more in first date of sowing (15th June) and sharply declined with delay in sowing and the minimum values were found with 30th July sowings (Ghosh and Dasgupta, 1975). Murthy (1982) found maximum plant height and dry matter production of groundnut when sown in third week of July beyond which a reduction was observed. Kulandaiavelu and Morachan (1983), from a field trial on sandy loam soil at Coimbatore with the groundnut cultivar Pol-2 during monsoon season, reported higher vegetative growth due to higher relative humidity.

Reddy *et al.* (1984) reported that July first fortnight sowings recorded higher pod yield due to maximum number of filled pods per plant which can be attributed to optimum available soil moisture at the time of pegging and pod development and escape of dry spells at pod development stage.The biomass production of groundnut was drastically reduced when the crop was sown in the month of August compared to May and June sowings at Florida (Auma 1985). The pod development was less affected by sowing dates than the vegetative yield (Bell 1986). Dhoble *et al.* (1987) also reported the advantage of advanced sowing of groundnut on 15th June during *kharif* season.

Freire (1987) observed the superiority of first date of sowing of groundnut i.e., 17th June in respect of total dry matter production. However, reduction in plant height and leaf number in groundnut with delayed sowings was noted during *kharif* season. Donga *et al.* (1990) from a dates of sowing trial conducted at Junagadh in *kharif* season with sowings taken up on 20th May, 4th June and 11th June noted that the plant height (30.6 cm) and number of branches (9.0) palnt^{-1} were more in 20th May sown crop than the 4th and 11th June sown crops. Nur and Gasim (1978) while studying the effect of sowing dates on LAI of groundnut observed higher values from early sown crop (1st June). Duncan *et al.* (1978) also observed maximum LAI (7.0) from early sown groundnut. Murthy and Rao (1986) found high Dry matter in July sown crop on 17th and 24th July as compared to August sown crop. Kevin and Bergmark (1987) while testing five planting dates of 14th and 29th April, 18th May, and 15th June, using Florunner peanut cultivar observed that there was significant difference in leaf index due to different planting dates. Gopalkrishna *et al.* (1967) found that first fortnight of July was the best time for sowing bunch groundnut under rain fed conditions in Tamilnadu.

According to Saini *et al.* (1970), the optimum time of sowing for groundnut was considered to be 30th June for maximum kernel weight and yield. Significantly more volume weight of groundnut pod (325 g p1^{-1}) was recorded by crop sown on 22nd July than 18th August sown crop (Subbaiah *et al.,* 1974). Ghosh and Dasgupta (1975) noted that the optimum period for sowing groundnut was from 15th to 30th June which gave higher pod weight plant^{-1} and yield hectare^{-1}, delayed sowings reduced the pod yields due to sharp decrease in temperature, rainfall and humidity.

Nur and Gasim (1978) found higher unshelled nut yield due to early sowing done on 1st June and very low yields with late sowing taken up on 21st August and 5th September. Similar observation was also made by Lewin *et al.* (1979). Significant differences between dates of sowing were observed in respect of shelling percent which was in the range of 66-80 in *Kharif* and 66-73 in *Rabi* where as 100 pod weight was in the range of 74 to 107g in *Kharif* while in *Rabi* it was 65 to 110g (Rao, 1982). Gupta *et al.* (1983) from Haryana in a field trial with groundnut cultivar MH-2 (Bunch type) and M-145 (semi spreading) sown on four different dates from 26th June to 25th July reported that the maturity period and 100 kernel weight of both the cultivars decreased with the delay in sowings. Kulandaiavelu and Morachan (1983) reported that sowing of groundnut CV POL-2 taken on sandy loam soils during monsoon and summer season resulted in increased pod yield from 2.37 and 2.33 t. ha^{-1} to 2.93 and 3.0 t ha^{-1} during both the seasons, respectively.

Reddy *et al.* (1984) noted much reduction in pod yields of groundnut due to delayed sowings (15th July, 30th July to August) due to reduction in number of pods $plant^{-1}$, 100 kernel weight and shelling percentage and also observed that the difference in pod yield of first and second fortnight sowings in the month of July was not much as compared to late sowing in August. Usharani *et al.* (1985) reported that sowing of groundnut during *Kharif* season under rainfed conditions resulted in 71.50 g of 100 pod weight, 29.32g of 100 kernel weight, 9.25 filled pods $plant^{-1}$, 1218 kg ha^{-1} pod yield and 71.25% shelling percentage. Chhonkar and Arvind Kumar (1985) reported that 100 kernel weight and pod number were significantly higher in earlier plantings (10th and 25th June) over late planting (10th and 25th July). Singh *et al.* (1986) in an experiment conducted with four dates of sowing viz 20th and 22nd June, and 10th and 30th July with groundnut cultivar M-13 observed significantly more pod (82%) and haulms yield (26%) from June sown crop than July sown crops and also pointed that sowing time had no effect on mean pod and kernel weight of crop sown between June to July under rainfed conditions. Patel *et al.* (1986) observed more number of filled pods $plant^{-1}$ (11.2) and test weight (30.8g) with the earlier sowings i.e., 21st June and 5th July and also decreased pod number with delayed sowing. Sowing of three groundnut cultivars, on 15th and 25th June and 5th July resulted in an average pod yield of 1.37, 1.32 and 1.12 tonnes ha^{-1}, respectively and yields were 1.51 t ha^{-1} in crops harvested at 130 days after sowing compared with 0.95-1.49 t ha^{-1} in those harvested at 100 to 120 and 140 days after sowing (Dhillon and Dhaliwal, 1987).

Basu and Reddy (1989) found that the advancement of sowing of groundnut after onset of monsoon to first week of June with one presuming irrigation in Gujarat state increased yield by 46 per cent whereas in Punjab state a fortnight advancement of sowing date (1st week of July) gave 19 per cent higher yield and concluded that pre monsoon sowing was more advantage wherever irrigation facilities exist. Shelke *et al.* (1989) conducted a 3 years field trial on a clay soil with groundnut cultivars ICGS-11, UF 70-130 and K-4-11 sown on 1st, 15th 30 May and 14th June and observed that sowings from 1st to 30th May in 1985 registered dry pod yield of 1.72-1.83 and 1.59-1.79 t ha^{-1}, respectively and the haulms yield of 3.30-5.65 t ha^{-1} and 3.68-4.05 ha^{-1}. Experiment conducted around the year at Regional Agricultural Research Station, Tirupati on sandy loam soils to study the effect of time of sowing on yield of groundnut revealed that highest pod yield was with the crop sown on July. In summer groundnut haulm yield showed a study in crease at the cost of pod yield resulting poor harvesting index even though the total dry matter was maintained. The decrease in pod yield was due to decrease in pod number per plant, average pod weight and average kernel weight. Munda and Patel (1998) conducted two filed trials with JL-24 on terrace land at Barapaani farm, Meghalaya and recorded a significant difference in pod yield of groundnut sown in the middle of May (2.05 t ha^{-1}) and June (2.03 t ha^{-1}) and noted that sowings on 15th July reduced the pod yield (1.73 t ha^{-1}) significantly.

Sudhakar Reddy (1992) reported that among different seasons Rabi groundnut gave an increase yield of 156 per cent in 1989 and 134.6 per cent in 1990 over summer seasons. Lowest pod yield was with summer groundnut. In both the years the harvest index was high (39.9 and 48.02) in Rabi than *Kharif* (32.71 and 37.29) and summer (24.53 and 18.97).

Donga *et al*. (1990) conducted a field experiment at Junagadh, during *Kharif* with three dates of sowings viz., 28th May, 4th June and 11th June with groundnut cultivar "Gaug-10" spreading variety and found that sowing on 28th May give more number of pods palnt^{-1}, shelling percentage, dry pod weight plant^{-1}, pod yield (16.20 q ha^{-1}) and haulm yield than the 4th and 11th June sowings under study. The pod development was less affected by sowing dates than the vegetative yield (Bell 1986). Dhoble *et al.* (1987) also reported the advantage of advance sowing of groundnut on 15th June in *kharif* season. Padma *et al.* (1991) at Hyderabad observed that the pod yield of *kharif* groundnut decreased from 3530 kg ha^{-1} with early date (19th June) of sowing to 2300 kg ha^{-1} with delay in sowing. She also observed that moisture stress was pronounced on number of filled pods (7% reduction) and more pronounced on 100- kernel weight (32% reduction), Shelling (20% reduction) and pod yield (30% reduction) under delayed sowings. Patil *et al.* (1993) Raichur (Karnataka) studied three groundnut cv. KRG 1, CGC 4018 and JL 24 with four sowing dates *viz*:, 28th June, 8th, 18th, 28th July 1985 and 6th,16th,26th July and 5th August 1986 and observed that the yields were decreased due to delay in sowing dates .Krista Rao (1996) revealed that among 3 dates of sowing in Ananthapur region, considering the period of assured rainfall and daily mean minimum temperature the optimum time for sowing of groundnut was found between 28th and 29th standard weeks (9-22 July) and resulted in higher yield. He also reported that early sown groundnut exposed to drought for initial 100 days except for a short period of 10 days between 50 and 60 DAS, coincided with seed initiation. As there was no drought during last 35 days, and due to continuous rains after 100 DAS, the crop duration was extended to 135 days. Patel *et al*. (1986) reported that significantly higher filled pods, shelling percentage and pod yield with normal date of sowing.

Reddy *et al.* (2000) studied the effect of sowing date on groundnut cv. JL24 and TMV- 2 at Bangalore (Karnataka). The experiment was conducted with six dates of sowing at an interval of 15 days from 28th May to 26th August during the *kharif* season. They recorded highest pod yield (2780 $^{kg\ ha-1}$), plant height (44.7 cm), number of branches per plant (6.6), leaf area index (LAI) (5.6), dry weight per plant (44g) in 28th May sowing. The above parameters were decreased with further delay in sowing. High flower production was extended up to five weeks in crops sown during May and June. In both the varieties, time to first flower opening was less in early sown crops compared to late sown crops. The rate of flower initiation was higher in early sown crops, which recorded distinct peaks of flowering periods. Pod yield per hectare was significantly correlated with number of flowers and pegs per plant, number of filled pods per plant, shelling percentage and 100-kernel weight.
Suresh Babu (2006) at Junagadh revealed that pod yield and haulm yields of groundnut (cv. GG 11, GG 13 and GG 20) were significantly affected by the dates of sowing and significantly highest yield (1387 kg ha^{-1}) was recorded when the crop was sown at the normal onset of monsoon followed by late monsoon, early monsoon and pre monsoon sowings. Caliskan *et al* (2008) reported that among five dates of sowing (15th April, 1st May, 15th May, 1st June and 15th June) 15th May and 1st June sown crops resulted higher yields due to suitable temperature regimes during vegetative and reproductive growth stages and more solar radiation and sunlight during entire growing period recorded higher yields. They observed lengthening of growth period to 140 to 160 days had positive effect on yield at early sowings.

Varaprasad *et al.* (2000) reported that high soil temperature significantly reduced flower production, proportion of pegs forming pods and 100 kernal weight. Patel *et al.* (1986) reported that significantly higher filled pods, shelling percentage and pod yield with normal date of sowing. Virendar *et al.* (2008) found the significant influence of sowing date on 100 kernel weight, shelling percentage and yield. They observed that in May sown crop under high temperatures significantly reduced dry matter production, partitioning of dry matter to pods and pod yield.

3. EFFECT OF VARIETIES

Spanish cultivars were consistently most responsive to sowing date and cultivar differences. In variety, Chico the growth rate of yield components was very quick compared to late maturing Spanish cultivars (Bell *et al.,* 1991).

He also reported that cultivar differences existed with in same group in peg and pod development and yield components.Cultivars are reported to respond differently to water stress at flowering stage. Soil water deficits during flowering phase have been reported to cause greater yield reduction than later stress in a short season cultivar (Billaz and Ochs 1961), however for a long duration cultivar, the damage caused by late season drought has been reported to be more than drought occurring at earlier stages of crop growth (Stansell *et al.,*1979).

Dhopate *et al.* (1992) reported that water stress during reproductive stage caused yield reduction of 32.1 per cent in JL-24 and 46.7 per cent in TAG-24. Padma *et al.* (1991) at Hyderabad reported that K-3 and M-13 performed better under rainfed conditions than JL-24 and K-3 where the latter 2 varieties performance is better than delayed sowings due to lesser duration which allows the crop to escape low temperatures during pod filling phase. Rao *et al.* (1985) observed that Robut 33-1 to initiate pod that it could subsequently fill and the prolonged water deficit had affected the initiation of pods.

Patra *et al.* (1981) reported that ICGV-8614, ICGS-44,JL-24 and TG-24 varieties have recorded higher plant height and dry matter accumulation due to difference in phonologies and pattern of assimilate partitioning between vegetative and reproductive components. They also reported varietal variation in yield components and yield of groundnut with ICGS-44 and JL-24 record the highest no of pods per plant and number of kernels per pod.

Rao and Singh (1985) conducted a field study with TG-14 Spanish groundnut type sown on 12^{th} July 1981 and obtained 7.9 q. ha^{-1} of pod yield and 2.45 q ha^{-1} of oil yield under rainfed conditions at IARI, New Delhi. Wright *et al.* (1991) reported that significant differences in the pod yield of four groundnut cultivars viz., MC Cubbin, Red Spanish, Virginia and Q-18801 by 17 to 25 per cent and variation in pod yield was largely as a results of differences in harvest index.

Auma and Gardner (1984) also reported that sowing in the month of August resulted in drastic reduction of pod yield while May and June sowings gave comparable yields in case of "Flourunner" where as in "Pronto" May sowing gave lower yields than June sowings.

4. INTERACTION EFFECT OF SOWING DATE AND VARIETIES

Reddy *et al.* (1984) found significant effect between dates and varieties for pod yields but all other yield attributing characters like filled pods, 100 pod weight, 100 kernel weight were found not significant.

Halem *et al.* (1988) from their field experiment with groundnut cultivar Giza-4 sown on 10^{th}. 30^{th} April and 20^{th} May on sandy soil observed decreased growth and yield due to delayed sowings.

The results of a three years field trial with ICGS-1, UF-70-103 and K-4-11 on clay soils of Parbhani conducted with different dates of sowing reported that 15 and 30^{th} May obtained maximum plant height and number of branches $plant^{-1}$ were recorded at 15^{th} May sown crop (Shelke *et al*.,1989).

Krista Rao, (1996) found that the two weeks period between 9-22 July found to be the optimum time for sowing TMV -2 variety in Ananthapur, Andhra Pradesh. The performance of Robut 33-1 cultivar was found better than TMV-2 under different kinds of drought at different dates of sowing during *Kharif*. Karunakar *et al.,*(2002) found higher dry pod yield in JL-24 when sown in last week of June at Akola and progressive reduction with delay in sowing. Warmer temperature and higher relative humidity during crop growth period favorably influenced the yield and yield contributing characters. Vasanthi *et al*. (2003) reported that the variety Narayani produced an average yield of 1675 $^{kg\ ha^{-1}}$ during rainy season which was higher by 13 per cent than JL-24. They found that the variety is tolerant to mid season drought and not suitable to high rainfall areas since it produces excessive vegetative growth under such situations.

Sahu *et al.* (2004) confirmed that late sowing beyond 27th standard week gave poor yields whereas under early (24th week) or timely sowing (25th and 26th weeks) i.e. June second fortnight, the yields were either higher or lower depending on the duration and distribution of the rainfall. By studying twenty three years of rainfall at Gujarat, They concluded that when the rainfall during flowering was very high, the yields were low. Virendar *et al.* (2008) found the significant influence of sowing date on 100-pod weight, shelling percentage and yield. They found that the crop sown under high temperatures significantly reduced dry matter production, partitioning of dry matter to pods and pod yield.

Early sowing of cultivar "Flornunner" had higher leaf area index than the "Pronto" sown late in the season (Auma, 1985). Kaul (1993) reported that SG-84, a Spanish bunch variety, when sown on 23rd April at Punjab conditions reduced 17 days in emergence, 16 days in the vegetative growth stage and an increase of 34 days in the reproductive phase compared to its normal 23rd Feb sowing.

Patel *et al.* (1986) reported that M-13 groundnut sown with the onset of monsoon recorded significantly higher pod yield when compared to GAU-10. Prakash (1984) observed significant difference between Robut 33-1 and TMV-2 cultivars with maximum leaf biomass accumulation occurred at 60 DAS in case of TMV-2 and 75 DAS in Robut 33-1.According to Chhonkar and Arvind kumar, (1985) there was no significant effect between dates and varieties for pod yield and other yield attributing characters. Patel *et al.* (1986) found significant interaction between dates and varieties for pod yield but not for other characters. Kaul (1993) also found significant interaction effect between different dates and cultivars with respect to pod yield, filled pods, total pods, where as they observed non significance for 100 pod weight, shelling percentage, haulm yield and harvest index.

A field trial at Gaine Seclillc, Florida, 29^0, 38^0N on an arredonda fine sand with "Pronto" "Florunner" groundnut varieties sown on 15th, 18th May, 25th, 21st June, 2nd and 3rd August sowing dates indicated that the plant height was highest in May sowings followed by June and August sowing dates (Gardner and Auma, 1989).

Padma *et al.* (1991) also reported that the interaction effect due to dates and varieties was found significant for filled pods, 100-pod weight, 100 kernel weight, harvest index and final pod yield but not for shelling percentage. Mukesh Kumar ujinwal (2008) reported that the interaction effect between dates and varieties was found not significant for plant height, number of matured pods, pod yield, haulm yield, 100 pod weight, and shelling percentage.

Caliskan *et al.* (2008) reported that sowing dates, cultivars significantly affected the yield and yield components, viz ; number of pods per plant, shelling percentage, 100 seed weight, and biomass and pod yield were significantly affected by dates of sowing and cultivars. Chandrika *et al.* (2008) reported that among the three dates of sowing (June 2nd fortnight, July 1st and 2nd fortnights) groundnut crop when sown during 1st fortnight of June recorded higher yield and yield attributes. She also reported that the cultivars did not exert any significant influence on yield and yield attributes of groundnut.

Virendar *et al.* (2008) studied the influence of sowing dates on the productivity of different types of varieties and found that the interaction effect of sowing date and genotype was found significant at all stages for dry matter production.

Sowing of groundnut on 1st June had marked effect on pod yield with all the varieties *viz.*, (TMV-7, TMV-9J, JL-24, CO-1 and MMV-12) and sowing beyond this time resulted in decline in pod yield (Swamy and Ramanathan 1988). Kulkarni *et al.* (1988) recorded average shelling percentage of 71.2 per cent and pod yield of 255.33 g m^{-2} with groundnut cultivar JL-24 grown during *Kharif* season at National Research Centre, Junagadh. Maliwal and Tank (1988) conducted a field experiment at Junagadh with groundnut cultivar "Gaug-10" and reported that 1st July and 19th June sowing gave an average haulms yield of 23.40 q ha^{-1}.

In Soybean different dates of sowing (30 May, 24 June and 30 June) with four cultivars (SH 40, DS 9814, PK 416 and PS 1042) had different effect on phenological stages, dry matter production and seed yield (Boote *et al.,* 2003).

5. CROP SIMULATION MODELING

Process based crop simulation models are increasingly being used in agricultural research, crop management recommendations and policy formulation. Crop growth models such as grain legume model CROPGRO (Hoogenboom *et al*., 1994; Boote *et al*., 1998) simulate crop growth, development and yield for specific cultivars based on the effects of weather, soil characterization and crop management practices (Jones *et al*., 2003; Miao *et al*., 2006). These models have been evaluated and applied in agriculture for diverse research areas (Tsuji *et al*., 1994). Examples are estimating the sensitivity of crop production to climate change (Hoogenboom 2000; Mall *et al*., 2004) evaluating cultivar performances (Boote *et al*., 2003; Baterng *et al*., 2006), studying the nature of genotype x environment interactions (Chapman *et al*., 2000, Phakanon *et al*., 2008) and forecasting crop yield before harvest (Bannayan *et al*., 2003, Nain *et al*., 2004 Mercau *et al*., 2007 and Soler *et al*., 2007).

Boote *et al.* (1986) studied the response to various management factors of groundnut crop using growth models. The crop growth simulation models, which had been developed, had shown to a considerable potential pattern for yield forecasting. Young and Rainey (1986) developed a growth simulation model 'PEANUT' at North California State University for Florigiant peanuts grown over a period from 1974 to 1982. This model with sub-routines for simulating soil moisture levels and root growth allowed the user to simulate the effects of management decisions such as irrigation dates and amounts.

Rainey *et al.* (1987) presented the 'PEANUT-PC' a microcomputer model, designed to allow the user to select either 'PEANUT' model or 'PNUTGRO' model to simulate peanut growth. Boote *et al.* (1988) reported that the research applications of 'PNUTGRO' model included simulating the effects of maturity traits, partitioning of dry matter, pod growth, pest effects and crop growth processes to predict the yield. Management applications were also included for prediction of growth and yield responses to planting dates, row spacing and irrigation.

Chen and Houng (1989) revealed that the 'PNUTGRO' program can simulate the changes in soil moisture content during the growing season, and can be used to predict the irrigation needs. Boote *et al.* (1991) in a review article on modeling growth and yield of groundnut described improvements to the 'PNUTGRO' model including addition of a hedgerow photosynthesis sub model to improve response to row spacing, seed rate and growth habit. They also included the Penman equation to incorporate vapour pressure deficit and wind speed to estimate evapotranspiration for arid regions; modification of functions for prediction of crop development; and modification of the effects of stress environments such as high temperature and vapour pressure deficit effect on partitioning.

Hoogenboom *et al.* (1999) reported that CROPGRO is a generic physiological process oriented legume crop model which simulate vegetative and reproductive growth and yield for three grain legume crops *viz.,* soybean (SOYAGRO), peanut (PNUTGRO), and dry bean (BEANGRO).

5.1. Genetic Co- efficients

Genetic co-efficients are the mathematical constructs designed to mimic the phenotypic outcome of genes under different environments to influence life cycle including fractional allocation to different phases, photosynthetic, vegetative, rooting, reproductive processes (Boote et al.,2003). The cultivar coefficients or cultivar specific traits are crop characters that define the development, vegetative growth and reproductive growth of individual genotypes (Boote et al., 2003). Many crop models including CROPGRO-Peanut (Boote et al.,1998; Jones et al.,2003) used the concept of cultivar coefficients to characterize genotypes (or) cultivar (Boote et al., 2003). Duncan et al. (1978) used crop simulation modeling to evaluate genetic traits which influenced yield potential of groundnut.

White and Hoogenboom (1996) successfully demonstrated the ability of CROPGRO cultivar coefficients to mimic specific combination of four genes affecting the photoperiod sensitivity. The model explained 75 per cent of the variation in days to first flower and 68 per cent variation in days to maturity of common bean grown in 14 environments.

Chapman *et al.* (2000) opined that crop modeling has the potential for evaluating the benefits of given traits in different weather conditions, particularly to find the best cultivar choice over long –term weather for a given locality.
Anothai *et al.* (2008) evaluated seventeen peanut lines with GENCALC program which is part of DSSAT and concluded that all the 17 peanut lines were in good agreement with the corresponding observed phenological traits with mean RMSE of 1.6 days for R_1 and 2.4 days for R_8 and RMSE of 0.64 t ha^{-1} for final pod yield. Suriharan *et al.* (2008) derived cultivar coefficients of 17 peanut lines varying in yield level and maturity duration from data of detailed field experiments in two growing seasons provided simulated values of various development and growth parameters that were in good agreement with their corresponding observed values.

5.2. Validation

Steele and Young (1982) used a basic language version of 'PEANUT' growth simulation model. The correlation coefficient (r = 0.49) for simulated and actual yields for two harvest dates over ten years study obtained as an index of model performance. The simulated yields were within 20 % of the observed yields. Boote *et al.* (1987) validated 'PNUTGRO' v.1.0 a groundnut crop growth simulation model, developed by adapting the 'SOYAGRO' v.5.3 crop growth simulation model. They appropriately changed crop and varietal input parameters, fit to dry matter accumulation in pods and in total crop, appeared to be acceptable for two years and parameters for photosynthesis and partitioning were best validated. Parameters such as pod initiation, pod maturation and change in shelling percentage were suitably simulated.
Grosz *et al.* (1988) compared the performance of 'PNUTMOD' a simpler model and 'PEANUT' a more complex model which were calibrated to simulate the growth and yield of spanish peanuts under Oklahoma conditions, and observed that both the models performed well in simulating pod yields. In PNUTGRO model the fit to dry matter accumulation in pods and in total crop appeared to be acceptable and parameters for photosynthesis and partitioning were validated. After calibration of Robut 33-1 the PNUTGRO model was able to account for 71 per cent of the pod yield variation. At Ludhiana the model over-estimated pod yield even though it was correct in biomass accumulation. Nokes and Young (1991) showed that the 'PNUTGRO' model efficiently simulated the groundnut growth and development. They perfectly predicted defoliation of leaf, which was in good agreement with the observed data. Singh *et al.* (1994) ICRISAT, Hyderabad in a collaborative research project at Anand, Anantapur, Bhavanisagar, Hissar and Ludhiana modified the functions for prediction of crop development in 'PNUTGRO' model and simulated the effect of stress environments such as high temperature and vapour pressure deficit on partitioning of photosynthates. They have used this model for predicting phenological development, light interception, canopy growth, dry matter production and yield of groundnut as influenced by row spacing and plant population. The model predicted the progression of vegetative stages accurately in the early stages than later stages during 1990 rainy season which is attributed to early prediction of pod and seed growth. They reported good agreement between simulated and observed pod yield at four locations and also observed over estimations of pod yields by the model by 30 per cent during post rainy season.
White (1995) when evaluated BEANGRO model under tropical conditions the model underestimated harvest index due to greater bias for canopy dry weight than for seed weight. The model also underestimated days to maturity due to the reason that water deficit usually accelerates maturation, while favourable growth conditions delay maturity. The simulation of seed yield under known conditions of water deficit showed good agreement with observed data. They concluded that the under estimation of harvest index could be due to greater bias for canopy dry weight than for seed weight and under estimation of days to maturity could be due to the reason that water deficit usually accelerate maturity while favourable growth conditions delay maturity. Baston *et al.* (2001) reported that in CROPGRO simulation for cowpea crop the deviation between the simulated and observed values was high which was attributed to the fall in reproductive growth rate as well as translocation of photosynthates under high temperatures.

Hoogenboom (2000) observed a significant impact of weather and management factors on crop growth and development by the crop simulation models. He suggested that the models can be used to make appropriate management decisions and to provide farmers with alternate options for their farming system.Singh *et al.* (1994) reported that the PNUTGRO model simulated flowering to pod initiation with $\pm$ 5 days at ICRISAT, Hyderabad, whereas at Anantapur, the model predicted advancement of flowering by 15 days during rainy season of 1989. The model also simulated the physiological maturity at 120 days where the observed days to physiological maturity were 133 to 134 days.
Kaur and Hundal (1999) at Ludhiana studied 'PNUTGRO' model to predict groundnut growth and yield in Punjab. They revealed that the simulated phenologic events showed deviations of only -3 to +3 days for flowering, -3 to +2 days for pegging and -4 to +2 days for physiological maturity of the crop. The model estimated the LAI to be within 95–108 per cent (mean 101·5%) and shelling percentage to be within 93–108 per cent (mean 100·5%) of the actual values. The model predicted the pod yields from 89 to 111 per cent (mean 100%) and seed yield from 90 to 110 per cent (mean 100%) of the observed yields. Gadgil *et al.* (1999) used the 'PNUTGRO' model, to study the growth and development of groundnut at Agricultural Research Station, Anantapur. Heuristic model for pests/diseases was also used in conjunction with the 'PNUTGRO' model. The simulated variation for the period 1970-90 was found to be close to the observed district yield. The model under estimated the tolerance to moisture stress in the years characterized by deficit rainfall. This model could be used for understanding the response of the groundnut yield to climate variability and in decision support systems for the region. Mukhesh (2008) reported that the PNUTGRO model under predicted days to pod and seed growth and reasonable agreement between the simulated and observed values for days to anthesis, harvest index, shelling percentage and pod yield. Rao *et al.* (2000) suggested the optimum sowing window for rainfed groundnut in the Anantapur (AP) region using the model 'PNUTGRO' which was validated for the region. The variation in the model yield had shown that the broad sowing window of 22nd June –17th August presently used by the farmers minimizes the risk of failure. Within this broad window, sowing after mid July enhanced the yields considerably.

Pandey *et al.* (2001) validated the 'CROPGRO' model for groundnut under *kharif* seasons of 1997-2000 at Anand (Gujarat). The results revealed that the observed phenological dates were closely associated with the simulated ones. The decrease in pod yield with delayed sowing as observed in experiment was well depicted by the model. However, under high rainfall situations, the model simulated higher pod and haulm yield for both the varieties and these were not in agreement with the observed yields. Thus the model could be used to predict the yield accurately under normal rainfall and different management conditions. Gilbert *et al.* (2002) also opined that the model simulations were 9 per cent above observed yields when there is low disease pressure and the model simulation was 24 to 44 per cent above observed yield when there is high level of disease pressure. Hence CROPGRO-PEANUT did not correctly predicted relative yield decreases due to water stress.
Mavromatis *et al.* (2002) reported that CROPGRO-PEANUT when calibrated with seven on station trails and validated with twenty one on farm trails in North Florida, yield was under predicted three times (Range -20 to -5%) and over predicted four out of seven times (range +1 to +23%) with an average absolute error of 13 per cent .Bhatia *et al.* (2005) estimated that long-term rainfed potential yield and water balance of groundnut for twenty locations representing different regions across the India using 'CROPGRO' model, the average simulated rainfed potential yield across major production zones, AEZs and states of India ranged from 2320 to 3170, 790 to 3750 and 1200 to 3490 kg ha^{-1} , respectively. They have also estimated the mean simulated yield of Junagadh as 3010 kg ha^{-1}, district average yield as 1870 kg ha^{-1} with the yield gap of 1140 kg hectares.
Suresh Babu (2006) observed Leaf Area Index (LAI) in close agreement at early stages of crop growth only, but afterwards the simulated values under estimated whereas biomass and haulm yields of rainfed groundnut were over estimated in early two sowing times and under estimated under later two sowing times. The model prediction of harvest index was also over estimated.

According to Suriharan *et al.* (2008) CROPGRO-Peanut model slightly underestimated R1 (Planting-First flowering), R3 (Planting-First pod), and R5 (Planting-First seed) stages for the dry season and slightly over estimated for the rainy season. Mukhesh (2008) found that dry matter production, LAI and hulm yield was over predicted by the model and days to first seed was under predicted. Simulation performance of the model in respect of pod yield was found good with an acceptable level.

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