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Physiological basis for realizing yield potentials in Groundnut

A. L. Singh
Directorate of Groundnut Research, P.B. 5, Junagadh 362 001, Gujarat, India
Email: alsingh@nrcg.res.in and alsingh_ad1@sancharnet.in

1. Introduction

The groundnut (*Arachis hypogaea* L) is an important food legume of tropical and subtropical areas ranking 13th among the principal economic crops of the world and grown in about 120 countries in different agro-climatic regions right from high rainfall areas to arid region between latitudes 40ºS and 40ºN. Though South America is the native of *Arachis*, through colonial sea board by Spanish and Portuguese it was disseminated to other countries and now being cultivated on about 25 million hectare (ha) of land mainly in Asian (13.35 mha), African (10.05 m ha) and American (1.16 m ha) countries. However, on large scale it is mainly grown in India, China, Nigeria, USA, Myanmar, Indonesia, Sudan, Senegal, Argentina and Vietnam. As on date the groundnut productivity is less than 1000 kg ha^{-1} in more than 50% of the groundnut growing countries in the world, between 1000-2000 kg ha^{-1} in 35-40% of the countries and only 10-15 % of the countries had the productivity above 2000 kg ha^{-1} (FAO, 2008). There is wide range of groundnut productivity varying from about 500 kg ha^{-1} (poor) in Angola and Mozambique (extremely low 300-333 kg ha^{-1}), Namibia, Niger, Cameroon, Uruguay and Zimbabwe, about 3000 kg ha^{-1} (high) in China, Egypt, Syrian Arab Republic, about 4000 in USA, Malaysia, Saudi Arabia, Palestine and Nicaragua, as much as 6400 kg ha^{-1} (very high) in Israel and extremely high (more than 12000 kg ha^{-1}) in Cyprus (FAO, 2008). However, the world average yield is around 1500 kg ha^{-1} and about 70% of the world groundnut production occurs in the semi-arid to arid tropics where the average yield is still around 1000 kg ha^{-1}.

The production of groundnut corresponds to the area under the crop. India has a cultivation history of growing groundnut around 250 years and now it is grown on an area of about 7 million hectare, producing about 9 million tonne (mt) of pod and is the most important oilseed crop of the country. Presently, India has the largest groundnut area (28% of the world) and till 1992 was the chief-producer of groundnut in the world. But, from 1993 onwards, due to high productivity and better management practices China (37% of the world Production) surpassed India (20 %) and became the highest producer of groundnut. In India, though the average yield is around 1400 kg ha^{-1}, using the combination of improved genotypes and best agronomic practices more than 6000 kg ha^{-1} pod yield are being recorded frequently at many places and occasionally upto 8000 kg ha^{-1} (AICRPG, 1993, 2001, Singh 2004; NRCG 2009) indicating that the yield potential of groundnut has not been exploited even by one-fourth by the groundnut growers. In spite of the instability in productivity under favorable condition, the groundnut has yielded 15 t ha^{-1} (Prasad, 1993). Thus, there lays tremendous scope to increase the groundnut yield through understanding of its physiology. As groundnut is not very old crop in India and in many other countries its physiology was not well studied till 1960s. The detail physiological studies of this crop started only in 70s, and in 80s and 90s a lot of studies were conducted. Due to underground fruiting, indeterminate growth habit and different botanical types still certain aspects of physiology of this crop are not very clear.

The knowledge of crop physiology is important for three reasons: (i) For optimal crop yield in an environment, the life cycle of the crop should match to the length of growing season, (ii) The introduction of an improved genotypes into new region is largely determined by temperature and phenology, and (iii) Phenology is an essential component of whole crop simulation model, which can be used to specify the most appropriate rate and time of specific developmental process to maximize yield. In this chapter an attempt was made to combine the knowledge of groundnut agronomy and physiology and management of abiotic stress to grow high yielding groundnut varieties with targeted yield and recommend the same to groundnut workers to increase the productivity.

2. Cultivation areas and problems

The cultivation of groundnut has been spread on almost all soils throughout the world due to its wide adoptability and now being cultivated on about 25 million hectare (ha) of land (Table 1). The sporadic cultivation of groundnut is found in most of the countries and to significant amount in about 120 countries, however, on large scale it is mainly grown in India, China, Nigeria, USA, Myanmar, Indonesia, Sudan, Senegal, Argentina and Vietnam producing more than 0.5 million tonne (mt) and in Ghana, Chad, Congo Republic, Mali, Guinea, Niger, Argentina, Brazil, Tanzania, Burkino Faso, and Malawi producing in between 0.25-0.5 million tonnes (mt) (Table 2). Though it is a energy rich crop, more than 85% of the world groundnut production come from low income food deficit countries with an average productivity of about 1500 kg ha^{-1} and having more than 90 % of the groundnut growing areas of the world.

The commercial cultivation of groundnut is mainly in Asian (54 % of the world groundnut area contributing 64% of the total world production), African (40% area, 26% production) and American (4.8% area and 9% production) countries due to suitable environment and photoperiod matching to the growing season. The southern, eastern and south-eastern part of Asia, western Africa and northern and south America are the main groundnut growing region as their soil and climate favours its cultivation. Though grown in limited area, the productivity of Cyprus (<100 ha area) is highest (>12000 kg ha^{-1}) followed by Israel (2600 ha and 6440 kg ha^{-1}) in the word mainly due to favourable season and high cultivation management practices. On the other hand the productivity of many African countries, with significant areas, are still around 400 kg ha^{-1} mainly due to poor resources and scanty rainfall. However, on large scale cultivation the productivity of USA, China, Egypt, Turkey, Argentina and Nicaragua are very high (>3000 kg ha^{-1}).

Table1. Groundnut area, production and yield in various continents during 2000 and 2008

Continents	Area (m ha)		Production (m t)		Yield (kg/ha)	
	2000	2008	2000	2008	2000	2008
Africa	8.873	10.05	8.460	10.05	953	1000
Americas	1.087	1.166	2.424	3.603	2230	3090
Asia	13.264	13.343	23.788	24.514	1793	1837
Europe	0.011	0.011	0.011	0.009	1050	824
Oceania and Australia	0.022	0.018	0.039	0.022	1765	1274
World	23.26	24.59	34.72	38.20	1493	1554

In India, the groundnut is grown in about 260 districts mostly as rainfed dry lands, crop on well drained sandy soils in low (<750 mm) and medium (750-1000 mm) annual rainfall areas, often subject to the vagaries of the weather and only 20 % of groundnut area is under irrigation. Between the decades of 60s and 70s, there is practically little difference in productivity (700-800 kg ha^{-1}) and the increase in production was largely due to the expansion in areas. But during 80s, particularly during 1988-89 due to favorable season and transfer of available technologies through TMO (Technology Mission on Oilseeds), first time the productivity crossed one tonne (1132 kg ha^{-1}). The average yield of the crop during 1990-2000 was 994 which during 2001-10 surpassed 1100 kg ha^{-1} with a maximum of 1357 kg ha^{-1} during 2005-06 and 1459 kg ha^{-1} during 2007-08. In India generally the groundnut is grown as rainfed crop during rainy season (Kharif) with one or two protective irrigation and also during Rabi, summer and spring season wherever there is irrigation facility.

Table 2. Area, production and productivity of groundnut in various countries during 2008 (FAO,2010).

Country Name	Area (ha)	Yield (kg/ha)	Production (tonnes)
Angloa	180,000	333	60,000
Argentina	227,389	2750	625,349
Brazil	113,085	2622	296,600
Burkina Faso	430,000	697	300,000
Cameroon	300,000	533	160,000
Chad	546,375	737	403,210
China	4,622,522 (18.8)	3102	14,341,075 (37.5)
Congo	475,578	778	370,000
Egypt	61,442	3398	208,835
Ghana	460,000	931	428,600
India	6,850,000 (27.9)	1071	7,338,000 (19.2)
Indonesia	636,229 (2.6)	1216	773,797
Israel	2,600	6437	16,737
Japan	8,310	2262	18,800
Malawi	266,115	913	243,215
Mali	331,000	981	325,000
Mozambique	295,000	320	94,454
Myanmar	650,000 (2.6)	1538	1,000,000 (2.6)
Nicaragua	38,579	3609	139,266
Niger	675,477 (2.8)	455	307,776
Nigeria	2,300,000 (9.4)	1695	3,900,000 (10.2)
Senegal	670,000 (2.7)	965	646,964
Sierra Leone	150,000	766	115,000
Sudan	953,781(3.9)	750	716,000
Tanzania	415,000	722	300,000
Thailand	65,000	1753	114,000
Turkey	24,835	3433	85,274
Uganda	244,000	709	173,000
USA	609,870 (2.5)	3828	2,335,050 (6.1)
Viet Nam	256,000	2085	533,800
Zimbabwe	150,000	524	78,600
World	24,590,075	1553	38,201,265

Figures in parentheses are the percent contribution to the total world area or production

The Gujarat (29.6% total area and 36% of production), Andhra Pradesh (28.6% area and 28% of production), Tamil Nadu (8.6% area and 11% of production), Karnataka (14.5% area and 8% of production), Rajasthan (4.5% area and 5.2% of production) and Maharashtra (6.4% area and 5.1% of production) are the main groundnut growing states (Table 3). The Madhya Pradesh, Orissa and Uttar Pradesh are the other groundnut growing states with 1-3% of area contributing 1-2% of the total production of the country. Upto 1960s, the groundnut was grown only during Kharif, but from 1971-72 its cultivation started in winter (Rabi) and summer also in A.P., Karnataka and Tamil Nadu where it showed higher yield potential than in kharif. In Gujarat the rabi/summer groundnut was introduced in 1977-78 and in Maharashtra in 1978-79 (Patel, 1988). Presently, in India the average productivity of rabi-summer groundnut is about 1900 kg ha^{-1}, much higher than kharif season (1400 kg ha^{-1}) indicating more production potential during this season.

Table 4. State wise groundnut yield (kg/ha) obtained during various years (2000-2009) and seasons (Source: Agriculture statistics at a glance, 2009)

States/UTs	Season	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009
Andhra Pradesh	Kharif	1060	568	426	482	778	565	301	1357	693
	Rabi	1636	1714	1397	1613	1657	1739	1806	1925	1932
	Total	1144	739	558	660	890	728	557	1451	880
Bihar	Kharif	2000	500	500	400	600	556	556	500	494
Chhattisgarh	Kharif	936	1234	1111	1107	1110	1078	1142	1256	1352
Goa	Kharif	1500	1000	2000	1333	750	1333	2000	2000	
	Rabi	1857	1600	1773	1767	1700	2500	1727	1875	
	Total	1778	1563	1792	1727	1588	2394	1769	1892	
Gujarat	Kharif	368	1401	508	2267	891	1707	725	1781	1367
	Rabi	1788	1473	1641	1556	2391	2225	2000	1724	1798
	Total	395	1402	539	2235	943	1734	809	1777	1394
Haryana	Kharif	1000	800	792	733	750	733	840	813	882
H P	Kharif	2000	1000	500	1000					813
Karnataka	Kahrif	998	592	549	435	737	590	434	784	606
	Rabi	1108	1142	1144	996	917	924	760	906	855
	Total	1017	685	639	530	766	645	497	807	650
Kerala	Kharif	730	750	524	741	944	727	1000	759	815
M.Pradesh	Kharif	1059	1121	632	1159	1158	1126	948	940	1140
Maharastra	Kahrif	894	1081	957	1096	1035	831	743	1112	1047
	Rabi	1267	1447	1676	1491	1430	1429	1355	1413	1407
	Total	959	1146	1074	1153	1123	958	889	1168	1138
Nagaland	Kharif	1143	1200	1250	1500	1273	1000	1000	1000	
Orrissa	Kharif	650	765	688	865	879	835	904	982	981
	Rabi	946	1207	1042	1438	1453	1414	1292	1376	1248
	Total	794	985	870	1207	1233	1171	1113	1219	1137
Panjab	Kharif	1000	1000	717	909	837	882	864	871	667
Rajastan	Kharif	924	1227	687	1566	1552	1549	1310	1728	1670
Tamil Nadu	Kharif	1557	1511	1146	1298	1159	1526	1329	1417	1805
	Rabi	2836	2753	2085	2145	2678	2103	3729	3078	2126
	Total	1942	1885	1429	1552	1632	1775	1981	1957	1951
Tripura	Kharif	1125	1000	1000	1000	1000	1000	1000	1000	
	Rabi	1000	500	1000	1000	1000	667	1000	1000	
	Total	1083	833	1000	1000	1000	889	1000	1000	
Uttar Pradesh	Kharif	835	839	618	637	816	851	730	598	705
	Rabi									2000
Uttarakhand	Kharif				667	1000	1000	2000	1000	2000
West Bengal	Kahrif	800	1000	929	1000	938	933	1000	909	958
	Rabi	1510	1542	1554	1678	1644	1727	1744	1968	1900
	Total	1471	1509	1526	1651	1620	1703	1713	1918	1869
Pondicherry	Kharif	1833	1583	1538	1923	2000	1938	1938	1875	
All India	Kharif	861	1030	587	1320	909	1097	689	1386	1077
	Rabi	1756	1808	1548	1602	1771	1702	1880	1857	1726
	Total	977	1127	694	1357	1020	1187	866	1459	1180

Table 3. Area, Production and Yield of Groundnut in major producing states during 2007-08

States	Area (m ha)	% to all-India	Production (m t)	% to all-India	Yield (kg/ha)	Area under irrigation (%)
Gujarat	1.86	29.57	3.30	35.95	1777	7.5
Andhra Pradesh	1.80	28.62	2.60	28.32	1451	18.6
Tamil Nadu	0.54	8.59	1.05	11.44	1957	30.8
Karnataka	0.91	14.47	0.73	7.95	807	22.5
Rajasthan	0.28	4.45	0.48	5.23	1728	66.8
Maharashtra	0.40	6.36	0.47	5.12	1168	23.4
Madhya Pradesh	0.20	3.18	0.19	2.07	940	7.7
Orissa	0.08	1.27	0.10	1.09	1219	37.5
Uttar Pradesh	0.10	1.59	0.06	0.65	598	1.4
Others	0.12	1.91	0.20	2.18	-	-
All India	6.29	100	9.18	100	1459	19.8

If we critically analyse the situation of groundnut production in India, though the productivity (average of both the season) of groundnut during the year 2000 to 2008 ranged from 766-1459 kg ha^{-1}, the productivity in three major groundnut growing states, accounting for about 75 % of the total productivity of the country, was in between 1473-2225 kg ha^{-1} in Gujarat, 1400-1930 kg ha^{-1} in AP and 1402-3729 kg ha^{-1} in Tamil Nadu during rabi-summer season, but fluctuated in between 349-2267, 301-1357, 1146-1829 kg ha^{-1}, respectively in these states during kharif season.

The poor productivity during kharif season is mainly ascribed to limiting water supply as it is mainly rain dependent and early, mid or late season drought due to poor distribution of rain restrict the crop productivity. On the other hand irrigation during rabi-summer resulted in high productivity. In India as groundnut, during kharif season is grown in fairly large area (> 70%), the productivity is relatively low and the production becomes rain dependent. However, the assured irrigation followed by proper nutrient management increased productivity in Rajasthan, UP during kharif and rabi-summer groundnut during summer in Tamil Nadu, Rajasthan, and UP with more than 3000 kg ha^{-1}. Also there are indications of shift in groundnut cultivation in various states both in area and season due to crop competition.

As groundnut is grown on almost all soils and throughout the world right from very high rainfall area to arid region, the soil acidity, calcareousness, alkalinity, drought and mineral stresses and salinity are the major problems limiting its productivity.

3. Cultivars and botanical types

There are about 15000 groundnut germplasm collections showing morphological anatomical and physiological variations available and more than 300 groundnut cultivars released for their cultivation world wide of these about 170 cultivars released in India. The cultivated groundnut (*Arachis hypogaea* Linn.) was initially divided into two large botanical groups, Virginia and Spanish-Valencia on the basis of branching pattern however several classifications were made based on the flowering and fruit bearing habit (Ramnath Rao, 1988). In Virginia group, the main stem does not have reproductive axes and alternate pairs of vegetative and reproductive axes (inflorescences) are borne on the cotyledonary lateral and other n+1 branches (alternate branching). In the Spanish-Valencia group, reproductive branches are borne in a continuous series on successive nodes of the cotyledonary and other lateral branches, on which the first branch is always reproductive (sequential branching pattern). Spanish cultivars produce n+2 vegetative branches irregularly, while Valencia cultivars do not. However, Gibbon et. al. (1972) described the subspecies and botanical varieties in details as follows:

a. Subspecies *hypogaea*: habit procumbent, decumbent or erect; alternate branching, inflorescence never borne directly on main axis, first branch on the cotyledonary lateral always vegetative; 2-4 seeded pod; testa colour commonly tan; seed dormancy usually present; foliage dark green.

i. var. *hypogaea* (Virginia bunch): habit procumbent to erect; main axis in procumbent form, short and not exceeding 40-50 cm; 2-seeded pod; medium late maturing.

ii. var. *hirsute* (Virginia runner): habit procumbent and main axis may exceeds 1 m; pod strongly beaked and with 2-4 seeds; very late maturing.

b. Subspecies *fastigiata*: habit erect to decumbent; sequential branching; flowers always present on main axis; first branch on cotyledonary lateral reproductive; seed dormancy usually absent; foliage usually lighter in colour than hypogaea.

i. var. *fastigiata* (Valencia): vegetative branches on primaries absent or regularly placed at distal nodes; inflorescence simple; pods with 2-4 seed (rarely 5); pods beak absent or slight; testa colour tan, red, white, yellow, purple or variegated.

ii. var. *vulgaris* (Spanish): vegetative branches occasional and regularly placed; inflorescence compound; pod usually with 2 seeds; beak present or absent; testa colour tan, red, white or purple.

For cultivation, the improved groundnut varieties adapted for the region are taken the list of which are available in a recently published book on groundnut (Basu and Singh, 2004) and also updated annually in the annual report of the all India coordinated research Project on Groundnut (AICRPG, 2009, Table 5). However, some of the promising varieties, in India are JL 24, GG 2, GG 7, GG 20, Girnar 2, Girnar 3, VRI 2, TAG 24, HNG 10, SG 84, GG 4, LGN 2, BAU 19, TKG 19A among bunch and Somnath, GG 11, GG 13, BAU 13, ICGS 76, Chandra, M 13, Kaushal, CSMG 84-1 GPBD 4, M 145, M 197 in spreading groups. The seed rate depends on the variety and spacings. For bunch varieties the recommended spacing is 30 x 10 cm and seed rate 100-110 kg kernel ha^{-1} and for spreading the recommended spacing is 30 x 15 cm or 45 x 10 cm and seed rate 95-100 kg ha^{-1}. However, the traditional farmers in various states in India follow their own spacing based on their convenience and availability of equipments and 45 x 10 cm spacing for bunch and 60 x 10, 75 x 10 or 90 x 10 cm spacing for spreading are very commom. In Saurashtra region of Gujarat, wide row spacing in set furrrows cultivation is in the practice since last 50-60 years. Seed before sowing is treated with Thirum or Dithane M-45 30 g 100 kg^{-1} seed and sown 3-5 cm deep in the soil under sufficient moisture which germinates within a week.

The degree of similarity between and within Valencia and Virginia bunch germplasm collections introduced from 39 countries were studied by Rajgopal et al. (1997) for pod features (pod beak, constriction and reticulation) and testa colour taking 578 Valencia (subsp. fastigiata var. fastigiata) and 511 Virginia bunch (subsp. hypogaea var. hypogaea), among the Valencia the predominant characteristics slight pod beak, slight constriction and slight reticulation were found in 54%, 44% and 56% accessions and in Virginia bunch accessions slight pod beak, moderate constriction and slight reticulation were 66, 61 and 62%, respectively. As many as 12 primary testa colours were found in mature seeds of Valencia, and 10 among the Virginia bunch germplasm which ranged from off-white to blackish-purple in Valencia accessions with red most common (61.1%) while the colour rose was most common (83%) in Virginia bunch germplasm (Rajgopal et al. 1997). The bunch varieties mature in about 100-120 days and spreading in 130-150 days. Yellowing of foliage and dropping of older leaves are the prominent symptoms of maturity. The inside surface of shell shows dark discoloration. The bunch varieties are generally harvested by pulling with hand while the spreading by blade harrow. The plants are stacked for about a week and pods are stripped. The produce is dried to 6-8% moisture content and stored in gunny bags or storage bins.

There are several physiological processes occurring right from seed germination to harvest and systematic study of these is essential for the success of any crop in a given area. Phenology is the study of developmental timing in relation to the calendar. In groundnut, both perennial and annual species occur, but the perennial or indeterminate growth habit is most common. Harvesting of groundnut *(Arachis hypogaea L)* crops is rarely determined by physiological maturity. Phenological studies have been more concerned with the timing of developmental processes i.e. the start, the duration and the end rather than with the rate of development. The rate of developmental process such as leaf production is usually expressed as number per day, whereas events which occur once in life cycle are generally expressed as the duration (D), for example for 50% of the population to reach that stage.

Broadly, expansion, podding and filling are the three major phenophases in groundnut. However, Williams et al. (1978) divided the groundnut crop's life time into ten phases: 1-germination and emergence; 2-vegetative growth only; 3-vegetative growth and first flowers; 4-active flowering with first pods being produced; 5-flowering, peg production, pod production and the start of significant kernel growth; 6-vegetative growth ceasing and rapid kernel growth commencing; 7-pod initiation ceasing and rapid kernel growth continuing, defoliation usually starts; 8-first mature pods present; 9-30 to 40% of the pods mature; 10-50 to70% of the pod mature, defoliation rapid and crop lifted at the end of this phase. The expansion starts from emergence to canopy closure at 100% ground cover. The crop growth during this stage is in exponential stage and is entirely vegetative. The podding phase begins 10-15 days after the first flower appears, pods are added linearly until a full pod load has been set. The early stages of podding overlap with vegetative one. The filling phase begins when a full pod load has been set, and continues until maturity. In a 110-120 days crop, the flower initiation starts at 30 DAS, and that of pod at 45 DAS. The pod achieves maximum number at 55 DAS and then filling starts and depending upon the duration, the crop matures in 110-120 days. The pod fill is maximum at 80 DAS.

A rapid expansion phenophases, short podding, long filling coupled with high partitioning of assimilates to pods are the main desirable characters. These processes are discussed in more details under the separate headings as vegetative and reproductive growth and seed development.

4. Photosynthesis and Vegetative Growth

4.1. Germination and seedling growth

The active growth of quiescent seed is resumed after water uptake imbibitions. The metabolism in groundnut seed is very low at seed moisture levels below 10% but increases rapidly during water absorption and hydration of cell walls and protoplast. Generally groundnut seed requires more than 35% seed moisture for germination. Besides water, the external substances required for seed germination are oxygen and suitable temperature. During germination of groundnut seeds, C_2H_4 production rises prior to any visible signs of growth and reaches to peak twice, at emergence of the hypocotyl-radical and when radical emerges from the hypocotyl (Morgan et al., 1970). The groundnut seed consists of two cotyledons, upper stem axis and young leaf primordia (epicotyl), and lower stem axis (hypocotyl) and primary root. The epicotyl consists of 3 buds-1 terminal with 4 leaf primordia and 2 cotyledonary laterals with 1-2 leaf primordia. Thus, the embryo contains all the leaves and above ground part that appears during the first 2 weeks of growth.

The field emergence of groundnut is neither epigeal nor hypogeal, it is of intermediate type. However, Dwivedi and Saha (1981) found epigeal germination behaviour in groundnut where the hypocotyl carries cotyledons to the soil surface and remains there. The germination completes in 7-10 days after seed is sown. The minimum and maximum temperature requirements of groundnut are not well established but it germinates more quickly within range of 20-35ºC with optimum temperature between 30-33ºC for most rapid germination and seedling development. In moist soil, the primary roots emerge in 24-36 h and root grows 0.5 to 4.0 cm in 4 days. The lateral roots appear after second day and become as many as 100 in 5 days. During the first few hours of germination the radical consists of about half hypocotyls and half primary roots, depending upon the depth of sowing. The hypocotyl is the portion of stem, which lies between the primary root, and cotyledons and it can elongate enough to bring the cotyledons to the soil surface.

The hypocotyl played an important role in the transition from development to germination of groundnut seeds and there appeared to be two different pathways of endogenous ABA biosynthesis in groundnut seed, via C40 in the cotyledons and via C15 in the hypocotyls, and under conditions of precocious maturation or germination, the endogenous ABA content decreased (Lin et al. 1996a). In groundnut cv. Yueyou 116, during seed development, endogenous ABA content increased steadily to a peak at 40 d after pegging in the hypocotyls, levels in the testa decreased 40 d after pegging, and in the cotyledons increased to a peak at 60 d after pegging before decreasing slightly. There was a close relationship between the increase in vigour index and net loss of endogenous ABA in seed germinating in vitro.

Addition of osmoticum (mannitol at 12%) to the medium increased endogenous ABA in the cotyledons and hypocotyl, and fluridone decreased levels in the cotyledon (Lin et al. 1996a).

Table 5. Groundnut varieties released from 2002 to 2010 in India (AICRPG, 2010)

S. N.	Varieties	Habit Group	Originating Centre	Year of release	Releases for region /area	Pod yield (kg/ha)	Days to maturity	Special attributes			Additional information	
								Shelling (%)	Oil (%)	HKW (g)	Disease/ insect pest reactions	Salient Features
1	AK 159	SB	Akola	2002	Maharashtra and M.P.	1606	106	66-68	51	34	-	Early
2	Kalahasti (TCGS 320)	SB	Tirupati	2002	Andhra Pradesh	3764	110	74-76	52.3	50-60	tolerant to bud necrosis, resistant to jassids	Suitable for rabi and kharif in North coastal and North Telengana of AP
3	Narayani (TCGS 29)	SB	Tirupati	2002	Andhra Pradesh	3764	100	72-76	47.5	40-45	Susceptible to insect pest, LLS and rust.	Tolerant to mid season drought for kharif and rabi
4	Sneha	VB	Vellayani	2002	Kerala						Free from major pest and diseases	Short duration with small two seeded pods
5	Snigdha	VB	Vellayani	2002	Kerala						Resistant to pest and diseases	Medium size pods with reticulated venation
6	GG 6	SB	Junagadh	2003	Gujarat	2782	119	73	50	45	-	For summer
7	GG 14 (JSP 28)	VR	Junagadh	2003	North Raj., Punjab, Haryana, UP and all India	2159	123	65	52	49	Tolerant to thrips, Spodoptera, Leaf miner	Suitable for rainfed, medium maturity
8	TPG 41	SB	BARC, Mumbai	2004	All India	2088	122	69	49	65	Moderately resistant to rust	High O/L ratio (3.267)
9	TG 37A	SB	BARC, Mumbai	2004	All India	1900		64	48	39	Moderately tolerant to collar rot, rust and leaf spot	Suitable for rabi-summer, fresh seed dormancy for 15 days
10	GPBD 4 (Vikas)	SB	UAS, Dharwad	2004	All India	1900-2200	105-110	68	49	36	Resistant to LLS and rust	Early (105-110 days)
11	TLG 45	SB	MAU, Latur	2004	Maharashtra	1506	114	66	51	59	-	Large seeded, medium maturity
12	SG 99	SB	PAU, Ludhiana	2004	Punjab	2501	123	65	52.3	42	Tolerant to bud necrosis	Suitable for kharif season
13	Phule Unap (JL 286)	SB	Jalgaon	2004	Maharashtra	2231	93-95	72-75	49-50	37-38	Tolerant to LLS, rust and stem rot. moderate tolerant to thrips, leaf minor and spodoptera	Suitable for both kharif and Rabi/Summer

14	Dh 86 (Prutha)	SB	Dharwad	2005	All India	4022	125-127	68	48	43	Tolerant to tikka, sucking pests	Suitable for rabi-summer, semi dwarf with high HI
15	Kadiri 5	SB	Kadiri	2005	AP	1800-2200	100-110	70	48	44	tolerant to leaf spot	Moderately tolerant to drought,
16	Kadiri 6 (K 1240)	SB	Kadiri	2005	AP	1800-2400	100-105	70	49	39	tolerant to leaf spot	Early, suitable for Rabi Summer & Kharif
17	Pratap Mugphali 2 (ICUG 92195)	SB	Udaipur	2005	Rajasthan	1800-2800	97	69	48-50	38	Moderately tolerant to ELS, LLS and PBND and tolerance to *S. litura*, leaf minor and thrips.	Early
18	Pratap Mugphali 1 (ICUG 92035)	SB	Udaipur	2005	Rajasthan	2500-3000	108	62	48-50	40	Moderately resistant to ELS, LLS and PBND, *S. litura*, leaf minor and thrips.	Early
19	Co(GN) 5	SB	Vriddhachalam	2005	TN	1585	125		53.8	46	Tolarent to rust and bud necrosis, leaf minor and *spodoptera*	Suitable for rainfed
20	LGN 1 (Ratneshwar)	SB	MAU, Latur	2005	Maharashtra	1487	105	69	51.2	32	Moderately tolerant to LLS, stem rot, rust and PBND and tolerant to sucking pests	Suitable for rainfed
21	Utkarsh (CSMG 9510)	VR	Mainpuri	2005	UP, Punjab, North Rajasthan.	2192	125	66	49	54	Resistant to rust	Fresh seed dormancy 40-45 days
22	GG 21 (JSSP 15)	VB	JAU, Junagadh	2005	UP, Punjab, Northern Raj.	1843	123	64	53	53		
23	RG 382 (Durga)	VR	RAU Durgapura	2005	Rajasthan	2203	129	64	55	59	Moderately resistant to leaf spot and rust, fairly resistant to jassids, leaf minor and thrips.	Tolerant to biotic and abiotic stresses. Suitable for sandy and loamy soil.
24	GG 8 (J 53)	SB	JAU, Junagadh	2006	Northern Maharashtra and Madhya Pradesh	1716	104-107	69	46	35	Moderately tolerant to bud necrosis, collor rot and rot diseases	Suitable for rainfed conditions

25	TG 38B (TG 38)	SB	BARC, Mumbai	2006	Orissa, WB, Bihar & North eastern states	2768	115-125	71	48	44	Higher tolerant to stem rot	Suitable for Rabi/Summer season
26	Prasuna (TCGS 341)	SB	Tirupati	2006	Andhra Pradesh	2000-2500 (Kharif) 4-4.5 t (Rabi)	110	74-77	50	45-50	Moderately tolerant to Kalahasti malady	Early Kharif and irrigated crop and as regular Rabi season
27	Abhaya (TPT 25)	SB	Tirupati	2006	Andhra Pradesh	2300 (Kh.) 3756 (Rabi)	106	76	52.3	38-40	Tolerant to LLS and sucking insects (jassids and thrips) t and spodoptera	Tolerant to early and mid season drought during kharif
28	TMV (Gn) 13	SB	Coimbatore	2006	Tamil Nadu	2580		-	50	40-42	Moderately resistant to LLS, rust and bud necrosis	Tolerant to early and mid season moisture stress conditions.
29	GG 16 (JSP 39)	VR	Junagadh	2006	Tamil Nadu, AP, Kerala, Southern Maharastra	2058	119	63	46	43	Tolerant to bud necrosis root rot diseases thrips, Spodoptera, Leaf miner	Medium Maturity (115-121 days)
30	Dh 101 (Vasundhara)	SB	Dharwad	2007	WB, Orissa, Jharkhand and Assam	2877	120-130	67	50	35	Tolerant to stem rot and PBND, tolerant to thrips and spodoptera.	Suitable for Rabi/Summer season
31	ICGV 91114	SB	ICRISAT, Hyderabad	2007	Andhra Pradesh	2000	90-95	75	48	41	Moderately tolerant to rust and LLS	Suitable for kharif season
32	AK 265	VB	PDKV, Akola	2007	South MS, Karnataka, AP,TN	1903	120	68	47	42	Resistant to foliar diseases	Drought tolerant, rainfed situation
33	M 548	VR	PAU, Ludhiana	2007	Punjab	1508 (Seed)	123	69	51.4	61	Resistant/Tolerant to leaf spots and collar rot	High protein content, large kernel,
34	AK 303	VB	PDKV, Akola	2007	Maharastra	2100	125	72	49	80	Less susceptible to foliar diseases, leaf minor and jassid	Large seeded.
35	TG 51	SB	BARC,	2008	W.B, Orissa, Jharkhand and Assam	2675	124	68	49	39	Tolerant of stem rot and root rot	High yielding, suitable for rabi-summer season.
36	Ajeya (R 2001-3)	SB	Raichur	2008	South MS, Karnataka, AP, TN	2440	105-120	68	46-48	30-36	Resistant to PBND	Drought tolerant, wider adaptability

37	Girnar 2 (PBS-24030)	VB	NRCG, Junagadh	2008	UP, Punjab, Northern Raj.	2907	130	69	51	61	Torelant to rust, LLS PSND & suching pests.	Virginia buch type with 'stay green' leaves and large seeded.
38	ICGV 00348	VB	Viriddhachalam	2008	South MS, Karnataka,AP,TN	2013	124	66	47	41	Tolerant of leaf spot and rust disease	-
39	VRI (Gn) 7	VB	Viriddhachalam	2008	Tamil Nadu	1865	120-125	72	48	46	mderately resistant to leaf minor, LLS and rust	-
40	VRI (Gn) 6 (VG 9816)	SB	Vriddhachalam	2009	South MS, Karnataka, AP, TN	2259	100-106	66	47	29	Tolerant of LLS, rust, PBND	_
41	Jawahar Groundnut 23 (JGN 23)	SB	Khargone	2009	Madhya Pradesh state	1631	104	70	49	36	tolerant to ELS & LLS	Suitable for kharif, drought tolerant
42	Kadiri 9	SB	ARS, Kadiri	2009	Andhra Pradesh	2500-3000	105-110	65-75		31-35	Tolerant to thrips, jassids, mite and nematodes, and leaf spot, rust dry root rot & collar rot	Tolerant of drought with high RWC and quick regeneration capacity
43	Greeshma	SB	RARS, Tirupati	2009	Andhra Pradesh	2000-2500 (Kh), 4.0-4.7 t (RS)	95-100	75-76	48-50	42-45	Tolerant to LLS	Tolerant to drought, high temp. and aftatoxin,
44	Kadiri 7	VB	ARS, Kadiri	2009	Andhra Pradesh	1643	120-125	68	47	65-75	Tolerant to sucking pest and leaf spots	Large seeded with 65-75 g HKW
45	Kadiri 8	VB	ARS, Kadiri	2009	Andhra Pradesh	1523	120-125	69	47	65-75	Tolerant to sucking pest and leaf spots	Large seeded with 65-75 g HKW
46	ICHG 00440 (Mallika)	VB	Hanumangarh	2009	All India	2579	125-130	66-70	48	73	Resistant to collar rot and PBND	Large seeded with 73 g HKW
47	TGLPS 3 (TDG-39)	VB	UAS, Dharwad	2009	Karnataka	2500-3000	115-120					High HI, large kernel with less aflatoxin
48	JL 501	SB	Jalgaon	2010	Gujarat and southern Rajasthan	1661	102	67	48	36	Suitable for early as well as late sowing	Kharif
49	Vijetha (R 2001-1)	SB	Raichur, ICRISAT, Hyderabad	2010	WB, Orissa, Jharkhand Assam, MS, Karnataka, AP, and TN	1600	105-120	68	46-48	30-36	Resistant to PBND	Kharif/ rabi-summer
50	HNG 69	VB	Hanumangarh	2010	UP, Punjab, Northern Raj.	2800	131	66	50	51	Tolerant to collar rot, stem rot and ELS	kharif

The root nodules are not plant structure but they have close association with plant and make their first appearance on 15-18 days old plants caused by *Bradyrhizobium*. Generally, the Virginia cultivars nodulate more profusely in the hypocotyl region than Spanish and Valencia. The groundnut roots do not possess real root hairs, the tufts of hairs in root axils nodulate the bacteria. Presowing soaking treatment of groundnut seed for 32 h in 0.5% calcium chloride followed by air drying for 10h resulted in higher field emergence and increased pod seed yield in Tamil Nadu (Subbaraman and Selvaraj, 1989), however this may vary depending upon the climatic situation and hence need to be tested before implementation to a new area. However, application of Calcium chloride in the furrows or as seed coating is beneficial (Singh 2002). Low free fatty acid content of an accelerated aging test indicates better storability potential of calcium chloride soaked treatments.

The breakdown of seed storage reserves, transport of reserve material to embryonic axis and synthesis of new materials from the breakdown products are the three main chemical changes occurring in rehydrated imbibed seeds. In groundnuts as the metabolic reserves are largely lipids (40-54%) and proteins (20-30%), the lipids breakdown takes place through glyoxylate cycle and enzymes malate synthatase and isocitric lyase are essential during conversion of fats to carbohydrates. The abscisic acid (ABA) inhibits germination and synthesis of isocitric lyase and ethylene reverse the inhibitory effects of ABA on germination (Ketring, 1975). The gibberellic acid and ethylene promotes the germination and isocitric lyase enzymes control the balance between fat and carbohydrate. The protein degradation occurs 4 to 9th days of germination. The chemical compound after breakdown are translocated to the growing points of the embryonic axis and utilized for seedling growth. During germination the dry weight of developing seedlings decreases (cotyledons dry wt. decreases by 60% and protein depleted by 70%). Misra *et al.* (1992) however, reported that sucrose, indigenously present in cotyledons, is translocated to the growing axis for first three days, subsequently catabolism of oil began; the proteolysis begins soon after imbibitions and free amino acids increased, but the rapid degradation of protein was observed after 4th day of imbibition.

The rich food material in groundnut seed invite microbial invasion in soil as a result the field emergence of groundnut seeds is always less than laboratory germination and this reduction is more pronounced with bold size seeds in Spanish bunch groundnut and with small size seed in Virginia runner cultivars (Singh et al., 1998). Though, it is reported that large-sized seeds (>7 mm diam.) increased germination percentage, plant height and spread, LAI, shelling percentage and seed oil, N and protein contents over small (<5 mm) size seeds in red soil of AP (Reddy 1978), the same is not true in calcareous as well as in many soils as the maturity of seed is more important than the size. To resolve these issues, two important studies were conducted at this research centre, one on the seed size and another on maturity class, as Saurashtra farmers prefer sowing with large seeded groundnut.

Singh et al (1998) studied the effects of seed size on the germination, growth and yields of Spanish bunch (J 11, X 17-20, Girnar 1, SB XI, GG 2, and ICGS 44) and Virginia runner (GAUG 10 and M 13) groundnut varieties reported that both the laboratory germination and field emergence were better with small (seeds with < 6.8 mm diam.), and medium (6.8 to 7.8 mm) size seeds than bold (> 7.9 mm), seeds except GG 2 and Girnar 1. The bold size seeds produced more vigorous plant having more shoot and root biomass at initial growth stages and higher percentage of bold seeds than the small and medium size seeds. However, at maturity, the various size seeds did not differ significantly in their plant height, pod yields, 100 seed weight, and shelling percentage (Singh *et al.*, 1998). In another study, the influence of seed maturity classes (using colour of the inner surface of the pod shell) on plant stand variation in bunch (cv. GG 2) and spreading (cv. M 13) types of groundnut when studied the medium maturity group (semi-mature, mature, and semi over-mature class) of kernels in cv. M 13 and the mature class kernels in cv. GG 2 showed higher germination (laboratory and field), seedlings least infected by fungi, greater plant stand and seedling vigour index (SVI), better growth and improved pod yields compared to immature and over-mature classes of kernels, while seedling mortality was higher in the immature class (Dayal et al.1999). Later on these were again evaluated in rainfed alfisols of Anantapur the different categories of seed viz., assort, bold, medium, small and partially shriveled in groundnut cv. TMV2 with test weight of 38, 42, 28, 20 and 24 g respectively when tested the emergence and seedling vigour index was higher in medium, small and shriveled seed than in the bold seed, while abnormal seedlings were more in bold seed (34.9%) than small and shriveled seed (10.6%). Pod yield and shelling percentage was not influenced by seed size (Sulochanamma and Reddy, 2007). Thus good quality small and partially shriveled seed that passed through 6 mm sieve with test weight ranging form 20-40 g, which germinate better and require less weight of seeds per unit area could be used for sowing of groundnut under high risk rainfed condition.

Also in a study, of 30 lines of groundnut, heavy seeds tended to give a high percentage of normal seedlings, without much effect on seedling growth (Abd Alla and El Mandoh, 1996). A positive trend between germination percentage, tolerance to adverse conditions and field seedling emergence occurred. Lines of heavy seed weight had a high capacity for germination under high osmotic pressure induced by D-mannitol and NA339 and NA128 were promising lines showing positive results in most conditions suggesting their potential for use in plant breeding (Abd Alla and El Mandoh, 1996). In Ghana hot water at 50°C, Dithane M-45 (mancozeb) and maceration increase germination in groundnut cultivars ‘Chinese’ and ‘Manipintar’ and among these Maceration (M) was superior among the treatments and hence can be adopted by farmers to increase germination percentage and plant stand at farm level (Frimpong et al. 2004).

The seed physiological conditions are characterized by the standard germination and vigour tests (first count of the standard germination, seedling vigour classification, accelerated aging, seedling emergence rate, field emergence and seedling dry weight). Germination percentage and seedling vigour were lower in cut seeds and decreased more rapidly during storage, thus the cut seed should be sown immediately after ELISA indexing (Manivel, et al. 1997). Evaluation of 20 genotypes (erect and semi-spreading types) of groundnut for seed traits (shape, size and weight) and seed tests (seed germination test, normal seedling classification test, seedling measurements, accelerated aging test and chemical analysis) recorded the highest values for seed germination percentage, normal strong seedlings, seedling growth rate, seedling vigour index, accelerated aging and seed oil percentage in M 32 (Abd Alla and Sorour, 2004). Decreasing water potential from -0.3 to -1.0 MPa (PEG-induced water stress) in 10 groundnut cultivars (TCGS-20, GG-2, TMV-2, JL-24, ICGV-86031, K-134, TAG-24, JL-220, CSMG-84-1 and TCGS-41) reduced germination, seedling growth and seedling vigour index with, ICGV-86031 showing the highest resistance to water stress and germination and seedling growth even at the highest water stress situation of -1.0 MPa where all other cultivars completely failed followed by TMV-2 and TCGS-41 (Prathap et al. 2006). Weed affects groundnuts through direct competition for light, nutrient and moisture, as well as through allelopathy. In a study, aqueous extracts of *Lantana camara, Digera muricata, Chenopodium album, Ageratum conyzoides, Cirsium arvense, Abutilon indicum* and *Cyperus rotundus* caused reductions in seed germination, and shoot and root growth of groundnut, but root, shoot or whole plant extracts of Amaranthus spp. increased germination and seedling vigour of groundnut as well as the growth of Rhizobium spp. (Ghosh et al. 2000).

4.2. Canopy development, leaf area, LAI, LAD and specific leaf weight

The Virginia (sub species *hypogaea*) has dark green foliage with small leaflets and Spanish (sub sp. *Fastigiata*) has light green and larger leaflets. The leaflets have hairs mainly on the abaxial surface and on the margins which is related to resistance to leaf hoppers. The groundnut leaves are tetra foliate, peripinnate with two pairs of opposite subsessile, obovate leaflets with entire ciliate margin, are born spirally in 2/5 phyllotaxy and arrangement is distichous. Stipules are prominent, linear and adenate to some length and become free at the pulvinus. The leaf size ranges from 4 cm^2 in the first seedling stage up to 80 cm^2 in upper leaves of fully developed stand. The specific leaf weight ranges from 4.1 to 6.7 mg cm^{-2} in young fully expanded leaves. The leaf is the photosynthetic unit and in groundnut it exhibits nyctiotropic movements daily where the adaxial surfaces of leaflets come together and petiole bends downwards. Stomata appears on both sides of the leaf. The groundnut leaves show exponential increase in their number from 20 to 90 days after sowing, but the leaf production during this period differs with botanical types and is higher in the Virginia-runner followed by semi-Virginia bunch and erect Spanish types. With plant age, the leaf number increased most for spreading varieties and leaf weight increased most for semi-spreading varieties (Velu and Gopalakrishnan, 1987).

Spreading (runner, trailing, procumbent and prostrate) and erect (upright, erect bunch and bunch) are two distinct growth habits in groundnut. However, 6 types of growth habit (procumbent 1 and 2; decumbent 1, 2, and 3 and erect) have been described for groundnut (IBPGR-ICRISAT, 1985). The groundnut plant has a distinct main stem and varying number of lateral branches and carriage of laterals is an important character determining the growth habit. The bunch types have thicker stem than runners. The internodes are short and highly condensed at the base but are longer at the higher nodes. The groundnut stems develop anthocyanin pigments in their epidermal cells, the colour of which may be purple (violet), pink, dark red, light red or green. The stem contains long shoot and glandular hairs with bulbous base. The leaves of the erect types are larger than of spreading. Varietal differences in the pattern and coverage of canopy in different plant types under non-competitive conditions are observed. The leaf area and dry matter regularly increased from 3rd leaf stage up to peg formation. The quick coverage of canopy is related to the length of cotyledonary laterals and maintenance of high leaf area index (LAI) is advantageous. It could also be manipulated by plant density and to achieve maximum yield, the LAI, leaf dry matter and total dry matter at 14th leaf stage should be more than 4.0, 175 g m^{-2} and 500 g m^{-2}, respectively (Forestier, 1973). However, in USA, the groundnut intercepted more than 95% light by 55th day after planting, the LAI continued to increase to more than 7, but since light interception appeared complete at about LAI 3, further increase in LAI had no measurable effect on the crop growth rate, Duncan et al., (1978).

It is worth maintaining high leaf area index during pod filling period since the yields were not limited by the size of the photosynthetic sink but probably by the low leaf area and less efficient leaves during the final filling period. In ‘Florunner’ cultivar, in USA, the canopy closed on the 64th day at LAI 3.0, at 87th day when LAI was 7.1 the flowering ended and later on LAI decreased to 1.7 at 137th day at maturity (Mc Cloud, 1974). In Saurashtra, the LAI of bunch varieties spaced at 45 x 10 cm was 1.7 at 60 DAE and reached to 4.0 at 90 DAE, while in spreading planted at 90 x 10 cm it was 0.5-1.2 at 60 DAE and 2-3.6 at 90 DAE. The spectral reflection characteristics of canopies of groundnut were used to evaluate canopy chlorophyll content and LAI in Japan (Aoki and Totsuka, 1985) and SPAD meter in India (Samdur et al, 2001).

In Indian condition the LAI is maximum 4-5 during podding and not affected by the onset of flowering. At Anand, India when the sole crop and intercropping of groundnuts cv. GG-2 with millet (*Pennisetum glaucum*) cv. GHB-32, pigeon peas (*Cajanus cajan*) cv. BDN-2, and tobacco cv. GT-7 were compared the LAI increased with plant development in sole or inctercrop systems, but was always higher in sole groundnuts crop (Sutaria and Mehta, 2000). However, the productivity increased by 23% when groundnuts were intercropped with pigeon peas or tobacco. In a cassava-groundnut intercropping systems, in Colombia, the rapidly growing groundnuts were able to use space between rows of cassava during the first 100 DAS with minimal effect on cassava growth and produced 42-250 g m^{-2} more DM than did cassava alone between 50 and 105 days after sowing (Mason et al, 1998). In Queensland, Australia 50 % thinning at 42 DAS reduced intercepted photosynthetically active radiation but radiation use efficiency, crop growth rate and total dry mass increased by maturity, however, a thinning intensity of 50 % at 91 DAS or 66% at 42 DAS significantly reduced growth suggesting that early control of insect pests could result in yield compensation amongst the remaining plants such that yield losses would be minimal by maturity (Tarimo and Blamey, 1999b).

The leaf area duration (LAD) during later stage of growth had positive effect on pod filling, resulting to higher number of pods per plant. The growth traits of 8 groundnut cv. having variation in pod yield, nodulation and, N_2- fixation when analyzed Among the 12 growth analysis, the Leaf area duration accounted for 70-75% variability and leaf DM accounted for almost 75% of the variability in both nodulation and N fixed (Wynne et al (1981). The runner cultivars maintain more leaf area (higher active assimilation surface) and higher percentage of nitrogen in their leaves than the erect one (Singh and Joshi, 1993). There is no difference in SLW and N, P and K content between leaves of the upper and lower nodes of the main stem, and the lower leaves did not enter into senescence at pod maturing stage of groundnut (Narayanan and Chand, (1986). However, due to higher incidence of leaf diseases like rust and leaf spot, the leaf senescence was comparatively more during the monsoon season than in post-monsoon season and Spanish genotypes show high percentage senescence of leaves than Valencia and these show higher than Virginia (Narayanan and Chand, 1986). During summer crop the LAI, CGR and LAD increased with increase in irrigation frequency. In Orissa, the LAI at pod filling and maturity stages and pod yields were highest with sowing on 15 February, 3 irrigations and a spacing of 25 x 12 cm however, sowing on 15 March gave the highest LAI, CGR and LAD up to 70 days after sowing (Patra et al, 1998). In a summer field trial at Bangalore, India, irrigation at 0.8 CPE gave the highest DM, LAI and LAD, and the pod yield increased with increasing irrigation level and the effects of water stress on LAD were greatest early in the growing season, while effects on yield were greater later in the season (Sridhara et al 1996).

The runner types also had a larger leaf area and higher percentage of N in their leaves throughout the season. Pod yield and DM production were greater in the rabi-summer season than in the kharif season due to the longer duration of the crop. In field trials at Junagadh, India during the kharif and rabi-summer seasons, 5 erect (Spanish bunch) and 3 Virginia runner (spreading) groundnut cultivars were evaluated for chlorophyll content, DM production, growth rate, nodule weight, N uptake, pod number and pod and haulm yields by Singh and Joshi (1993). Chlorophyll content peaked soon after emergence and was lowest at 4 weeks after emergence due to low N levels. Nodules developed 3 weeks after emergence and started fixing N and so increased chlorophyll content again. Chlorophyll content was higher in runner (cv. Robut 33-1, Punjab 1, GAUG 10) than in erect cultivars (GAUG 1, Kisan, TMV 2, JL 24, GG 2) and the runners accumulated more N as it fixed more N. The Virginia runner cultivars had a higher pod number and yield than the erect types due to more DM and N accumulation and higher crop growth rate. Physiological functions are usually expressed on a leaf area basis, whereas leaf mineral concentrations are often expressed on a dry matter (DM) basis. If specific leaf weight (g DM m^{-2} leaf) differs among genotypes then variability in mineral concentration may depend on the basis of expression.

The leaf ash content was negatively correlated with SLW mainly due to correlations with Ca and Mg (Brown and Byrd, 1997). The slope of a plot of leaf constituents per unit of leaf area against SLW for a range of genotypes is a measure of the contribution of that leaf constituent to increased SLW. From data in the literature it appears that increased SLW is due mostly to the increase in cell wall components and non-structural carbohydrates, and sometimes protein. Leaf mineral per unit of leaf area appears to be unrelated or only slightly increased with increased SLW and thus declines on a unit weight basis because of dilution by increased cell wall content or soluble carbohydrate. The Fe deficiency reduced chlorophyll contents, and SLW in groundnuts (Rao and Narayanan, 1990) and the SLW correlated with respiration but not with photosynthesis (Jun et al, 1999). On a Tifton loamy sand in Georgia (USA), the management practices, such as twin row groundnuts, can maximize groundnut canopy development early in the growing season and minimize the time in which bare soil is vulnerable to a runoff producing rainstorm, thus reducing runoff and soil loss and conserving valuable natural resources (Truman and Williams, 2001).

In Ismailia, after evaluating 11 groundnut genotypes (differing in the thickness of root and root nodule tissues) for morphological and anatomical characters in relation to growth behaviour, Giza 5 and imported forms 256/2 and 385 had overall the best growth parameters and were recommended for breeding programmes for sandy soils (Sakr et al. 1997). In genotype 391, reduction in nodule formation was accompanied by increased periderm thickness, number of xylem clusters and rays and absence of meristematic tissue, active zone and vascular tissue from the nodules (Sakr et al. 1997). Pod yield of groundnut was positively correlated with plant height at 90 DAS, number of filled pods per plant, leaf number and area at different growth stages and total dry matter accumulation, but was negatively correlated with unfilled pod numbers and 100-seed weight. (Jayaramaiah and Thimmegowda, 1998).

A high seedling vigour during early stages of crop growth up to the pod filling stage, maintenance of high leaf area duration from the pod filling stage to maturity and efficient translocation of photosynthates (high harvest index) were the major physiological parameters responsible for high yields from early sowings. The canopy development at crop maturity was not always related to kernel yield, however, canopy development at peak flowering had a strong positive association with kernel yield and higher levels of stability for kernel yield could be achieved through correction of canopy development towards compaction in Virginia runners and more pronounced in case of Spanish genotypes (Prasad, 1993), however the Spanish genotypes being grown in India, in general, have reached a critical genetic balance for canopy development and further compaction might result in low reproductive efficiency. The breeder should concentrate the stable character such as canopy developement at peak flowering as one of the selection criterion.

The canopy characteristics and solar energy utilization efficiency in groundnuts with yields of 8.5 and 6.0 t/ha when studied in field, a longer duration of maximum leaf area index (LAI) was a marked character in super high-yielding groundnut (SHYG), the LAD reached 400 m^2/d/m2 and the dry matter production rate was constantly higher in SHYG compared with that in high-yielding groundnut (HYG) during the whole growing season, especially during the late growing season, the LAD in yield-forming stage was more than 80% of the whole growing season, though the efficiency of light interception per unit leaf area in SHYG was lower than that in HYG (Wang, et al.2004). The growth parameters, intercepted radiation and radiation use efficiency (RUE) in Japanese (Kanto 83, Nakateyutaka) and Chinese (Huayu 16, Luhua II) high-yielding cultivars of groundnut grown under dense planting when evaluated over three years all cultivars showed a high leaf area index (approximately 5) and seed yields of more than 450 g m^2 particular, Kanto 83 and Huayu 16 cvs showed a yield of more than 500 g/m^2 (Cao and Isoda, 2008). The variation in total dry matter production depended on both the amount of intercepted radiation and RUE and the crop growth rates during all growing periods, except for the early growing periods were mainly affected by RUE. Huayu 16 had the highest RUE values resulting in high dry matter production and seed yields. The factors, that caused high seed yields of Huayu 16 and Kanto 83 were rapid leaf area extension in the early growth stage, high RUE values, and large pod and seed numbers as a sink (Cao and Isoda, 2008). In Florida, USA the diclosulam applied preplant incorporated at 0, 18, 27, or 54 g ai/ha in a weed-free environment did not affect groundnut canopy development, percentage extra-large kernels, sound mature kernels, sound splits, total sound mature kernels, other kernels, or yield for any three runner market-type groundnut cultivars 'Georgia Green', 'C-99R', and 'MDR-98' (Main et al. 2002).

4.3. Crop growth rate, NAR and RGR

Detailed growth analysis and developmental data are normally required for calibration of crop simulation models in order to determine the cultivar coefficients that correspond to the unique characteristics of each crop and cultivar. The early growth is due to stem elongation and leaf production, simultaneously the lateral branches accounts for the bulk of later growth. The leaf and stem dry weight increases in sigmoidal fashion upto maximum value, which occur 90 to 100 days after planting. During this period leaves and stems accumulate weight at similar rates, after that the leaf weight declines but stem weight either remains constant or decreases. Though growth is a genotypic character, largely influenced by seasonal and environmental conditions, the dry matter accumulation in groundnut crop follows the growth pattern characterized by (i) a lag phase in early growth, (ii) exponential increases in weight from vegetative to flowering stage, (iii) a linear and maximum growth rate during late vegetative to early pod filling, and (iv) leveling of weight during late pod filling stage. The growth rate is faster in the erect varieties and they attain high dry matter earlier than in the spreading ones, but in spreading the growth continue for a longer period and hence accumulate more dry matter (Singh and Joshi, 1993). However, the genotypes did not differ markedly in their relative growth rate (RGR) between 25-40 days. The mean net assimilation rate (NAR) of an average crop ranged in between 13.1-15.0 g m^{-2} $week^{-1}$, the runner and bunch did not differ much in NAR, but it was higher in runner during pod initiation (Enyi, 1977). The NAR was low during flowering initiation (25-40 days), pod initiation and pod development (40-70 days) stages but higher during pod filling stage.

During rabi season the maximum dry matter accumulation at Junagadh reached to a climax at 9th week (60 DAE) of growth and thereafter declined. The runner cultivars showed higher chlorophyll content in leave, higher crop growth, produced more pod and haulm yield than erect types. The crop growth rate was low till 6 WAE (week after emergence), which increased sharply afterwards and was maximum in between 7-13 WAE Singh and Joshi (1993). The groundnut crop achieve maximum biomass earlier during kharif season and accumulated highest dry matter at 11 and 12 WAE in kharif season in erect and runner genotypes, respectively 14 and 15 WAE in dry season (Singh and Joshi, 1993). The crop growth rate during 7-13 WAE was more 3.0-13.7 g m^{-2} day^{-1} during wet season (sown in the first week of July) than dry season (sown in first week of February) crop (2.14 - 11.8 g m^{-2} day^{-1}) and hence the former took lesser time for its maturity than the latter one, but the average per day dry matter production was similar during both the seasons (Singh and Joshi, 1993). The roots accounts for 5 to 7 % of the total dry matter, at one month after planting and only 1 to 2%, at harvest. Singh and Joshi (1993) found 8.6, 18.8 and 20 g m^{-2} root dry matter at 30, 80 and 100 DAE and varied with groundnut varieties.

The average growth rate (dry matter production) in groundnut has been reported vary 3-26 g m^{-2} day^{-1} (Dwivedi 1986a; Singh and Joshi (1993). The erect type achieved highest growth rate (8.0-9.5 g m^{-2} day^{-1}) at 10 WAE (70 DAE) during dry season and 9 WAE (8.4-13.7 g m^{-2} day^{-1}) during wet season, but runner showed highest growth rate for longer period than the erect type of 8.5-11.8 g m^{-2} day^{-1}) from 8-10 WAE during dry season and 8-11 WAE (8.1-12.9 g m^{-2} day^{-1}) during wet season (Singh and Joshi, 1993). However, the time of maximum growth varies with environmental factor and yet in another environment, Mohammed Ali et al. (1974) found the period of maximum growth between 56-97 days in bunch varieties and

70-125 days in spreading ones. In bunch type nearly 45-50% of total dry matter produced in plant was accumulated in kernels, 16% in shell, 20% in stem, 11% in leaf and 1% in roots.

There is a relationship between CGR, LAI and both to grain yield and the environmental factor of the surrounding. In Rhodesia, the maximum CGR were 88, 120 and 194 g m^{-2} $week^{-1}$ at 17.9, 20.1 and 23.3ºC temperature, respectively (Williams et al., 1975a) and at mean daily temperature 23.3ºC, the CGR was highest, but maximum seed yield was obtained at the 20.1ºC (Williams et. al., 1975b). The average crop growth rate of groundnut in USA is reported to be 191 kg ha^{-1} day^{-1} (Duncan et al., 1978). While calculating the crop growth rate during pod filling stage the pod weights because of their high energy contents are adjusted by multiplying with a factor coefficient of 1.65 (Duncan et al., 1978) for a well irrigated crop. However this is inappropriate for stressed crop because of lower ratio of kernel to pod weight. Using the shelling percentage of well irrigated crop a conversion coefficient of 2.4 therefore was calculated for kernel tissue weights alone for stressed crop and was used by Matthews et al. (1988b) in their experimentation. Plant height had a positive relationship with leaf area index, crop growth rate, harvest index and leaf nitrogen content, whereas it had negative relationship with number of branches, net assimilation rate and nitrogenase activity (Antony et al 2000).

Leaf area index was positively correlated with crop growth rate and negatively correlated with NAR. Further the pod yield had positive correlation with total dry matter at 60 DAE, leaf area index, net assimilation rate, nitrogenase and leaf nitrogen, however, total dry matter at harvest had negative relationship with harvest index. Chhonkar and Kumar (1987) reported that CGR, RGR and NAR between 60-90 DAS were significantly correlated with pod yield. In Japan, NAR was negatively correlated with LAI, specific leaf area and the distribution of DM to the pod and was positively correlated with leaf N content Ono (1982). Guerra et al. (2008) taking three commonly grown peanut cultivars of different maturity an early maturity cultivar (Virugard), a medium maturity cultivar (Georgia Green), and a late maturity cultivar (C-99R) in the southeastern USA demonstrated that variety trial data in which no phenology data have been collected could be used successfully to derive cultivar coefficients for the CSM-CROPGRO-Peanut model where simulated values of various development and growth parameters were in good agreement with their corresponding observed values for almost all parameters evaluated. Synthetic cultivars with corresponding values for the different combinations of the selected cultivar coefficients were created for the CSM-CROPGRO-Peanut model; the model was then run for each of these cultivars. The set of coefficients for the synthetic cultivar that produced the lowest root mean square error (RMSE) between simulated and observed yield from the variety trials was adopted as the final values for the candidate cultivar. The accuracy of the cultivar coefficients was evaluated using data on plant growth, development, and yield in a research station and two farmers' fields in southwest Georgia. The calibration procedure described could facilitate the estimation of cultivar coefficients for new groundnut cultivars if local variety trial data are available (Guerra et al. 2008).

When simulated by equation, the peak LAI and crop growth rate occurred in the mid pod-setting phase (78-81 days after sowing, DAS) and about 80% of the total dry mass was accumulated during pod formation (Shan et al 1996). Pod dry matter accumulation initiated at 58 DAS, and the peak pod growth rate (pod mass) occurred at early pod maturing (95 DAS). During the yield-formation phase, about 75% of the total dry mass was partitioned to the pods (Shan et al 1996). Kumari et al (1988) assessed the RGR and CGR in 7 cultivars in the field and found JL 24 (Spanish bunch) as best with highest yield and the most efficient physiology. In West Bengal, NAR at 50-70 DAS was the key growth variable and number of pods $plant^{-1}$ was the key yield attributes influencing pod yield of groundnuts (Patra et al, 1994). At Tirupati, India the maximum LAI was achieved at 75 DAS in Valencia, Spanish and Virginia bunch cv. and 90 DAS in Virginia runner cv. and thereafter leaf senescence commenced (Murty *et al*,1983). However the CGR and NAR were highest at 46-60 in Valencia and 31-60 DAS in Spanish and Virginia bunch, in Virginia runner maximum NAR occurred 31-45 DAS, with peaks in CGR at 61-75 DAS. In New Delhi, India the LAI, NAR, total dry matter accumulation and per plant productivity of groundnut in a groundnut-sunflower intercropping system were favored by a one month delay in planting of sunflower during the kharif seasons, NAR of groundnut decreased at the early growth stage due to simultaneous sowing of both crops, but at the later stage, it was recovered and TDM and productivity were compensated, the total productivity was not influenced by intercropping (Maity et al. 2003).

In Between-row sub soiling and broad bed and furrow significantly improved the growth parameters, dry matter accumulation and LAI, number of pods, peg to pod ratio, pod weight, test weight shelling and higher yields over flat bed in groundnut variety GG 20 grown in calcareous clayey soil of Junagadh during kharif season (Vaghasia and Khanpara, 2008). The broad bed and furrow system, showed higher soil moisture content, recorded the maximum growth parameters, yield, monetary return (Rs. 18154 and 18829) and benefit:cost (B:C) ratio (1.73-1.77) on the productivity of rainfed groundnut cv. VRI2 in the clay loam soil of Tamil Nadu (Baskaran et al. 2003). In a field study with 27 groundnut cultivars, mulching with transparent vinyl increased yield by 34% and was highest in Shinpung-type cultivars, while variation was highest in Virginia cultivars, mulching increased branch numbers and harvest index, but decreased branch length and shoot dry weight (Pae et al., 1998).

4.4. Photosynthesis and translocation

The groundnut is a C_3 plant and assimilates CO_2 by reductive pentose phosphate pathway with CO_2 compensation point near 50 ppm. However, the photosynthetic efficiency of groundnut is almost equal to C_4 plants (Dwivedi et al., 1984). The carbon fixation comprises a major part of the dry matter, the net CO_2 assimilation is the principle factor determining the productivity. The improvement in the photosynthetic efficiency to obtain high biomass and yield is one of the recent areas of research for crop physiologist. The groundnut leaf is amphistomatus as the stomatal frequency is similar on abaxial and adaxial surfaces with the total for both ranging from 300-400 per mm^2 (Bhagsari and Brown, 1976). But the adaxial surface show high rate of CO_2 diffusion and 2/3rd of net photosynthesis. The average photosynthetic rate of groundnut has been reported to be 24 to 41 mg CO_2 dm^{-2} h^{-1} with an apparent photosynthetic (AP) rate of 0.7-1.0 mg CO_2 dm^{-2} s^{-1}) in USA (Bhagsari and Brown, 1976), 20-25 mg CO_2 dm^{-2} h^{-1} in India (Nautiyal et al., 1999b), however photosynthetic rate of as high as 77 mg CO_2 dm^{-2} h^{-1} has been also reported (Trachtemberg and Mc Cloud, 1976). The percentage nitrogen, chlorophyll and specific weights are positively correlated with photosynthetic rate, but the stomatal frequency and photosynthesis are negatively correlated.

The ontogenetic changes in growth and diurnal changes in photosynthesis and stomatal conductance show that screening for high P_N has to be made at the pod-filling phase and in between 0900-1000 of the day (Ravindra et al 1995). The groundnut leaves become less efficient with age after full expansion, the photosynthetic rate increased until the leaf was about 2 weeks old and then decreased as the leaf aged. The AP was highest in leaf-3, the youngest fully-expanded leaf on the branch and lowest in leaf-8, leaf-5 exhibit intermediate (Henning et at., 1979; Sastry et al., 1980). The weekly maximum canopy AP increased from about 1g CO_2 m^{-2} h^{-1} at 3 weeks after emergence to a value of 6.5 at 8 to 9 weeks and thereafter it drops nearly to 1 g CO_2 m^{-2} h^{-1} at 14 to 15 weeks (Ketring et al., 1982). The AP decreased with the plant age, and at 110 and 140 days the average AP decreased 21 and 58% from that of 80 DAE (Trachtemberg and Mc Cloud, 1976). In Growth chamber the AP reached to nearly zero at 40 days after unfolding of leaves, but in field grown crop even the significant AP was observed at 60 days old leaf (Trachtemberg and Mc Cloud, 1976). In Haihua 1 and Luhua 11 cultivars, in China, the LAI, canopy apparent photosynthesis rate (CAP) and canopy respiration rate (CRR) reached to their maximum values on 82nd, 90th and 90-95th day, after sowing respectively, and a linear relationship existed between LAI and CAP prior to 82 DAS only (Fu et al (1995)) respectively. It showed a single-peak diurnal pattern in their CAP reached its maximum value at noon and negative values from early evening to early morning. The photosynthetic rate of wild species are generally lower than cultivated *A. hypogaea*.

The groundnut attains its maximum leaf AP rates at about 30°C, the rate decreases above and below this optimum and at 40°C rate was reduced to 25% and at 10°C by 65% (Bhagsari, 1974). On ground area basis the AP of well developed canopies of groundnut may reach values of 6 to 8 g CO_2 m^{-2} h^{-1} in Tifspan and Florunner cultivars, with the respiration of the soil and plant 1.4 g CO_2 m^{-2} h^{-1} or about 1/3rd of maximum AP (Boote et al., (1980). The average photorespiration in groundnut is about 4 mg CO_2 dm^{-2} h^{-1}, dark respiration of 1.7 to 2.6 mg CO_2 dm^{-2} h^{-1} and 2.7 K lux is needed for compensation by photosynthesis (Bhagsari, 1974). At atmospheric concentration of CO_2 and O_2 the reduction in apparent photosynthesis (AP) by O_2 is about 30% (Pallas and Samish, 1974). The net photosynthetic rate (P_N) ranged from 0.58 to 1.03 mg CO_2 m^{-2} s^{-1} and CGR was significantly correlated ($r = 0.94$) with P_N (Rao and Das, 1981). Chlorophyll a+b content and leaf area was better correlated with P_N than when expressed fresh matter unit. Chlorophyll: P700 ratio was negatively correlated with P_N thereby indicating that the greater the number of photosynthetic units the greater the P_N and CGR. Ribulose 1,5-diphosphate carboxylase activity, LAI, leaf diffusion conductance for CO2 and LAR were other characters, which were significantly positively correlated with P_N. The SLW and rate of gross photosynthesis and respiration was higher in runner cv. M13 than the erect cv. J 11.

Nautiyal et al (1999b) studied the net photosynthetic rate (P_N), in field-grown groundnuts cv. GG 2 in relation to leaf position, time of day, reproductive sink, and phenophase and reported that, in general, P_N remained higher in upper leaves (top 1-4) than in lower leaves (5-8). The mean P_N of the leaves situated upper and the leaves lower in the canopy increased from the morning, reached a maximum during noon hours, and decreased thereafter. Between 09:00 to 10:00 h, P_N, stomatal conductance (gs), and transpiration rate (E) in the upper leaves were higher than in the lower leaves, but between 12:00 and 13:00 h, these activities increased significantly in the lower leaves. Highest P_N was found during pod-development phase. The P_N per unit leaf area in plants with reproductive-sink (WRS) was similar to those without reproductive-sink (WORS). However, leaf area of WORS plants decreased significantly, mainly due to the reduction in number of leaves. The diffusive resistance of leaves were constant from 9 a.m. to 3 p.m. then increased upto 10 p.m. It ranged from 1.5 to 5 S cm^{-1} between 9 a.m. and 3 p.m. and was 84 sec cm^{-1} at 10 p.m. for *A. hypogaea* never at from 5 to 12 sec cm^{-2} between 9 a.m. to 3 p.m. for *A. villosulicaropa and A. glabarata* (Pallas and Samish, 1974).

There are a few reports that the canopy is not able to meet the photosynthetic demand of developing pod due to lesser CO_2 concentration in the atmosphere. The net photosynthesis (P_n) increased linearly as the CO_2 concentration increased from 50-600 ppm, the Florunner have had highest P_n at CO_2 concentration 300ppm and above (Bhagsari and Brown, 1976). CO_2 enrichment with 1000 ppm during seed fill stage increased biomass of leaves, roots and pods, although the pod yield increased only 15% the 100 seed weights increased 30% due to better pod filling (Chen and Sung, 1990). However, CO_2 enrichment from 400 to 800 µmol mol^{-1} had positive effects on growth and yield groundnut cv. 'Georgia Red', but above 800 µmol mol^{-1} enrichment seed yield increased only marginally (Stanciel et al, 2000). The elevated CO_2 in groundnuts increased foliage weights, branch length, number and weights of pods, harvest index, total seed yield increased 33% with increased from ambient to CO_2 up to 800 µmol mol^{-1}, but declined at 1200 µmol mol^{-1}, however, specific leaf area decreased and the yield of immature pods was not influenced. while linearly as CO_2 increased from ambient to 1200 µmol mol^{-1} (Stanciel et al., 2000). Net photosynthetic rate was highest at 800 µmol mol^{-1}, but stomatal conductance decreased with increased CO_2, the carboxylation efficiency was similar among plants grown at 400 and 800 µmol mol^{-1} and decreased at 1200 µmol mol^{-1} CO_2. The CO_2 enrichment from 400 (ambient) to 800 µmol mol^{-1} had positive effects on groundnut growth and yield, but above 800 µmol mol^{-1} enrichment seed yield increased only marginally (Stanciel et al., 2000).

The top leaves had a higher photosythetic rate and contributed more to the developing pods than did middle or lower leaves. Sengupta and Jadhav (1988) reported that decrease in light intensity either continuously or at any growth stage reduced the photosynthetic rate and re-exposure to natural light caused a post-illumination burst in the rate of photosynthesis which depended upon the amount of shade before the exposure to full sunlight. Decrease in light intensity also decreased the assimilate translocation to the pods. Maximum reduction in translocation occurred when the plants were exposed to low light intensity at the peak pod development stage which resulting in low pod yield. Boote et al. (1980) observed that upper 42% of the canopy leaf area intercepted 74% of the light and fixed 63% of the total CO_2 taken up by the whole canopy. Removal of 25% of the total leaf area, from the upper half of the canopy, reduced CO_2 uptake by 30% and CO_2 exchange rate by 35%. Severe leaf spot damage by *Cercospora* reduced the leaf area index by 80%, CO_2 uptake by 85% and canopy CO_2 exchange rate by 93%. The Leaf and stem photosynthesis contribute equally to DM yield till 60 DAS and thereafter stem photosynthesis is more important. Efficiency of reproduction and translocation was highest in Valencia and Spanish. The decrease in photosynthesis (Pn) under stress was associated with a decrease in stomatal conductance (g_s) and RWC (Nautiyal et al., 1995). The PN and RWC were high under stress in drought tolerant GG 2 cultivar than drought sensitive JL 24 cultivar and on the relief of stress the g_s and RWC recovered more quickly in tolerant than sensitive, hence maintenance of higher RWC (>80%), g_s and PN under stress appears to be imparting drought tolerance in groundnut. It is suggested that low light intensity at the pod development stage would severely affect the groundnut yield due to the decrease in photosynthesis as well as reduced translocation of assimilates to the pods.

Defoliating insects and *Cercospora* leaf spot are major yield-reducing pests of groundnuts and effects on photosynthesis, apparent canopy carbon exchange rate (CER), $^{14}CO_2$ assimilation and light intercepting characteristics. Bourgeois and Boote (1992) reported that 15% necrotic leaf area due to late leaf spot reduced 65% photosynthesis. Canopy carbon dioxide exchange rate was reduced by 45-70% in groundnut immediately after 75% defoliation, but subsequently considerable recovery was achieved by changes in leaf area and re-adaptation of shade leaves to full sunlight (Jones et al. 1982). The latter involved increases in specific leaf weight. These recovery mechanisms were less efficient in older plants. The canopy photosynthesis is inversely proportional to disease severity, which is related to both defoliation and necrotic areas. Boote et al. (1980) observed AP rate of 2-4 g CO_2 m^{-2} ground area h^{-1} in leaf spot damaged crop. The AP reduced 35 and 65% at leaf spot damage of 11 and 56%, respectively at a light intensity of 1500 µE m^{-2} sec^{-1} (Boote et al., 1980).

Rates of leaf transpiration and photosynthesis are both affected by the thickness of the boundary layer (BL) and by the rates at which gases diffuse through it. Pachepsky et al., (1999) studied the transpiration rates and BL for two Argentine groundnut (*Arachis hypogaea*) cultivars, Florman INTA, Virginia type, and Manfredi 393 INTA, Spanish type, were studied with the two-dimensional model 2DLEAF which accounts for leaf anatomy, i.e. for leaf internal structure and stomatal density. Transpiration rate was presented (a) as a function of BL parameters d and B with four empirical parameters which depended on cultivar and stomatal aperture, and (b) as a function of stomatal aperture and d. Dependence (b) showed that the transpiration rate of Manfredi 393 INTA is higher than that of Florman at the same environmental conditions, and that this is completely due to the difference in leaf anatomy. It was shown that the values of BL, thickness, d, grow with increasing stomatal aperture. For amphystomatous leaves of groundnut, two empirical parameters, d and intercellular space and B are necessary and sufficient to quantitatively describe the effect of the BL on transpiration (Pachepsky et al., 1999). In a study from flowering, leaves of groundnut cv. Luhua 11 and Fu 8707 were studied from the day of unfolding, for net photosynthesis rate (Pn), intercellular CO2 concentration (Ci), stomatal conductance (Cs), stomatal resistance (Rs) and transpiration rate (Tr) were measured every 10 days at 1000 to 1400 h on sunny and calm days where chlorophyll was the main factor affecting Pn and reflected the rate of Pn, during leaf growth to senescence, the changes of Cs and Tr were basically similar to Pn but during senescence Pn decreased more rapidly than chlorophyll content (Li et al., 2002).

The rate of translocation is positively correlated with net photosynthetic rate; however, environmental factors affect efflux and distribution of photosynthates. The translocation of photosynthates involves movement of metabolites from mesophyll cells to phloem tissue, phloem loading, translocation in phloem, unloading and metabolism of photosynthates in the site of utilization. During the early stages the partitioning of dry matter is into the leaf and stem but in later stages it accumulates simultaneously in the vegetative parts and fruits as these two phases overlap in groundnut. Thus the quicker cessation of the vegetative growth (dry matter accumulation in stems) makes more photosynthates available for pods and is a desirable character. In USA the yield improvement was due to partitioning of assimilates between vegetative and reproductive parts, length of grain-filling period and rate of fruit development (Duncan et al., 1978). The autoradiographic study have shown that in vegetative stage, growing leaves exported most of the ^{14}C to the apices, young expanding leaves and to the roots, but soon after the initiation of pegs and pod the developing pod became the major sinks, at pod developmental stage the foliage of each branch was restricted mostly to the pods produced by that branch (Khan and Akosu, 1971). The basal leaf (L-3) of the first branch exported only downwards to the pods attached to it, the fifth leaf exported both acropetally to the apex and basipetally to the pods, and the youngest unfolded leaf exported mostly to apex and only a small portion to the pod attached to the branches (Khan and Akosu, 1971).

The metabolic reserves are built up on the fruit and seed coat during early maturation and utilized later during seed development when available translocated photosynthate gets diminished. Spray of a nutrient solution containing 0.21, 0.16, 0.20, 0.10, 0.015 and 0.014 mM of N, P, K, Ca, B and Mo, respectively, with 10 ppm 6-BA (benzyladenine) and 5 ppm GA3 at 10, 20 or 30 days after the beginning of anthesis increased the rate of photosynthesis and promoted the translocation of assimilates from the leaves to the pods and increased the pod number, percentage of well-filled pods and 100-pod weight (Li et al 1994). A combination of the nutrient solution with 6-BA and GA3 gave the best result, with yield per plant and yield per plot 15.4% and 20% higher than the control, respectively. Ram et al (1994) reported that rates of net photosynthetic CO_2 uptake (P_N) and the import of ^{14}C-labelled assimilates in developing groundnut leaves were followed over a 20-day maturation period where maximum import of labelled assimilates into the leaf was observed on the 2nd day after leaf emergence, when the developing leaf had attained 10-12% of its final leaf area (% Af). Thereafter, by the 5th day the ^{14}C-import rate declined rapidly and asymptotically to a near zero value. The rapid decline in import was offset by a rapid rise in P_N which was first observed at 20-30% Af. Maximum P_N values were attained by the 6th day, irrespective of leaf area attained by the developing leaves, and were maintained up to the end. Zhuang et al (1991) reported that groundnut treated with 800 or 1200 ppm B9 (daminozide) at about 2 months after sowing increased leaf thickness and gave deeper green leaves but decreased plant height. The ATPase activities of the whole leaf and at the plasma lemma of the mesophyll cells, sieve elements, companion cells and transfer cells increased resulting in increases in photosynthesis and transport of carbohydrate, which could relate to active loading of the phloem.

Thouth leaves are the primary sites of $^{14}CO_2$ fixation in groundnut, their contribution generally declined late in the season; whereas fixation by stems was initially low but increased sharply when stress was released in the late-irrigated stands (Stirling et al, 1989). The effects of phosphorus and potassium deficiencies on CO_2 fixation and translocation of photosynthates were studied using ^{14}C feeding and it was noticed that K deficiency had a direct effect on translocation and P deficiency had an indirect effect by increasing the metabolic activity (Basha and Rao, 1981). The ^{14}C-fixation by stem apices and pegs also rose sharply following irrigation of the late-stressed stands. Leaves are the primary source of assimilates, but translocation tended to decrease as the season progressed, even in the late-irrigated stands. Stems were initially the major sinks, but their activity disappeared almost completely when stress was released in the late-irrigated stands. Assimilate import by stem apices declined progressively and pod sink activity was negligible in the late-stressed stand, but both increased markedly when early-season stress was released. increasing moisture stress from 0 to 2, 4 and 6 atm decreased the relative leaf water content, increased water saturation deficit and relative saturation deficit, decreased DM accumulation in the shoot and increased it in the root, decreased RGR, increased specific leaf weight, decreased non-reducing sugar content and increased the reducing sugar content in groundnut seedlings. Jun et al (1999) using a gas-phase oxygen electrode measured the photosynthesis and respiration of 13 groundnut cultivars grown in pots in a natural-light phytotron under 28/23°C day/night temperatures, 60% RH and 380 ppm CO_2 and reported that though the cultivar differences in the rates of photosynthesis and respiration were within a range of mean values ±17%, the cultivars Jenkins Jumbo, Posados 64 and Satonoka with high photosynthetic oxygen evolution (24% higher than the mean) had high respiratory oxygen absorption (17% higher than the mean), and there was a weak correlation between photosynthesis and respiration.

Wang et al. (1996) in a field trials at Laixi, China, studied physiological characteristics related to their canopy morphology in 2 high-yielding groundnut cultivars (Luhua 11 and Haihua 1 characterized by few branches, medium duration of growth, and large pods) and listed the physiological indices for the groundnut canopy that would ensure yields of 7.0-7.5 t ha^{-1} . The major area of photosynthesis was the upper one-third of the canopy which received four-fifths of the solar radiation and contained about half of the total leaf area. The light interception rate of the canopy remained low (50% of solar radiation reached the ground) until the flowering-pegging stage but rose to a peak which was maintained until the early-mid pod-filling stage. Measurements of diurnal variations in photosynthesis on a clear day showed a peak between 11.00 and 13.00 h. No sign of 'noon rest' or light saturation was evident under natural conditions so the dominant factor was intensity of solar radiation. Dark respiration was maximum at 11.00-15.00 h and minimum at 03.00-05.00 h, and was strongly dependent on air temperature. Over the growing season the net photosynthetic rate increased slowly during the seedling stage and accelerated from the flowering-pegging stage until mid pod formation when it reached a peak (Wang et al., 1996). Photosynthesis was more sensitive to water deficiencies than dark respiration (Wang et al., 1996). Diurnal variations in photosynthesis, the enzymes of sucrose metabolism, and soluble sugars, were determined in 85-d-old groundnut Girnar 1 plants. Carbon exchange rate was closely related to photosynthetically active radiation. Stomatal conductance was highest when leaf temperature was highest. Sucrose phosphate synthase (SPS) activity was highest at 2200 h and lowest at 1400 h, while sucrose synthase (SS) activity was highest at 1000 h and lowest at 1800 and 0200 h. Sucrose and fructose contents had a peak at 1800 h. Theoretical analysis suggested that the observed levels of SPS were inadequate to cope with the levels of photosynthate required for export (Misra et al., 1995).

The relationship between LAI and CRR varied at different stages: a synchronous increase in the first 50 d after sowing; a rapid increase in CRR in the same period; a gradual decline in

LAI from the 82nd to 98th day in contrast with a sharp increase in CRR in the period; and a simultaneous decline in both parameters after the 98th day. The relationship between CAP and CRR was described in three stages: a simultaneous increase in the first 50 d after sowing and a decrease from the 98th day, and their relationship was not clear between these two dates. CRR exhibited a single-peak pattern in its diurnal fluctuation at all growth stages. The diurnal changes in CAP differed with genotypes. At the seedling stage, Haihua 1 showed a double-peak pattern with a distinct "noontime rest" whereas Luhua 11 showed a single peak. Starting from the 50th day after sowing, both cultivars showed a single-peak diurnal pattern in their CAP; it reached its maximum value at noon and its values were negative from midnight to early morning and from early evening to midnight (Fu et al., 1995). The moisture content of groundnut seeds could be decreased to at least 3.32 %, which was suitable for germplasm conservation at ambient temperatures (Cheng et al., 1997).

5. Reproductive Growth

The underground fruiting habit and highly condensed reproductive branches (inflorescence) has led to an inaccurate description of this plant till 1950s. The *Arachis* is a perennial or annual legume with 3 or 4 *foliolate*, stipulate leaves, papillionate flowers, a tubular hypanthium and underground fruits (pods). A unique structure `peg' is an expanded intercalary meristem at the base of the basal ovule resulting in a lomentiform carpel of 1-5 segments, each containing single seed with two massive cotyledons and a straight embryo. The bunch and runner groundnut types differ in their duration (110-120 days in sequential and 130-150 in alternate branched) and seed dormancy. The branching in groundnut is related with pod yield and there is a good correlation between yield and branching and the length of internodes. It is desirable to initiate early branching, which increase the total flower bearing areas and the chances of pod formation because the flower borne at the basal part of the plant has greater chance to develop into pods. The cultivated groundnuts are classified by assigning main axis, as `n' and the first, second and third branches as n+1, n+2 and n+3. The two main botanical sections of A. hypogaea differ in the distribution of vegetative branches and inflorescences on the main axis and the branches. In sequential type (Spanish and Valencia), inflorescences are borne from the second nodes of the primary branches (n+1) and are usually bunch type. In the Spanish type the n+1 branches grow upwards from the very beginning whereas in the Valencia group, these branches grow outward first and then upward. In the alternate branching type (Virginia), the first two nodes of primary branches bear secondary (vegetative) branches (n+2), the next 2 nodes bear inflorescences and the next 2 again vegetative branches and so on. The same sequence is repeated on the secondary branches, but the inflorescence never develops on the main axis. The runner forms have prostrate n+1 branches (Virginia runner), whereas the spreading forms have more upright branches (Virginia bunch). The flowering, pollination and pegging are the main reproductive growth phases, which are described, separately in the following text.

5.1. Flowering, Pollination and pegging

There are usually 4 stages of flowering, the pattern of which depends upon cultivar and environment. At first stage only a few flowers are produced followed by a stage of rapid flowering, peak is reached at the third stage and decline in the fourth stage. The flowering in groundnut commences 20-40 days after emergence (DAE) depending upon genotypes and environment and most of the flowers appear in between 35-70 DAE, however ‘Makalu Red’ flowers at 55 DAE in Rhodesia (Williams et al., 1975a). The groundnut produces much more flowers than it develops pods. Nearly 40% of the flowers fail to develop, while another 40% produce only pegs. The ratio of pod produced to flower is generally 1:7 and removal of flowers result in prolong flowering. The flower bud is only 6-10 mm long a day before anthesis, during the day hypanthium elongates to 10-20 mm, but at night elongation is faster and at the time of anthesis the buds are 50-70 mm long. The buds generally open at the beginning of the light period, but may be delayed due to cold or wet weather. The Anther may dehisce 7-8 h before the opening of flowers. On warm and sunny days, the flowers wither within 5-6 h after flowering leaving ovary and style which remains turgid after the day of anthesis. As the daily mean temperature rises from 20 to 30ºC the number of days required for first flowering is reduced from 38 to 25 days in sub species *hypogaea* (Virginia runner) and from 35 to 24 days in sub species vulgaris (Valencia and Spanish) (Ono, 1979).

The number of flowers produced per plant varies among genotypes and between botanical group. Runner produced more flowers per plant and also had a longer duration of flowering than the erect one. The number of flowers produced per plant ranged from 40-250 in Runner and 100-150 in bunch types. The cumulative flower production of `Makalu Red' a spreading type was 240 (Williams et al., 1975a). Flowering gets reduced as pegging and fruiting progress. Flowering stops when the soil moisture drops to wilting point but continuation of fruiting depends on the length of drought. RH had a positive effect on the daily production of flowers. The groundnut is a self-pollinated crop as the stigma is enclosed in the keel, but high frequency of cleistogamy has been reported (Murty et al., 1980). The stigma protrudes above the anthers and is receptive before anthesis. In nature the stigma and anther are exerted in few groundnut causing cross-pollination from less than 1% to 3.9%. Fertilization is completed in about 6 h after pollination (before mid-day) and flower wither. The ovary at the base of the calyx tube becomes mobilised for growth within a week after fertilization and an intercalary meristem below the ovary is activated. The developing ovary pierces through the floral parts by the activity of the meristem to reveal an elongating peg called carpophore (gynophore) which bears fertilized ovules at its tips.

Peanut crops are often exposed to day temperatures > 35°C for short periods during flowering, resulting in lower yields. Vara-Prasad, et al. (2001) critically examined the effects of short episodes (1-6 days) of high temperatures during the pre- and post-anthesis stages of floral development on fruit set, pollen viability, germination and tube growth and reported that floral buds were most sensitive to high temperature at 4 days before anthesis and at anthesis, coinciding with microsporogenesis and pollination or fertilization, respectively. Exposure of floral buds to temperature >39°C for 1 day significantly reduced fruit set compared to the control at 28°C, and the magnitude of the reduction varied with stage of floral development. The critical bud temperature at these stages was 33°C, above which fruit set was reduced by 6% $°C^{-1}$ and high temperatures at pre-anthesis and anthesis stages caused pollen sterility and retarded pollen tube growth, respectively resulting in lower fruit set (Vara-Prasad, et al. 2001). In Turkey Calskan et al. (2008) while studying on the reproductive growth and yield components of 8 groundnut genotypes (PI 269084, PI 355276, 75/1073, NC 9, Edirne, Osmaniye 2005, Com and NC 7) found that number of flowers per plant was negatively correlated with the percentage of flowers turned to pegs and pods, whereas the percentage of flowers turned to pegs and pods was positively correlated with pod yield and were the most promising generative plant characteristics that could contribute to seed yield increase in groundnut production in a typical eastern Mediterranean climate (Calskan et al.2008).

The growth of peg is geotropic until it penetrates the soil upto 5-7 cm depth. The tip then becomes diageotropic and ovary starts developing into fruit. The peg begins rapid geotropic elongation and starts to penetrate the soil about 7 to 14 days after fertilization of the flower. Following soil penetration the ovary at the peg tip reinitiates growth and a groundnut fruit is formed. If the pegs fail to contact and enter the soil it usually wither, however, in humid conditions some cultivars belonging to *fastigiata* occasionally form underdeveloped small and green aerial pods. The portion of peg in the soil is white, while the aerial portion of peg normally develops pink to purple colour due to anthocyanin pigments which is cultivar dependent and very much influenced by the environment. The thickness of peg is 1-2 mm, the cultivars of subspecies *fastigiata* have thicker pegs than *hypogaea*. The peg growth is affected by relative humidity and on an average, the daily peg growth is 0.62 cm at 100% RH, and only 0.02 cm at 57% RH. But generally the RH of the air is quite low in many groundnut-growing regions at the start of flowering and at the time of pegs penetrate into the soil. In China, Jun and Ke (1988) controlled peg growth by adopting a crop technique `A n M' by transforming the ridge into a narrow bank, which gave the base of plant better ventilation and the distance between the pegs and the surface of soil increased resulting delay in peg penetration. This technique increased the accumulation of photosynthetic products in the ovaries, and increased the diameter of the vascular bundles in pegs and the pod yield by more than 20% in China.

In groundnut, the flowering and fruiting are of an indeterminate type, which generally has an effect on pod yield and quality. The ideal type of groundnut would be one that sets all its young fruits within 4-5 days and spends the rest of the growing season filling them. Same times there are two peaks of flowering in normal sown crop many part of India causing higher reproductive efficiency than the late sown crop which has no peak. More numbers of flowers produced upto 45 DAS cause a greater reproductive efficiency and higher pod yield. The continuous removal of flowers increased the daily flower production from 3 to 20. Vegetative growth was increased by flower removal in groundnuts cv. M 13, pod number increased by removing early phase (0-4 weeks) flowers and decreased by removing middle (5-9 weeks) phase flowers, or middle + late flowers (9 weeks to maturity) (Talwar et al 1992). Gynophore removal in the late phase increased numbers of mature pods. Removal of pegs for one week from the onset of flowering increased root biomass and aerial pegs but reduced pod yield (Narayanan et al., 1984). The Virginia cultivars compensated better for initial lost pegs than bunch types.

5.2. Seed growth and pod development

The peg, after reaching its maximum depth in soil, becomes diageotropic and horizontal and pod development initiate from enlargement of pod at the base. For the initiation of pod formation darkness is essential and a mechanical stimulus is needed for the normal thickening and diageotropic orientation of the pods. The normal podding zone is 4-7 cm below the surface. The pod expands rapidly in the soil by the development of a large parenchymatous tissue called endocarp lying between the ovules and shell. The endocarp recedes with ovules growth and disappears completely when the seed have matured. In the mean time the inner face of the shell becomes increasingly dark brown due to increase in tannin content and become very dark brown at maturity. It takes about 60 days from the time of fertilization to full maturity. The swelling of ovaries commences two days after, the pod attains its maximum size within 3 weeks. During the pod filling the leaves near the plant periphery contribute most to the pods and the photosynthetic capacity of leaves decreased during this period (Henning et al., 1979). The optimum soil temperature in the podding zone is 31-33ºC (Ono, 1979), at lower temperature of around 23ºC the number and weight of pod increases but require longer filling period (Dreyer et al., 1981).

The fertilized flowers ranged from 50-60% in runner and 20-70% in bunch types and only about 60-65% of these fertilized flower elongated as pegs. All the pegs do not grow long enough to reach the soil and to develop into pods, and all the pegs entering into soil do not develop into mature pods. On an average about 40 % of the pegs do not produce pods. Thus finally only 8-16 % of the flowers turned into pod in bunch types while 12-18 % turned into pod in runner types. Generally most of the early formed flowers develop into pods, but the flowers that appear 70 DAS form only immature pods at harvest. Also the early formed flowers of an inflorescence inhibit the development of the other flowers into pegs (Bunting and Elston, 1980). The groundnut fruit, that is generally referred to as a pod, is a lomentiform carpel, indehiscent and up to 10 cm in length. The mature pod normally contains 2-4 seeds but 5 and 6 seeds per pod have also been recorded occasionally. The fruit consists of two valves, structurally dehiscent but functionally indehiscent and when pressed, splits along the longitudinal suture. The shell consists of an outer spongy layer, a middle fibrous and woody layer and an internal layer that with maturation becomes thin and papery. The mechanical tissues on the pod give it the reticulate pattern. The cultivars differ in fruiting patterns, in bunch type the pods are more near the tap root than in runner type.

The pod number and weight can be measured at about 60 to 70 DAE, pod number rises rapidly to a maximum at 100-120 DAS and than remain constant till harvest. The potential reproductive growth rate (R) of a good groundnut crop is about 100 kg ha^{-1} day^{-1}. The pod weight increases in a linear fashion during pod filling and the linear growth rate continues until near harvest. The rate of pod dry matter accumulation during linear growth phase ranges from 5 to 10 g m^{-2} ground area day^{-1} (Singh, 2003). The competition between the developing vegetative sinks and the reproductive sinks appears to be one of the limitations in the productivity. Shading at full bloom stage reduces yield. As the assimilate supply is not limiting factor the pods initiated earlier had a higher growth rate than those of later. This is the reason why the earlier pods contained more seeds than later formed, and the basal nodes bear more pod than upper nodes. It is possible to induce the upper nodals gynophores to set pods but that reduces the yield of the basal nodal pods. Moreover, the induction of pods in upper nodal gynophores prolongs the life cycle of plant. Each inflorescence bears only a single fruit even though several fertilized ovaries develop from the latter flowers. But if the first ovary or fruit is damaged or removed or treated with gibberellin, the later formed ovary from the same inflorescence can form peg and fruit, which insure the plant against the misfortune. Duration of the reproductive growth is an important factor affecting yield, and a small differences in this can result in poor decision about the merit of the selected materials.

The crude protein percentage of seed decreases during fruit growth after 3 weeks but not below 20 to 30% of dry wt., however, the protein percentage of shell and testa continue to decrease throughout the development. The lipid content of seed increased from 30 % at 2 weeks of age to 50% at 6 to 7 weeks. As more energy is required for lipid synthesis, the CO_2 equivalent (Change in dry weight divided by change in CO_2 equivalent) decreased from 0.64 during vegetative period to 0.29 near maturity, and if the maximum CGR (19.6 g m^{-2} day^{-1}) is corrected for the reduced dry weight/CO2 equivalent "transformation factor" observed during early to mid-pod filling then becomes 25 g m^{-2} day^{-1} (Watanabe, 1975). The cost of synthesizing groundnut seed is 2.54 g glucose g^{-1} of seed including N assimilate, and 2.09 g glucose g^{-1} of seed when amides are available from proteins, however the glucose cost is 1.704 and 3.106 g glucose g^{-1} of protein and lipids, respectively (Penning de Vries and Van Laar, 1982). As the major constituent of oilseeds are triglycerides, it require a plant to expend 3.3 g photosynthate to produce one gram of triglycerides.

The seeds size, weight and seed coat colours are the important economic and distinguishing characters of groundnut cultivars. The seed length varying from 7 to 21 mm, diameter from 5 to 13 mm and seed wt. from 0.10 to 1.5 g have been reported. Generally, the cultivars belonging to Virginia group have larger and heavier seeds and those of Valencia and Spanish have smaller seeds. However, the seed and pod size distribution are a function of pod maturity and plant age (Williams et al. (1987). The seed size also varied according to the position within a pod and generally basal seeds were smaller than the other in 4, 3 and 2 seeded pods. Light rose to rose colour are most preferred by the people. Generally there are two seeds per pod, the single seeded pods may occur in almost all cultivars but it is not a cultivar specific. Three seeded pods are found in both *hypogaea* and *fastigiata* sub species. Bunch cultivars belonging to var. *fastigiata* possess predominantly three or four seeded pods. As groundnut matured the Moisture content decrease, protein content remaine unchanged, carbohydrates decrease and oil content increase. Sum of oleic and linoleic acids as percentage of total fatty acid is increased with maturity as did unsaturated fatty acids contents. The number of days and cumulative degree days are the important factor assessing the maturity. The BAPAase [benzoyl-L-arginine p-nitroanilide hydrolase] activity existed in developing seeds, and increased with the maturation of the seed, when seed were made to germinate in vitro, BAPAase activity increased rapidly, no synthesis of new peptidase was observed during germination, however, the ABA inhibited BAPAase activity. In deteriorated seeds, both BAPAase activity and seed vigour vigour index (expressed as germination percentage x radicle length) dropped significantly (Lin et al. 1995). In further study activity of BAPAase (benzoyl-L-arginine p-nitroanilide hydrolase) was detected in groundnut cotyledons and hypocotyls during embryo development, and increased during germination, but its synthesis occurs in the hypocotyl (Lin et al. 1997). Williams and Drexler (1981) developed Hull-scrape, a non destructive method of maturity classification based on the changes that occur in the colour and structure of the pod mesocarp which can be used. However, cracking sound when a pod is pressed and blackening of inner surface of shell is the most important criterion for assessing pod maturity.

The cysteine endopeptidase (EC 3.4.22), which plays an important role during seed germination, is synthesized during seed development and can only degrade modified storage proteins (Bin et al. 1996). This enzyme was purified 28.1-fold from groundnut cotyledons giving a final recovery of 15.9% of the crude extract and existed in 2 forms, which had MW of 58 and 55 kDa shown by SDS-PAGE and its activity was optimum at 50°C and pH 8.1, it only hydrolysed 5-10% of arachin or coarachin I or 2s protein of ungerminated groundnut seeds in vitro(Bin et al. 1996). The germination capability of groundnut seeds was completed before 40 d after pegging and vigour formation increased rapidly after this date, the synthesis and accumulation of storage proteins coincided with the formation of seed vigour and with the accumulation process of different storage proteins, arachin was degraded more rapidly than conarachin and 2S peptides (Lin et al. 1996c).

Transcription factors ABSCISIC ACID-INSENSITIVE3 (ABI3), LEAFY COTYLEDON (LEC2) and FUSCA3 (FUS3) play important roles during seed development. RNA extracted from groundnut root, stem, leaf and developing cotyledon and microsections of root, stem, leaf and developing cotyledon (including embryo) of groundnut when hybridized using a probe from the conserved B3 domain of *Arabidopsis thaliana* ABI3 protein, the positive results of hybridization signals observed only in groundnut cotyledon revealed that the homologous genes of AB13, FUS3 and LEC2 may exist in groundnut and that they are only distributed in the cotyledon and embryo of groundnut (Guo et al. 2006).

The acetyl-CoA carboxylase and all the enzymes of fatty acid synthetase from developing groundnut seeds are soluble and in developing groundnut seeds (30-35 d after flowering) the major fatty acids formed were stearic (77%) and palmitic acids (14%) with 4% of oleic acid (Sreenivas and Sastry, 1995).

Parvathi and Rajasekharan, (2002) reported identification of a non-MAP kinase cascade dual-specificity kinase involved in abiotic stress and seed development. Tyrosine (Tyr) phosphorylation represents an important biochemical mechanism to regulate many cellular processes. A 1.7-kb cDNA that encodes serine/threonine/Tyr (STY) kinase was isolated by screening groundnut expression library using the anti-phospho-Tyr antibody. The histidine-tagged recombinant kinase histidine-6-STY predominantly autophosphorylated on Tyr and phosphorylated the histone primarily on threonine. Genomic DNA gel-blot analysis revealed that STY kinase is a member of a small multigene family. The transcript of STY kinase is accumulated in the mid-maturation stage of seed development, suggesting a role in the signalling of storage of seed reserves. The STY kinase mRNA expression, including kinase activity, markedly increased in response to cold and salt treatments; however, no change in the protein level was observed, suggesting a posttranslational activation mechanism. The activation of the STY kinase is detected after 12 to 48 h of cold and salt treatments, which indicates that the kinase may not participate in the initial response to abiotic stresses, but may play a possible role in the adaptive process to adverse conditions. The transcript levels and kinase activity were unaltered with abscisic acid treatment, suggesting an abscisic acid-independent cold and salt signalling pathway.

Jain and Padmaja, (2004) studied the induction of maturation proteins in the germinating seeds by exogenous application of abscisic acid (ABA; 25, 50, 75, 100 and 125 µ M) and sodium chloride (NaCl; 50, 100, 150 and 200 mM) in groundnut cv. DRG-12 and the SDS-PAGE protein analyses revealed that proteins of 65, 31 and 22 kDa accumulated in abundance in embryos during late seed maturation, but expression of these proteins declined to undetectable level by fourth day during seed germination. The relative amounts of 65, 31 and 22 kDa proteins varied in the groundnut seeds germinated in the presence of ABA and NaCl at different concentrations. Proteins of 65 and 31 kDa accumulated to a higher level in the presence of 75 µ M ABA, while 22 kDa protein was present in relatively lower amounts at this concentration. There was a gradual decrease in the amount of 65 kDa protein with further increase in the concentration of ABA (100 and 125 µ M). Application of higher concentrations of NaCl (100, 150 and 200 mM) inhibited seed germination and promoted the accumulation of 65, 31 and 22 kDa proteins (Jain and Padmaja, 2004).

Developing seeds of the groundnut (subsp. fastigiata var. vulgaris) high-oleic acid variant F435 and its presumed isogenic, normal line (78-1339) when compared using two-dimensional gel electrophoresis, a pair of 20 kDa polypeptides focusing at pH 6.8 and 7.3 was present in all of the polypeptide profiles from both isolines regardless of maturity or genotype except for F435 at stage 1 maturity which contained, instead, an 18 kDa polypeptide pair focusing at about pH 9.3 (Wheeler et al. 1994). It is postulated that the 20 kDa polypeptides could be components of the DELTA12-desaturase complex, the 18 kDa polypeptides appeared to be associated with lower desaturase activity, reduced linoleic acid and increased oleic acid seed content and as 18 kDa polypeptides focusing at pH 9.3 are not found at later stages, they are probably under developmental control (Wheeler et al. 1994).

Senthil et al. (1997) while studying the Peroxidase and esterase isozymes and storage proteins in seeds of different developmental stages of groundnut pods found an ontogenic variability for both isozyme and protein levels. The peroxidase isozyme pattern showed that the Prx1 and Prx2 genes were expressed in early stages of development but Prx3 and Prx4 extended up to 45 days after fertilization (DAF), ehe esterase isozymes loci showed Est1 expressed in 20 DAF and not in later stages, the 29 kDa protein accumulated up to 30 DAF and later it was converted to other forms. The acquisition and induction of desiccation tolerance associated with the expression of heat-stable proteins in developing groundnut seeds were studied by Yang et al. (1998). Desiccation tolerance was achieved during 45 to 65 DAP (days after pegging), while a set of low molecular weight (9 to 15.5 kDa) heat-stable polypeptides was preferentially expressed. A slow drying regime applied in vitro to 25 and 35 DAP groundnut embryos induced desiccation tolerance and the expression of the same subset of polypeptides. Prior drying treatment enhanced the ability of 65 DAP embryos to withstand fast drying, and increased the heat stability of arachins, the major groundnut storage protein, which was heat labile at 45-65 DAP. They concluded that the heat-stable proteins may contribute to desiccation tolerance of the groundnut seeds, and the low molecular weight heat-stable polypeptides may confer heat tolerance on groundnut storage proteins which were normally heat labile (Yang et al. 1998).

6. Yield components

6.1. Partitioning and harvest index

The high yield is associated with rapid increase in pod number and near cessation of vegetative growth during pod filling. The partitioning coefficient range from 40-98 % and the partitioning of a higher percentage of photosynthate to pods result in higher pod growth rates (g m^{-2} day^{-1}) and higher yields. The partitioning of photosynthate to fruit during pod filling stage is the most influential physiological factor in yield determination of groundnut. Duncan et al. (1978) made the first attempt to analyse the physiological factors accounting for increase in yield potential in USA and reported that the partitioning of assimilate had the greatest effect on fruit yield and the estimates of partitioning to fruit ranged from 41% in the `Dixie Runner' released in 1943 to 98% in `Early Bunch' released in 1977.

In India many related released cultivars are phosynthatic efficient and have high yield too. Ravindra et al. (1990) reported that TMV 10 and JL 24 varieties are photosynthetically efficient but their poor yield during drought is associated with poor sink formation and translocation efficiency the partitioning has been forward to be 20-50% depending upon the cultivars and locations and season. In Indian cultivars, the variety MH 2 showed maximum partitioning of 42% followed by GG 2, 39%. In North Carolina, USA each breeding cycle increased yield of 30 g m^{-2}, and the groundnuts developed from a number of breeding cycles have smaller vegetative mass, shorter main stem length and greater reproductive dry matter allocation (Walls et al. 1991). The duration of pod fill is another plant characteristic associated with yield. Williams et al., (1975d) reported that `Makalu Red' a high yielder have a similar pod growth rate to a low yielder, but have a longer filling period. The partitioning factor (PF) is the rate of the pod growth (1.65 x pod wt) as a percentage of the contemporary crop growth rate (CGR) during pod fill: PF =100*PGR/CGR, where CGR is calculated based on biomass of shoot plus the energy adjusted pod wt (Pod wt x 1.65).

Mc Cloud et al. (1980) used partioning ratio (PR) for assessment of yield variation among groundnut cultivars: PR = (PGR/ PCF) /CGR, where PGR is the pod growth rate fitted to the linear portion of the pod dry wt curve, PCF is the pod composition adjustment factor (0.61), CGR is the maximum crop growth rate from the vegetative dry wt curve before the pod fill begins. The yield of groundnuts differs mainly because of differences in their ability to develop the reproductive sink rather than differences in their leaf area or crop growth rate (Source). The peg production and pod formation are influenced differently by assimilate supply, the pegs may be initiated even when the plant does not have the assimilate `status' necessary to initiate pods on these pegs, however, once more pegs are initiated the assimilate supply is inadequate for the full achievement of reproductive growth potential which results in a fewer and smaller kernels in each pod (Williams, 1979c). At Vridhachalam, during the winter and rainy season polyethylene film mulch affected days to flowering, total number of flowers produced, pod setting ratio and total number of matured pods and resulted in highest pod yield in groundnut (Subrahmaniyan and Kalaiselvan, 2005).

Some groundnut cultivars have reproductive controlling mechanism, which normally results in the sink established being in excess of the supply potential of the crop, on the other hand some cultivars do not establish the pod sinks to utilize the full assimilation ability of the crop. The growth of groundnut fruit was influenced by the time of initiation relative to the changes in assimilates supply of the crop. The pod initiated at a time when there is apparently no limitation to assimilate supply in plant had a larger growth rate than those initiated later on when the reproduction sink was most active. The distribution of available photosynthate to reproductive components could be improved by selecting for more determinate types which cease stem growth as soon as the kernels start growing, and which have the capacity for growth in the kernel to use all the assimilate produced during the reproductive phase (Williams et al., 1975 a). However, Williams et al (1975 b) in another study reported that yield was influenced by the ability of the kernel sink to develop. For high yield peak kernel growth had to occur while leaf area was adequate to achieve the full potential of the kernel sink. It has been observed that the yield continue to increase as a result of continued pod setting, even though assimilate (source) shortage are likely. Thus, in groundnut it can be concluded that both source and sink are limiting factors depending upon the varieties, but in most cases the source is adequate and only sink is the limiting factor. Stimulation of photosynthesis of a large sink and the utilization of materials accumulated in vegetative structures could contribute to increase yield in future.

The yield advantages due to moderate water deficit during the pre-flowering phase are associated with greater pod synchrony after the release of water stress, resulting in production of more mature pods (Nageswar Rao et al., 1988). When stress is released, the plant try to set more fruiting sites with the existing assimilates as the vegetative site demanding assimilate supply are reduced. To improve the conventional irrigation management practices to enhance yield and water use efficiency in groundnut during summer seasons a field experiment was conducted by Nautiyal, et al. (2002) where dry matter partitioning among various plant parts, and leaf area index (LAI) varied significantly under water deficit and more dry matter accumulated in petiole and stem under stress. Transient water-deficit in vegetative phase resulted in higher dry matter accumulation in reproductive parts (peg+pod). Water use efficiency (Ef) was, however, higher under prolonged stress during vegetative phase; though cultivars response varied. Per cent reduction in total biomass under stress during flowering (F), and pod-development (P) ranged between 6 and 25%, this reduction in total biomass was mainly due to the reduction in the pod mass rather than in the vegetative mass. Water-deficit occurring during the vegetative stage, seedling stage until flowering, was most beneficial for the crop, and need to be utilized in irrigation scheduling (Nautiyal, et al. 2002).

In a series of multi-location experiments (MLT's) with differing drought patterns across India, the growth and yield performance of a wide range of groundnut lines selected on the basis of high water use efficiency (WUE) and high biomass partitioning (harvest index, HI) when studied, a number of promising genotypes with high pod yield levels which also incorporate high levels of yield component traits, were identified, some of these genotypes showed high levels of broad adaptation for these traits under a range of water limited environments. Subsequently, a number of these lines were imported to Australia, and are undergoing crossing, selection and evaluation programme, at QDPI, Kingaroy (Wright et al. 1998). Bell and Wright, (1998a) from a study of the humid tropics of Indonesia, the semi-arid tropics of north-west Australia and the humid coastal and inland elevated areas of north-east Australia found that temperature and irradiance played a major role in determining crop duration, individual plant size and partitioning of dry matter to pods across environments, and these plant characteristics provided the major determinants of pod yield and response to plant density. Crop duration was shortest in humid tropical and subtropical environments, with both high and low temperatures apparently delaying crop maturity. A relatively small individual plant size in humid tropical environments was due to a combination of low incident irradiance and short duration, with very high plant densities needed to maximize dry matter production. The progressive decline in harvest indices in more tropical environments was due to a decline in pod numbers per plant. Although increased plant density resulted in greater numbers of pod initials in the humid tropics, a high proportion of these pods did not contain developed seeds and pod yield at high densities remained relatively low at 2.5 t ha^{-1} (Bell and Wright, 1998a).

6.2 Yield and yield attributes

The yield is the summation of the rate of fill for each fruit multiplied by the duration of its filling period and depends on number of mature pods and 100 kernel weights. Most of the yield variation are due to differences in three physiological processes; the partitioning of assimilate between vegetative and reproductive parts, the length of the filling period, and the rate of fruit establishment. The number of flowers, branches and pod number per plant were reduced with closer spacing and increased with wider spacing. Though only a small percentage of flowers result into pods, conditions favoring rapid flowering early in the season contribute to high yields. The factors affecting yields depend on the environmental, agronomic practices and biotic stresses. This is probably the main reason why the newly evolved high yielding varieties bred for one area do not perform better at other places. The yield is determined by total number of pod as the fruit size for a cultivar is constant at maturity. As a thumb rule, with 2-3 lakh plants ha^{-1}, each single seeded pods plant^{-1} adds 100 kg pod ha^{-1} and double seeded pods plant^{-1} 200 kg pod ha^{-1}. So to achieve 1 t pod ha^{-1} each plant should bear 5 double seeded pod and for 10 t pod ha^{-1} each plant should bear 50-75 double seeded pods. The high yielding varieties produce more pods through higher number of pegs (flower to peg ratio), higher percentage of the pegs forming mature pods (peg to pod ratio) and more number of branches and higher 100-kernel weight. In USA, the improvement in yields by newly evolved cultivars over the old one were mainly due to (i) more efficient carbon fixation through efficient leaves, better canopy geometry or greater leaf area duration, (ii) the partitioning factor, and (iii) duration of fruit growth (Duncan et al. (1978).

Higher pod yield was attributed to high photosysnthetic efficiency of the canopy and remobilization of stem reserves resulting in a better partitioning (Narayanan et al., 1981). Due to longer duration and more sunshine hours, the dry season crop produced more pod yield and total dry matter than the wet season crop (Singh and Joshi, 1993). As the dry season crop took 10-14 days more time for its maturity, it received more PI, PAR than the wet season crop (Singh and Joshi, 1993) but the energy harvesting capacity of groundnut do not differ during kharif and rabi-summer seasons (Dwivedi and Saha, 1983). Under field conditions in bunch groundnuts a positive relationship was observed between the total number of flowers produced during the first 2 weeks after commencement of flowering and pod yield, but the total (cumulative) number of flowers produced plant^{-1} was not related to pod yield (Sastry et al 1985). Flower production is therefore not a constraint in productivity. The genotypes having the highest number of developing pods at the 70th day were those, which also produced the highest number of flowers during the first 2 weeks after commencement of flowering. Genotypes, which showed greater synchrony in flowering during the earlier phase of reproductive growth also, showed higher pod yields.

The variation in economic yield (kernel DM) depends on pod harvest index (HI), kernel HI, ratio of pod to peg plus pod number, kernel number per pod and kernel size and all these were maximized at the optimum plant population density. The proportion of TDM diverted into stems generally increased with increasing population. The competition for available moisture by induced root growth, and plants grown in higher densities are better able to exploit available moisture by increased rooting depth. In Saurashtra, Gujarat, the pods distribution in the 5, 10, 15, 20 and 30 cm diameter from the plant was 61, 87, 94, 98 and 100 % respectively in bunch groundnut varieties and hence 45 cm spacing is suggested for easy intercultural practices and harvesting through groundnut digger (Khistaria et al., 1985), however maximum pod yield are observed at 30 x 10 cm spacing. More yield under 30 x 10 cm spacing (33 plants m^{-2}) in GG 2 was attributed to more of first formed flowers and greater partitioning of assimilates to pods at the expense of stem growth (Vithalpura and Mandavia, 1991). In Queensland Australia, the TDM and economic yield were maximized at 25 plants m^{2} in all cultivars, and so were the radiation use efficiency (Ec), CGR and DM partitioning to pods and kernels the reproductive components (Tarimo and Blamey (1999a). In Shandong, China, an average pod yield of 7.8 t ha^{-1} in groundnuts cv. 79266 and highest yield of 8.5 t ha^{-1} in cv. Hua 37 was observed at a plant population of 27-30 plants m^{-2} in a relay-cropped summer groundnuts sown in between the wheat rows, 15-20 days prior to the wheat harvest (Shan et al., 1996). At Vriddhachalam total dry matter production and LAI showed positive correlations and harvest index negative with pod weight (Arjunan et al., 1997). The farmers of Sheel area in Mangrol Taluka of Junagadh, Gujarat are harvesting 5-6 t ha^{-1} pod yield using runner groundnut at 60-75 and spacing with (20-30 plant m^{-2}) regularly for the last 20-25 years under rainfed condition.

At the initiation of seed growth, reproductive growth becomes dominant and subsequent partitioning is determined by environmental influences. The yield differences among cultivars are most closely related to the partitioning of assimilate between vegetative and reproductive parts when maximum fruit numbers are being established. The mechanism seems to be that of linearly incrementing fruit numbers until fruit utilization of assimilate equals the genetically determined level of assimilate partitioned to fruit growth, implying the priority of vegetative over reproductive growth during this developmental phase. The heritabilities of crop growth rate (C), reproductive duration (DR) and partitioning (p) and their predictive value in early generations for C, p, DR and yield based on the F_2:F_3 regression were 0.10, 0.45, 0.10 and 0.16, respectively and on F3:F4 regression were 0.20, 0.46, 0.14 and 0.57, respectively, the effects of locations were significant ($P<0.01$) for C, p and DR in F_2 and F_3 but non significant for yield and C in F_4 and none of the yield-model traits had larger heritability than yield and that selection for these traits in segregating bulk populations is difficult (Ntare and Williams 1998b).

In China, groundnut yields of 6.0-7.5 t pods ha-1 are obtained over a large area, and yields of 10.5 t pods ha^{-1} over a small area under intensive cultivation (Sun et al. 1996). Groundnut is considered a very photosynthetically efficient crop, and in theory its potential yield can reach as high as 17.3 t ha^{-1}. The theoretical basis for obtaining high yields is discussed with reference to photosynthetic efficiency, yield potential, accumulation and distribution of biomass and structure and appearance of high-yielding plants and suggestions are given for high-yielding groundnut cultivation, including methods used to create a suitable soil structure, balanced fertilizer application, application of fertilizer to preceding crops, optimum plant populations, strengthening field management, and use of sustainable methods to create ecological conditions that ensure high and stable yields (Sun et al. 1996).

6.3 Seed quality

Seed quality, especially the germinability and vigour is essential to establish adequate plant stand for crop production, which can adversely be affected by environmental factors while seeds are still maturing on the plant, during harvest or processing or in post-harvest storage condition. During seed development, high temperature that inhibit photosynthesis (>30ºC) and water deficit could affect seed quality by reducing photosynthates and other metabolites required for seed formation. The percentage oil, protein, shelling and SMK increased with maturity but the soluble sugar decreased (Nagaraj et al., 1989). The harvest date after the maturity did not affect chemical composition, except carbohydrates content decreased and total unsaturated fatty acid contents increased slightly as groundnut matured (Kim and Hung, 1991). However the kernels become harder, crisper, crunchier and more brittle at higher maturity. The Mesocarp colour of pod is an index for grouping groundnuts with similar shear-compression energy which is correlated to sensory crunchiness. In a study in Turkey, seed oil content of the groundnut increased rapidly until the initiation of first maturity (R7) and then declined in the later growth stages, whereas the protein content generally increased gradually until physiological maturity (R8) (Calskan et al.2008). The HPLC protein profiles of different cultivars showed the presence of peak IV protein in all cultivars exhibiting a typical "mature seed protein profile" with respect to peak IV protein which is a potential indicator of seed maturity and named as `maturin' (Basha, 1990). The conversion factor for groundnut from nitrogen to protein is 5.45 instead of 6.25 (Misra and Yadav, 1992). The digestibility of the protein is very high and is comparable to casein.

Seed vigour was related to the synthesis and accumulation of storage protein, proteinases and heat-stable protein, acquisition of seed vigour was more rapid in the later stages of seed development and abscisic acid (ABA) played an important role in the development of seed vigour (Lin et al. 1996b). In groundnut cv. Haihua 1, Shuangji 2 and Hua 17 when pods were sampled at 7-10 day intervals from the initial podding the oleic/linoleic acid ratios, which correlated positively with dry seed mass, were lowest (65% of fatty acid composition) at the early pod stage, increased gradually with the development of pods and seeds, and reached a stable maximum (80%) near maturity. During pod and seed development, the oleic acid content increased, while the linoleic acid content decreased. From seed formation to maturity, palmitic and eicosenoic (gadoleic) acids decreased gradually. These characteristics were similar across cultivars, sowing dates and sowing patterns (Wan et al. 1996). Amino acid composition of the three major components (arachin, conarachin I and conarachin II) and the five purified polypeptides when analysed 17 amino acids, including 7 essential amino acids were detectable (Lu et al. 2000). The contents of asparatic acid, glutamic acid and arginine were high, whereas methionine and cysteine were extremely low. The methionine levels of the three major components in methionine-rich cv. Shanyou 523 were higher than those in cv. Haihua 1 and among the 3 major polypeptides, the methionine level was highest in conarachin II, the 17.5 kDa polypeptide had high methionine content, and its level of metabolism changed during seed development (Lu et al. 2000).

Physiological changes and chemical compositions in groundnut seed during maturation were investigated by Promchote et al. (2008) in two Thai cultivars: large-seeded Kaset 1 and medium-seeded Tainan 9 using nine maturity stages (5-13) designated by the physiological maturity index (PMI) method to determine the appropriateness of PMI for maturity classification and found that physiological maturity (PM) was evident at stage 10 in Kaset 1 with a seed moisture content of 36.4%, and at stage 11 in Tainan 9 with a seed moisture content of 35.5%. Groundnut seed size, weight and the seed/hull ratio increased as the seed matured, reaching peak values at PM, seed moisture content declined and was stable from PM onwards, seed dormancy was evident at stage 5 and most pronounced (90%) at stage 9 in Kaset 1, but was marginal in Tainan 9 at stages 12 (4.0%), the oil accumulation increased rapidly during seed maturation while carbohydrate content declined and protein content did not markedly change during seed development (Promchote et al. 2008). Oleic acid and the O/L (oleic/linoleic acid) ratio also increased, while palmitic, linoleic, ecosenoic and behenic acid contents decreased and at maturity stage 13, oil, carbohydrate and protein contents were 55.9, 21.7 and 20.1%, respectively in Kaset 1 seed and 54.8, 21.5 and 21.2%, respectively in Tainan 9 seed regardless of the difference in seed size, the oil contents of Kaset 1 and Tainan 9 seeds were only marginally different, while the O/L ratio of Kaset 1 seed was higher than that of Tainan 9 seed (Promchote et al. 2008). The PMI method was appropriate for classifying the maturation of groundnut fruit and predicting the harvesting date for groundnut cultivars (Promchote et al. 2008).

The groundnut cultivars showed large variations in pod loss due to in situ sprouting of seed and fresh-seed dormancy (FSD), fresh-seed dormancy index (FSDI) varied from 2% in cv. Chico to 88% in cv. ICGS 44 and cultivars with an FSDI value of less than 10% showed more pod loss in situ than the cultivars with high FSDI. Cultivar SB XI did not show any in situ sprouting or pod loss. A direct relationship (r = 0.86) was found between fresh-seed germination of groundnut cultivars in the laboratory and the percentage of its plants with sprouted seed in the field (Nautiyal et al. 2001). Seed of two Spanish cultivars ICGS 11 a dormant and GG 2 a non-dormant when tested for germination after treatment with ethrel or ABA at various seed development stages GG 2 showed up to 40% germination even at an early stage of seed development, whereas the seed of ICGS 11 responded to the ethrel only at maturity. Regulation of FSD appeared to be more under the control of the testa than the cotyledons (Nautiyal et al. 2001). The variation in the degree of in situ sprouting can be used for breeding Spanish cultivars with various desirable levels of FSD (Nautiyal et al. 2001).

Knowledge of the genetic basis for seed shrivelling trait is important for understanding the biosynthetic lesion involved and for manipulation of the trait in breeding programmes. By crossing three shrivelled-seeded lines (529B, 563A and 647A) to a normal-seeded cultivar, Sunrunner, and intercrossed Jakkula et al. (1997) identified a seed shrivelling trait in groundnut that severely affected seed morphology and lipid deposition, also showed partial penetrance and variable expressivity within true-breeding shrivelled lines. Crosses with shrivelled seed genotypes as male parents with Sunrunner showed that this trait is under the control of a single recessive gene, however, no segregation of shrivelled types was observed in the F2 of the reciprocal crosses when shrivelled lines were used as female parents. Segregation was observed in the F3 generation (F4 seed) for these crosses. Only shrivelled F1 and F2 seeds were obtained from the crosses among the three shrivelled lines, indicating that only one locus was involved in the expression of this trait in these three genotypes (Jakkula et al. 1997).

6.4 Pod and seed size

The relationship between seed size and pod maturity has been difficult to define because fruiting occurs over an extended period that depends on the variety and on the environment. But for a particular variety and environment variation in seed size are function of plant age and variability in maturity of pods. Seed size is an important factor to the peanut industry as it determines market quality and crop value, and pod maturity is an important factor determining seed size. Though the size of the pod is influenced to a certain extent by soil and other environmental conditions, it contributes to distinguish the cultivars. Varisai Muhammad et al. (1973) divided the groundnut into five classes depending on the mean length and pod weight (g 100 pod)$^{-1}$: very small (less than 1.5 cm and 35-50 g), small (1.6-2.0 cm and 51-65 g), medium (2.1-2.5 cm and 65-105 g), big (2.6-3 cm and 106-155 g) and very big (more than 3 cm and more than 155 g), however these classification are quiet old and several others standards have been fixed by the exporters. In a recent study Singh et al., (2004) Classified the various groundnut into three seed size, small (less than 30g 100 seed wt.), medium (30-50 g 100 seed wt.), and large (more than 50 g 100 seed wt.) seed groundnut. The Hand-picked and selected (HPS) groundnuts also referred as `table'nuts and are the main items of exports. Though the large size seed in the field show initial vigor it did not differ in germination and yield when compared with small size seed rather the small size seeds, reduces the amount of seeds to the tune of 25- 50 %, and hence should be used for sowing purpose (Singh *et al.* 1998).

7. Factors Affecting Physiology

In groundnut the environmental factors, influencing pod yield, operated mainly through their effects on the timing and duration of flowering and pod production. Light, temperature, water, hormones and mineral nutrients are the major factors affecting growth and reproduction of groundnut, which are discussed, separately in the following text.

7.1. Light

Light is the major controlling factor for photosynthesis and the groundnut leaves in response to light fold the leaflets each night and unfold at sunrise, but the blue light or far red causes the leaflet to open. A minimum of 500 µE m^{-2} S^{-1} of irradiance is necessary for photosynthesis to compensate for respiration by the canopy and on this the AP was zero (Ketring et al., 1982). The apparent photosynthesis (AP) increases linearly as the light intensity increase from 500 to 1600 µE m^{-2} S^{-1}, was saturated only at 1600 µE m^{-2} S^{-1} (near full sun light) and remain constant after increasing it further. However, the PAR (photosynthetically active radiation) increased upto 25 E m^{-2} day^{-1}, increasing the shoot dry weight and leaf area. Plants grown at low irradiance (300 µE m^{-2} s^{-1}) had the same number of leaves, but larger leaf surface area and were taller than plants grown at the high irradiance (500 µE m^{-2} s^{-1}), however, flowering and other reproductive components (pegs, pods and seeds) were reduced at low irradiance (Ketring, 1979). The low irradiance in shaded plant showed more vegetative growth but decrease reproductive components and harvest index.

The relationship between canopy structure, its components and solar radiation interception vary with the botanical types. The Spanish and Valencia types are tall, with leaflet areas, fewer leaflets and intercept more radiation per leaflet area. The light interception is about 95% complete at an LAI of 3 and the extinction coefficient for visible radiation was calculated about 1, but Boote et al. (1980) calculated the value 0.88. Thus, while the canopies may reach LAI values of 7 to 8 but the growth rate is maximum at LAI above 3. Virginia types show a short stature, smaller leaflet area, higher leaf area index (LAI) and more leaves and intercept the least radiation per leaflet area. The intercepted radiation by leaflet was higher at each layer of the canopy in the taller cultivars and lower in the shorter cultivars (Aboagye *et al*., 1995). Kanto 56 was exceptional, with a low plant height, medium leaflet size and LAI, it intercepted a greater amount of solar radiation. In Saurashtra, India, the pod and oil yields in groundnut are higher during summer season than in Kharif season due to more sun shine hours (Singh and Joshi, 1993; Dwivedi et al., 1985).

Shaded plants had a slow vegetative and reproductive growth rates but more seed weight. The yields and vegetative growth of groundnuts were linearly and negatively related to increasing shade from 0.73% (Wolff and Coltman 1988). The groundnut plants grown in shade at 25, 50 and 75% reduced light intensity decreased the LAI at 60 DAS, NAR between 30 and 60 DAS, but increased the specific leaf area and leaf chlorophyll contents at all growth stages however, shading had no effect on leaf wt ratio (George and Nair, 1990). In a field trial during the rainy season at ICRISAT, India, shading (intercepting 46% of the incident light) throughout the reproductive development (70-101 DAS) reduced branch and pod numbers but increased SLA and internode length, *however*. Shading from peg initiation (40 DAS onwards) increased 24% plant height at harvest Stirling et al., (1990). Thus shading reduced the duration of leaf area expansion and the rate of the linear growth phase because the reduced light interception was not offset by an increase in light use efficiency. Stirling et al, (1990) further reported that premature leaf senescence in shaded crops coincided with the virtual cessation of pod production, although continued DM allocation to reproductive structures in the crops shaded from peg initiation resulted in a greater proportion of mature pods at final harvest (30.6%) compared with the control (19.2%). Shade acclimatized groundnut plants were more efficient at low light intensity and accumulated less DW, were taller, and produced fewer roots, with root length density remaining nearly constant after shade imposition (Barbour et al, 1994). Partitioning was altered in shaded plants to optimize assimilate utilization, producing fewer pegs of which a larger proportion produced harvestable pods. PNUTGRO accurately simulated DM accumulation, but consistently overestimated specific leaf area and the model predicted yield losses of 30% in each year due to shading as compared with an actual losses of 26-33 %.

Photosynthesis in the canopy on a clear day recorded a single peak curve after bloom initiation, with the peak occurring around 1000-1300 h, no midday depression in photosynthesis was observed under natural light condition, dark respiration during day and night showed one peak around 1100-1500 h and one valley around 0300-0500 h, the dominant factors affecting photosynthesis and respiration were the intensity of solar radiation and temperature (Wang et al., 2004). The efficiency of total radiation conversion of groundnut is calculated 1.67%, in USA (Duncan et al. 1978) however, 0.7 to 1.21% of total solar radiation and 1.79 to 2.92% of PAR (400-700 nm) in India (Dwivedi et al., 1985). The energy efficiency of groundnut during the rainy season (June to October) under low solar radiation (5,77,920 k cal m^{-2} 120 days^{-1} total solar radiation and 2,40,408 k cal m^{-2} 120 days^{-1} PAR) was higher than that in the winter season (November to March) of the high solar radiation period (10,19,640 k ca m^{-2} 120 days^{-1} the total solar radiation and 3,99,232 k cal m^{-2} 120 days^{-1} PAR). However these observations are based on the incident radiation only. The tube solarimeters measure the whole spectrum solar radiation, both incident upon and transmitted through the foliage which should be recorded for net solar radiation utilization.

The Radiation use efficiency was negatively associated with the canopy extinction coefficient and minimum temperature (Bell 1986). Aquino et al (1992) investigated the relationships between disease severity, canopy reflectance, healthy leaf area duration, and pod yield of groundnuts. For ‘Florunner’, a cultivar susceptible to late leaf spot, pod yield decreased as the duration of healthy leaf area (HAD) decreased. Canopy reflectance at 800 nm decreased as disease severity and defoliation increased during the season. The yields predicted from HAD with the newly scaled model were within 11% of the actual yield of ‘Florunner’, but the yield predicted with the model for Southern Runner, was overestimated by an average of 18%. The HAD-yield relationship may be used to estimate the relative, radiation-use efficiency of a groundnut cultivar. The changes in leaf orientation indicate that groundnut has mechanism, which optimize energy interception when water is freely available but maximum dry matter: water ratio at limited water supply. The capacity of both diheliotrophism and paraheliotrophism to increase plant productivity when water is available, and to improve the chance of survival during drought, may contribute significantly to legume adaptation to the semi-arid areas of the world. Matthews et al. (1988b) reported that the groundnut genotypes grown under limited irrigations produced similar amount of dry matter per unit of intercepted solar radiation (e) before pod filling, but different solar radiation were observed during pod filling. When drought became severe, fractional radiation interception was reduced by folding of leaves. Chapman et al (1993a) reported that the groundnut cultivars subjected to a period of reduced soil water supply (RSW) during early reproductive development showed greater total biomass production in Virginia cv. ‘Virginia Bunch’ and ‘Q18801’, due to greater radiation use and transpiration efficiency, than Spanish cv ‘McCubbin’. The radiation use efficiency of the stressed crops was only about 45% of those that were fully irrigated over. Throughout RSW, noon leaf water potential was lowest in ‘McCubbin’. Under increasing soil water deficit, the leaves of McCubbin tended to wilt, while the Virginia cultivars displayed active leaf folding as a result the ratio of the fraction of radiation intercepted by the canopy to LAI was always lower in the Virginia type cultivars. For a given LAI, this phenomenon may have allowed these cultivars to decrease the effective atmospheric demand within the canopy, while maintaining radiation interception at saturation for photosynthesis.

Groundnuts cv. ‘Chiba-74' exposed to natural, red, blue, green, or far-red light, or darkness 20 or 30 days after seed formation, except for green light from the 30th day, resulted in lower dry weight of groundnut seeds. The groundnut seeds irradiated with natural, blue or far-red light from the 30th day onwards contained smaller amounts of lipids, lower levels of triacylglycerides (TG), and higher levels of total sugar and diacylglycerides (DG), than the seeds grown in darkness suggesting that the accumulation of lipid in the seeds of leguminous plants is depressed by light, with far-red light affecting most the accumulation of lipids, which may regulate the synthesis of TG via DG from glycerol-3-phosphate (Inanaga et al. 1996). Also in vitro, ^{14}C-glycerol-3-phosphate was converted to DG rather than to TG under irradiation with light compared with dark conditions, in contrast, the effect of light on the incorporation of ^{14}C-oleoyl-CoA into TG was not appreciable (Inanaga et al. 1996).

A model of maize/groundnut intercropping showed that light reaching maize increased and its distribution was more even in intercropping systems, while light reaching groundnuts decreased, the chlorophyll content and photosynthesis of maize leaves increased, while those of groundnuts decreased, although they increased with increasing numbers of groundnut rows (Zhou, et al., 1998). A layered canopy model was used to analyse the effects of diffuse light on canopy gross photosynthesis in plant growth chambers, where, in contrast to the field, highly diffuse light can occur at high irradiance. The model suggests that high diffuse light fractions (_0.7) and irradiance (1400 µmol m-2 s-1) may enhance crop life-cycle canopy gross photosynthesis and the spherical leaf angle distribution was not suitable for modelling photosynthesis of planophile canopies (e.g., soyabean and groundnut) in growth chambers (Cavazzoni et al., 2001) .

In Pune, Maharashtra, under sorghum-based intercropping system total reflected PAR by canopy + soil (RPARs) values increased with the increase in sorghum age and slightly decreased at harvest, RPARs values were significantly greater under sole pigeon pea than sorghum+pigeon pea and sorghum+groundnut intercropping. RPAR values were significantly highest under sorghum+groundnut intercropping 42 DAS. The lowest value of RPAR (3.4%) was recorded under sorghum+soyabean intercropping 70 DAS (Singh et al., 2002a). Further the highest transmitted photosynthetically active radiation (TPAR) value (59.5%) on sorghum, pigeon pea, groundnut, soyabean and their intercropping combinations was observed 28 DAS due to less leaf area and leaf area index (LAI), and the lowest TPAR (13.2%) at 70 DAS, when the LAI was highest (2.5-10.5). TPAR was significantly lower under sorghum+groundnut, sole sorghum and sole groundnut than sorghum+pigeon pea, sorghum+soyabean and sole soyabean 90 DAS due to slow growth of pigeon pea under sorghum+pigeon pea, and senescence of soyabean leaves as crop approached maturity, during this time(Singh et al., 2002b).

The larger amount of photosynthetic surface may not result in more reproductive growth as groundnut plant readily redistribute its available assimilates between vegetative and reproductive growth in response to irradiance and photoperiod. The plants grown at 16 h photoperiod at the high irradiance produced the largest amount of vegetative, but least amount of reproductive components, however plant at 8-h photoperiod had 33% as much total leaflet area as plants grown at 16 h, but 6 times more wt. of mature seeds (Ketring, 1979). The yields under long days ranged from similar to those under short days to 60% less, a photoperiod-sensitive genotypes showed slow peg development under long days and light intensity had little effect on fruit development, but fruit weight increased with light intensity under long days in insensitive genotypes (Witzenberger 1987).

In groundnut cultivars with very few branches, medium duration, erect growing habit and big pods the upper one-third of the canopy was the major light-absorbing layer during the mid-stages of growth of the crop, intercepting about four-fifths of the total solar radiation intercepted by the crop, the extinction coefficient ranged from 0.82 to 0.87 and the optimum leaf area index was 5.5 (Wang et al., 2004). Japanese (Kanto 83, Nakateyutaka) and Chinese (Huayu 16, Luhua 11) high yielding groundnut cultivars were studied to analyse their yield abilities in terms of intercepted radiation and photosynthesis. The Japanese cultivars had short plant height with a large leaf area in the upper 2 or 3 layers from the top of the canopy (5-45 cm), the Chinese cultivars had tall plant height with a small leaf area in each layer and the canopy of Chinese cultivars intercepted a larger amount of radiation than that of Japanese cultivars, due to higher values of intercepted radiation per unit leaf area despite smaller leaf area index. In particular, Huayu 16 intercepted a larger amount of radiation per unit leaf area in each layer than the other cultivars. Kanto 83 had the smallest light extinction coefficient mainly clue to the small leaflet size, despite the dense leaf distribution. The CO_2 assimilation rate and quantum yield of photosystem II in the later growing season were large in Kanto 83 and Huayu 16, which showed higher seed yields. Huayu 16 had effective characteristics for radiation interception, allowing it to maintain a high radiation use efficiency later in the growing season (Cao and Isoda, 2008).

7.2. Temperature

The growth and development in groundnut is influence largely by temperature and it ceased at daily mean temperature below 15ºC. Soil temperature more than 30ºC are also important limitations to groundnut pod yield in much of the semi-arid tropics (SAT) because local heating of the pod zone resulted in major reduction in pod yield when temperature exceeded 24ºC (Dreyer et al., 1981). The temperature optima are different for each growth phases and plants are very sensitive to temperature during early growth stages, but less sensitive as become older. The optimum temperature for early vegetative growth and for development are 27.5 and 24-25ºC, respectively (Cox, 1979). Though the optimum day/night temperature for growth of whole plant are reported to be 25/25, 30/26 and 35/25ºC (Cox, 1979; Ketring et al., 1982), the optimum mean daily temperature is 30ºC and production of flowers is maximum at 20-25ºC. The pod growth is better at slightly less temperature than that of vegetative growth and was optimum at 26/22ºC day/night temperature (Cox, 1979) and 31-33ºC soil temperature (Ono et al., 1974). Williams et al. (1975a) however, observed highest pod yield at 20.1ºC.

Crop is more sensitive to environment prior to seed filling particularly at the early vegetative and late pod-setting stages, which were most sensitive phases (Williams et al., 1978). Marshall et al (1992 reported that LAI increased with rise of temperature, and after 85 d was about 10 times larger at 31°C than at 19° C and over most of the range of temperature, both LAI and fractional interception of solar radiation (f) were functions of thermal time accumulated from sowing (base 10°) and were tightly coupled to developmental rate at the main apex. The low population density compensated by faster leaf expansion by each plant and a greater fraction of solar radiation intercepted by unit leaf area. The amount of solar radiation intercepted by stands increased with rise in temperature and greatest differences occurred before the canopies achieved complete ground cover (i.e. f >0.9). After 85 d, the stand at 31°C produced 8 times as much DM as that at 19° mainly due to the effect of temperature on the rates of development and expansion (Marshall et al., 1992).

Mortley et al. (2004) in a controlled environments study found that the vegetative (foliage, stem growth, total leaf area and leaf number) and reproductive growth and oil content of groundnut were best at warmer temperatures of 28/24 °C to 32/28 °C than at cooler temperatures of 20/16°C to 24/20 °C in 'Georgia Red' groundnut grown for 110 days in growth chamber (photosynthetic photon flux 436 µ mol m^{-2} s^{-1}, 12 h light/12 h dark cycle, and 70% ±5% RH) using modified half-Hoagland nutrient solution replenished weekly and pH maintained between 6.5 to 6.7 and electrical conductivity 1000 to 1300 µ S/cm^{-1}. Flowering was extremely sensitive to temperature as the process was delayed or severely restricted at 20/16 °C and number of gynophores decreased with temperature and was virtually nonexistent at the lowest temperature (Mortley et al. 2004).

In India, the spring and summer crop face cold spell during germination and seedling growth which is most injurious, however the rabi crop face cold during later stages that does not affect much on crop except it increases the duration. The groundnut seed does not withstand humidity in cold temperatures, albeit above freezing (Delecauex (1987). A considerable proportion of seeds are killed, others give rise to abnormal seedlings with critical structural modification. Damage mainly affects the sub terminal part of the primary root, after the cell walls collapse, the cortical zone becomes disorganized. In India, the winter/summer cultivation which was confined to the Tamil Nadu, A.P., Karnataka, Orissa, Maharashtra and Gujarat where winter is not severe and night temperature does not fall below 15ºC, but in certain pockets temperature of the top 10 cm of the soil falls below 18ºC during the sowing period and emergence of seedling is slowed down. Also recently the groundnut cultivation has been extended to UP, Rajasthan and M.P where during Nov-Feb, the night temperatures are very low (5-15ºC) and before March germination do not occur in the field. At low temperature the seedling emergence was delayed for 15 days, the crop growth was very slow till 50 days, the flowering began from 50-60 days (25-30 days delay) and delayed maturity from 25-40 days (Bhagat et al., 1988). Thus there is a dire need of groundnut varieties which can germinate during cold season.

Bhagat et al. (1988) in a field screening of bunch groundnuts for cold tolerance over four locations in India did not found a single genotype which could germinate timely at low temperature in December, flower between 35-40 days and mature within 100-110 days. However, in subsequent studies at Junagadh the groundnut genotypes Girnar-1, NRCGs 1339, 1664, 3696, 4485, 6408 and 7264, CGC 4018, *A.monticola* were found tolerant to cold as they germinated at 12/18ºC temperature cycle with a mean daily temperature of 13.5ºC, of these *A. monticola* was highly tolerant to cold and could be used in the breeding programme (Joshi et al.,1993). Planting of Spanish groundnut in 3rd week of Dec at Junagadh and Chiplima, due to low temperature, the flowering initiated 45-55 DAS, 50% flowering was observed in 70-77 days at Junagadh and 55-63 days at Chiplima as soon as the favorable temperature arrived resulting in delay in crop maturity (Bhagat et al., 1992). Crop having maturity days of 95-105 days during main rainy season took 130-140 days to mature in December sown crop. The effect of temperature (7 dates of sowing 1 and 16 Nov; 1, 16 and 31 Dec; and 15 and 30 Jan) on the phenology of a 100-110 days duration Spanish bunch groundnut Cv Vemana (K-134) during the rabi seasons in Reddipalli, Andhra Pradesh showed increase in temperature increased the emergence of groundnut seedlings with highest rate of emergence at mean temperature 23.9°C and lowest at 19.9°C. Accordingly the number of days taken to flower was less at higher mean temperatures, however the low minimum temperature during pod filling phase extended the duration of November sown crop (Padmalatha, et al. 2002).

A detail study on six groundnut cultivars (Florida MDR98, Southern Runner, Georgia Green, SunOleic 97R, Florunner and C-99R) by Prasad, et al. (2006) in natural field soil profiles in temperature-gradient greenhouses at eight dates between Jan and May in Gainesville, Florida where mean soil temperature from sowing to final emergence ranged from 15 to 32 °C, reveals that sowing date, temperature treatment and cultivar had significant effect on seedling emergence and development (V_2 stage), for all cultivars the lowest germination was observed at the earliest sowing date (coolest soil temperature), among cultivars, Florida MDR98 was the most sensitive to reduced (cool) temperature with the lowest germination and smallest seedling size at 21 days after sowing, followed by Southern Runner, Georgia Green was the most cold-tolerant with the highest germination followed by SunOleic 97R. There were no significant differences among cultivars for base temperature, which averaged 11.7 and 9.8 °C for rate of emergence and rate of development to V_2 stage respectively (Prasad, et al. 2006).

High temperature is the major constraints to adaptation of groundnut in tropical and subtropical areas. Heat tolerance in groundnut was evaluated under field conditions in Niger, using physiological traits identified in a yield model (crop growth rate (C), reproductive duration (Dr) and partitioning (p), and 625 diverse genotypes were screened under irrigation during the hottest months where estimates of p was found to be a more reliable selection criterion for identification of genotypes tolerant to heat than yield (Ntare, 1999). The genotypic variation for heat tolerance in groundnut using electrolyte leakage and fluorescence tests as membrane stability and photosystem (PS II) function in leaves at high temperatures work as a screening procedures for breeding heat-tolerant in legumes (Srinivasan et al, 1996). The damage to cell membranes (reflected by an increased leakage of electrolytes) and PS II (as reflected by a decrease in the ratio of variable to maximum fluorescence) was less, and recovery from heat stress was faster, in groundnut than in the other crops. Prior exposure of plants to 35°C for 24 h led to a reduced leakage of electrolytes at high temperatures. Membrane injury was negatively associated with specific leaf weight in groundnut ($r = -0.69$) and electrolyte leakage and fluorescence ratio were negatively correlated. Ketring (1986) evaluated the groundnut genotypes for heat tolerance by membrane thermostability using the in vitro leaf disc method and drought tolerance. Heat acclimation potential (HAP) is defined as the change in leaf heat tolerance based on plasmalemma thermostability at 40 to 60°C measured by electrolyte leakage after acclimation at 35/30°C day/night temperature. Talwar et al (1999) evaluated groundnut cvs. ICG 1236, ICGS 44 and Chico for their HAP and forward all these cultivars maintaining greater vegetative growth and higher photosynthetic rates under higher temperature regime though genetic differences in photosynthetic rate were related to HKT. The higher temperature regime reduced the reproductive growth by increasing flower abortion and decreasing seed size, however differences in chlorophyll fluorescence and membrane thermostability between growth temperature were found only after incubating the leaf tissue at temperatures of 50°C or higher. Shading by sorghum leaves reduces the temperature of the groundnut leaves by 5-10ºC during the day, which could be used as an intercrop during the rabi-summer season (Dreyer et al., 1981).

Among abiotic factors, high temperature is one of the major constraints to adaptation of groundnut in tropical and subtropical areas. Heat acclimation potential (HAP) is defined as the change in leaf heat tolerance based on plasmalemma thermostability at 40-60°C measured by electrolyte leakage after acclimation at 35/30°C day/night temperature. Heat killing time (HKT), defined as the time required to cause 50% relative injury, indicate the cultivars acclimated to high temperature stress, with significant variations in HAP. Talwar et al., (1999) evaluated three groundnut cv. ICG 1236, ICGS 44 and Chico for their HAP, and the growth, yield, and photosynthetic responses of these cultivars to temperature related to the HAP and found that All cultivars maintained greater vegetative growth and higher photosynthetic rates when grown under the higher temperature regime and genetic differences in photosynthetic rate were related to HKT. The higher temperature regime affected the reproductive growth adversely by increasing flower abortion and decreasing seed size, however differences in chlorophyll fluorescence and membrane thermostability between growth temperature were found only after incubating the leaf tissue at temperatures of 50°C or higher (Talwar et al., 1999).

Effect of sowing date on phenology, yield and the processes of yield determination for four groundnut cultivars in the dry seasons under irrigation was studied by Ntare, et al. (1998) at the ICRISAT Sahelian Centre where sowing date significantly affected phenology (time to emergence, flowering and maturity) with groundnut sown in November /December taking the longest time to reach these phenological stages, however, these November and December sowings gave the highest pod yield, despite the lowest crop growth rates, and yield declined progressively as sowing occurred later (50% decrease by March) despite increasing crop growth mainly due to the effect of temperature differences during the pod-filling phase on partitioning. Partitioning (p) to pods was optimized at approx. 30°C, with some indication of cultivar differences in partitioning response to temperature. Across all the environments, cultivars displayed substantial differences in yield stability, in late sown yields were low and lines with high partitioning were the best, but in early sown in the post-rainy season, cultivars with a high crop growth rates were the better choices. Plant habit differences and crop growth rates suggest that radiation interception was a limitation to yield, particularly when the crops were sown in the cool months of the year. However, haulm yield and crop growth rates were not consistently affected by sowing date across the years, and cultivars demonstrated different degrees of stability for crop growth rates (Ntare, et al.1998). Thus to achieve high pod yield the dry season groundnuts should be sown in November to allow the crop to develop under the relatively cool temperatures that maximize pod yield.

In Umiam, Meghalaya, the growth pattern, dry matter partitioning and yield performance of the large seeded groundnut HPS II lines were compared with BAU 13 and JL 24 by Patel, et al. (2005) during kharif seasons, under mid-altitude (950 m MSL) acid alfisols where temperature is comparatively low during pod filling stage, all the HPS II lines produced higher number of branches and biomass compared to JL 24. Among the bold seeded cultivars, HPS II 9705 accumulated the highest dry matter in pod while HPS II 9701 accumulated the highest dry matter in shoot. The dry matter partitioning percentage was more towards the pod in JL 24, HPS II 9703 and HPS II 9705 compared to the shoot. Pooled data on pod and kernel yields revealed that HPS II 9703 registered highest pod yield (24.6 q/ha) followed by HPS II 9705 (24.1 q/ha), however HPS II 9705 recorded highest kernel yield (18.7 q/ha) followed by HPS II 9703 (18.4 q/ha) (Patel, et al. 2005). The 5 groundnut cultivars (Khon Kaen 60-1, Khon Kaen 60-2, Khon Kaen 60-3, Tainan 9 and (MGS9xChico)-12-16-5) planted at 3 dates (21 May, 10 July and 22 August) in the rainy season showed that all the cultivars grew well in the 1st planting date but gradually decreased in the 2nd and 3rd planting dates with growth rates during the linear stages ranged from 10.7-13.9, 6.64-11.50 and 5.92-8.68 g m^{-2} day^{-1}, respectively and pod weight positively correlated with the total dry matter (Taksina, et al. 1993).

The effect of pod and root temperature regimes from peg penetration until harvest (in four combinations of 28/22 and 40/34°C day/night temperature), when studied in three Spanish groundnut genotypes (Comet, TMV 2 and AH 6179) a decrease in pod temperature from 40/34 to 28/22 °C increased yield, oil, starch and protein, affected fatty acid composition through a decrease in palmitic acid, a reduction in pod temperature decreased protein concentration and increased oil and starch concentration and linoleic acid at a root temperature of 28/22°C, but at a root temperature of 40/34°C a decrease in pod temperature increased protein concentration (Golombek, et al.2001). This indicated that field management practices and choice of genotype can influence groundnut yield and seed composition through effects on pod and root temperature.

Using open-top chambers the groundnuts cv. TMV 2 exposed to ambient (330 ± 30 ppm) or elevated CO_2 (660 ± 30 ppm) at 35°C (normal) or elevated temperature 40°C the elevated CO_2 and temperature increased plant growth and biomass production, with CO_2 having a greater effect than temperature, and the combined effect being greater than that of the individual factors (Rao, 1999). Coupling the transient diagnostics of two atmosphere-ocean general circulation models, NASA/Goddard Institute GISS and the Hadley Centre's HadCM3, to the CropSyst crop model the potential effects of greenhouse gas, climate change, as well as the direct fertilization effect of CO_2 on crop yields to simulate current and future (2020, 2080) crop yields in 8 agricultural regions of Cameroon when studied by Tingem, et al. (2008), the future estimate substantial yield increases for bambara groundnut, soyabean and groundnut, the effect of temperature patterns on climate change is much more important than that of precipitation. Findings call for monitoring of climate change/variability and dissemination of information to farmers, to encourage adaptation to climate change (Tingem, et al. 2008).

7.3. Water

The groundnut is relatively drought resistant and important in semi-arid regions where evaporation exceeds precipitation for 5-10 months of the year. On fresh weight basis about 80% of the plant wt and reduction of the plant water status much below this level causes wilting and affects the rate of many plant functions. The plant water-status is the result of a balance between water uptake and loss which has been less understood in groundnut. Though different stages have different sensitivity to water deficit, none of these can proceed normally below some minimum water. The water requirement of groundnut is lowest from germination to flower formation and reaches maximum during pod formation. However, the utilization of available moisture is greatest during flowering and pod formation and the crop receiving adequate water during these stages only can give equal yield to the well watered crop. During these stages if stress is given and later on water supply is resumed only the vegetative growth is benefited not the reproductive growth of crop. Thus the period of maximum sensitivity to drought occurs between 50-80 days after sowing, the period of maximum flowering and vegetative growth.

The water flow in intact plant under high soil moisture condition is for growth and transpiration and two concepts are expressed about the driving force for transpiration water flow: one consider the water potential differences between the root and leaf as the primary force while the other consider hydrostatic and osmotic pressure differences as the factors determining water flow. The management practices should aim to optimize the availability of growth resources at the time of pegging in order to ensure that pod initiation is not delayed. In order to sustain plant growth and hydration, water must be continuously supplied to the leaves as it is lost by transpiration. This becomes difficult under low soil moisture condition. The ability of groundnut genotypes to maintain water supply to leaves measured by apparent sap velocity (V_a) was 0.8-1.1 cm min^{-1} and declined with stress in field (Ketring et al., 1990). The water stress affects the vegetative, root and reproductive growth and a proper scheduling of irrigation is required. Effects of water stress on these components are discussed separately, however all of them are interrelated.

7.3.1. Leaf water potential, transpiration, RWC and osmotic adjustment

The leaf area, which is in rapid growth stage during the vegetative and flowering stages tends to be most affected due to water stress causing reduction in photosynthesing surface and crop growth rate. The most common symptoms of water stress in the fields is stunted growth as water stress first affects the cell enlargement rather than cell division, but long exposure of water stress inhibited cell division also. The stem length is reduced more markedly than leaf size and the leaf arrangement becomes more compact. During vegetative and reproductive stages the net assimilation rate is inversely proportional to LAI and it is possible to define optimum LAI for maximum dry matter production in particular area. Turgor potential (ψ_p) and leaf extension rate (R) are reduced at high saturation deficits and R is linearly related to ψ_p between 0900 to 1600 hr., in driest condition. The groundnut maintains high leaf water content even in dry soil and also continues photosynthesising at lower leaf water content than other crops.

There are equal number of stomata both on the upper and lower epidermis of leaves in groundnut. Unlike other crops in groundnut the stomata remains open during drought, but are more sensitive to light. The groundnut does not have complete stomatal control over transpiration loss but some control is achieved through folding and orientation of leaves parallel to the incoming radiation. At wilting point the transpiration rate in groundnut decreased to 67%. The diffusive resistance increased during drought and after withholding the irrigation for 2-6 days, the relative water content (RWC) was only 30-38% of that at full turgidity. The leaf water potential (ψ_l) is an important parameter, which is measured through psychrometry in laboratory, however in field the pressure chamber technique and hydraulic press methods are most common. Saturation deficit (SD) is an important agroclimatic factor controlling the potential evaporation. The groundnut crops are often irrigated or grown on stored moisture during the post-rainy season when SD exceeds 3-4 kPa. This SD have a major effect on the water-use rate and the growth of groundnut as the water use efficiency is inversely proportional to SD. SD more than 2.5 kPa accelerated the depletion of soil moisture reserves and greatly reduces LAI by lowering the turgor potential of expanding leaves. Because expanding leaves are more sensitive to moisture deficit than pods, the partitioning of dry matter is likely to be affected by SD.

The relative water content (RWC) is the water-relation components that seems most directly related to cell-hydration. Other factors such as osmotic adjustment and apoplastic water content contribute to cell turgor through maintaining high RWC and it can be readily measured for larger plant populations. A biochemical test using 0.1M EDTA was developed for detection of moisture stress in youngest fully opened leaves, and the cultivars showing 2.77% decline in the pH of the leaves extract in EDTA at -10 bar were categorised as drought tolerant (Dwivedi et al., 1986). Leaves of groundnut have also been shown to accumulate proline under moisture stress (Misra et al., 1992), the level of which was significantly correlated with the level of activity of glutamate-oxaloacetate transaminase in leaves (Yadav et al., 1993). Generally 400-1000 mg proline m^{-2} accumulated in vegetative parts. Accumulation of K^+ in leaf was identified as one of the good parameter for drought tolerance in groundnut (Arjunan et al. (1988). The PP 333 (Paclobutrazol) caused the accumulation of indigenous ABA and the inhibition of GA biosynthesis in groundnut leaves and increases the drought resistance of peanut seedlings (Ling and Rui-chi, 1988). Nautiyal, et al, (2001) reported the response of groundnut to various aspects of deficit irrigation practices during vegetative phase.

Extensive root system combined with the ability to extract moisture under soil moisture deficits can delay dehydration and prolong the effective production period. Both of these can be evaluated at seedling stages in breeding lines. Matthews et al. (1988a) observed that the genotypes with limited irrigation, in central India, transpired similar total amount of water (220-226 mm) over the seasons, but produced different amounts of shoot dry matter varying from 390-490 g m^{2}. Joshi et al. (1988) identified GG 2 as drought tolerant variety and JL 24 as sensitive cultivar. The lower leaf water potential and diffusive resistance (DR), higher transpiration rate and quick recovery of stomatal activity after relief of the stress and maintenance of low leaf water potential even at high RWC were the main reason for resistance in GG 2. Moderate water deficit at pre-flowering phase (without irrigation from 21 to 50 DAS) showed higher mean stomatal conductance, crop growth rate, pod growth rate, and yield than the control getting regular irrigation alfisoil and vertisoil. Applying two irrigations at 11 and 21 DAS followed by withholding irrigation for 30 days (up to 50 DAS) and again irrigation (at 50% field capacity, FC) at 10 days intervals showed the mean stomatal conductance 8.3-11.5 mm s^{-1}, CGR 12.2-13.1 g m^{-2} day^{-1}, pod growth rate (PGR) 9-9.9 g m^{-2} day^{-1}, partitioning factor (PF) 74-76% and pod yield 5.3-5.5 t ha^{-1} in Robut 33-1 groundnut, however, the crop irrigated to 50% FC at 10 days intervals showed the stomatal conductance 6.9-10.4 mm s^{-1}, CGR 8.8-13.5 g m^{2} day^{-1}, PGR 6.4-10.2 g m^{2} day^{-1}, PF 73-75% and pod yield 4.6-4.7 t ha^{-1}. (Nageswara Rao et al., 1988)

The responses of crops to drought stress under five farming systems in China report that the differences in water potentials between the air and crop leaves were >100 times higher than those between crop leaves and soil in the surface 10 cm layer and the differences between the latter were also >100 times higher than those between soils in the 10 cm and 70 cm layers (Zhang, et al.1999). However, the differences in water potentials were lower with minimum tillage and narrow ridge tillage than with conventional tillage and wide ridge tillage respectively, indicating the serious water stress in the former treatments. The diurnal variation of water potentials in the soil-plant-atmosphere continuum indicated that groundnut is more tolerant of drought than soyabean and maize, leaf water potential decreased with the increase in soil water potential and its relationship could be expressed by binomial equations. With ridge tillage, leaf water potential was more related to the water potential of the deeper soil layers than to that of the soil surface under minimum tillage. Seasonal drought in the region is caused by combined water stress and high temperature, water potentials of soils and leaves increased with the increase in soil and air temperatures, respectively and the effect of temperature on water potentials of soils and leaves was influenced by farming practices and crop communities (Zhang, et al.1999).

7.3.2 Root growth

The groundnut roots extract most of the moisture from upper layer (36% in 0-30 cm depth and only 7% in the region of 120-150 cm depth). However, under moisture stress the crop extract water from greater depth. The root system is normally concentrated at a depth of 5 to 35 cm, and spread is confined to a radius of 12-14 cm. The groundnut is deep-rooted plant and its root can penetrate a depth ranging from 1.5-2.0 m, but rarely goes beyond 1 m. The spreading types are generally more vigorous than bunch types. Most of the roots are in shallower region having root densities of 1.5 cm cm^{-3} in 0-30 cm zone and only 0.1-0.4 cm cm^{-3} at higher depth. The epidermis sloughs off as the root extends destroying the basis for root-hair production as a result there is no root hairs. However, Meisner and Karnok (1991) observed the existence of both lateral (0.3 mm) and rosette type (4 mm) root hairs on groundnut root under varying soil and soil-water conditions. In some wild species the hypocotyl and root may be modified to form tubers. Tap roots may vary from a few millimeter in diameter in annual species to 10 cm in perennial species.

The maintenance of higher leaf-water status, by few genotypes of groundnut during soil water deficits is due to greater density of roots in the lower depth of the soil profile, however, this does not account for the major variation in the harvest index associated with drought (Matthews et al., 1988a; De Vries et al.,1989). Meisner and Karnok (1992), in a Rhizotron study observed reduction in root growth in upper 40 cm depth during moisture stress from 20 to 50 DAS compared to well watered control, but the root growth was not affected in the lower depth because adequate moisture was there. In groundnut more than 60% of the root growth is established by 50 DAP and 80% by 80 DAP, water stress imposed after 50 DAP reduce only root growth in upper depths where root density is highest and soil moisture readily extracted. NCAc 17090 is an efficient in extracting water from the top 40 cm of soil and also got greater water use efficiency, (ICRISAT, 1986).

The effect of water deficit on phenology (vegetative and reproductive growth) of two groundnut cultivars (Tatu and PI-165317) reveals that, water stress reduced both root and shoot dry matter production, and root/shoot ratio and flower production, but number of secondary and tertiary ramifications was not affected, the peg and fruits were reduced by water stress affecting both yield and harvest index (Oliveira Jr et al. 2004).The soil moisture extraction patterns and root growth parameters when examined in five groundnut cultivars under various levels of soil water stress variation in soil moisture extraction, root length density and total dry matter production were observed among the cultivars and the differences in water extraction in deeper soil profiles were related to the variation in root length density and the cv. ICGV 86031 and TMV2NLM were efficient in soil water extraction and suffered least losses (17-18%) in total dry matter production under moisture stress (Reddy et al.1999).

7.3.3. Reproductive growth, yield and yield attributes

There are three major aspects of drought, duration, intensity and timing relative to crop phenophases which vary independently. Water stress delay pod initiation, and the major cause of variability in pod yield and harvest index is the delay between peg initiation and onset of rapid pod growth, because once pods were initiated, the proportion of dry matter allocated to reproductive sink was relatively conservative (Stirling and Black, 1991). The period of reproductive growth stages in groundnut occurs over a period of nearly two months and moisture stress has a depressing effect on flowering, stem growth and nodulation. No flowering occurs during the stress, but once the stress is removed, there is a flush of flowering depending on the growth stages and sometimes it results in more flowers than control. The Virginia groundnuts, due to their longer duration, are more tolerant to drought than Spanish and Valencia however the later due to short duration escape the late season drought. The flush of late flowers following mid season drought delay maturity and hence late harvesting. Flowering stopped when soil moisture dropped to wilting point, but fruiting continued (Scandaliaris et al., 1978). The fruiting occurs once the gynophores enter into the soil. The soil physical condition is important and must be wet during the gynophore entering the soil as the gynophore can exert a force equivalent to 3-4 g only.

The yield is a function of many plant and environmental factors and moisture stress play an important role particularly the stage at which moisture stress occurs. The ratio of pod number: peg number reduced from 0.8 in normal irrigated crop to nearly 0.15 in stressed crop (Harris et al., 1988). Moisture stress at flowering reduced phytobiomass and pod yield by limiting the number of mature pods per unit area as compared to stress at pegging and pod formation stages (Rao et al., 1986). The variation in harvest index accounted for the large proportion of variation in yield and recommended to make selection for high harvest index. As reproductive development is sensitive to drought resulting to poor yield The strategies explained by them to combat drought in genotypes are (i) early production of flowers pegs, and pods, with subsequent filling of the pods at a moderate, but essentially at constant rate despite the drought, (ii) faster development of later developed pegs into pods once water become available after drought late in the season, Drought stress effects on groundnut depend primarily on the stress pattern because genotypic variation is usually of secondary significance. Ravindra et al. (1990) observed that moisture stress at flowering (45-70 DAS) and pod development (60-90 DAS) phases was highly detrimental to leaf area development, dry matter production, pod formation and yield in comparison with stress at the vegetative phase (20-50 DAS) and the reduction in yield was 57 and 66%, respectively due to moisture stress at these stages. The recovery of growth from water stress was better after relief at the vegetative phase than at later growth phases. Nautiyal et al (1999a) reported that transient soil-moisture-deficit stress for 25 days, at the vegetative phase (20-45DAS) followed by two relief irrigations at an interval of 5 days, resulted in closely synchronized flowering, greater conversion of flowers to pods and higher pod yield and total biomass accumulation indicating that stress in the vegetative phase was beneficial for groundnut growth and pod yields, but was highly detrimental when imposed at flowering (40-65 DAS) and pod development (60-85 DAS). Nageswara Rao et al. (1985) while studying with Robut 33-1 (a 140-150 days crop) observed maximum reduction in kernel yield when stress was imposed during seed filling phase i.e. 93 DAS onwards however the treatment receiving 12-15% less water than control during the early phase (line source irrigation at 11 and 21 days followed by no irrigation upto 50 DAS) increased the pod yield by 13-19% over fully irrigated (irrigation at 50% FC) treatment (Nageswara Rao et al. 1988). The increase in yield due to pre-flowering drought is mainly due to promotion of root growth during water stress which promoted subsequent growth during pod fills and inhibition of number of vegetative sites (leaves and branches).

The early and continuous availability of water until the start of pod filling result in large canopy and during the period of drought stress the transpirational demand increases. As pod yield is a function of transpired water (T), transpiration efficiency (TE) and harvest index (H), the TE derived from measurements of carbon isotope discrimination in leaves indicated only small variation (Wright et al., 1991). The yield losses (%) due to mid season drought are estimated as: Yield loss (%) = 100(1 - D_y/W_y), Where, W_y is the pod yield under adequate irrigation and D_y is the pod yield under drought treatment. The yield reductions have been reported to be 22, 18, 47 and 47%, respectively when drought was imposed from 10-30, 30-50, 50-80 and 80-120 days after sowing respectively (Billaz and Ochos, 1961). The greatest yield reduction in 50-80 days stress treatment corresponds to, peak flowering to early pod filling stage. Meisner and Karnok (1992) observed the pod yield reduction of 49 and 37% by water stresses imposed at 50-80 and 80-120 DAP and suggested that adequate moisture during these period is critical for obtaining maximum yield. Under water stress there is poor pod filling that reduced kernel size, shelling, SMK % and lipid content of kernel. Nageswara Rao et al. (1989 b) in a study observed that when water deficit occurred during seed filling phase, genotypic yield potential accounted for approximately 90% of the variation in pod yield sensitivity to water deficit, and further elaborated that it is unlikely that breeders will be able to combine high yield potential with low sensitivity to drought spanning the seed filling phase, therefore other important strategies are necessary. The pod yield potential accounted for less of the variation in drought sensitivity (15-64%) in the early and mid-season droughts. For these circumstances it may be possible to identify genotypes with both high yield potential and relatively low drought sensitivity.

Plant population influenced both the temporal and spatial patterns of water use, with high density crops extracting water from lower depths sooner than low density crop. High water use prior to early pod filling in high density crop was associated with more rapid leaf area development (Wright and Bell, 1992b). The more rapid water extraction in a high, compared with a low, population density groundnut crop is associated with greater root production at depth (Nageswara Rao et al., 1989). As gypsum increase early pod development, it provide an escape mechanism from drought (Williams et al., 1986). Gypsum applied at flowering increased yield of genotype subjected to drought but there was no response if there was no drought since soil contain adequate amount of available calcium of about 600 ppm (Rajendrudu and Will1iams, 1987).

Experiments conducted on Warin soil series at the Agricultural Development Research Center (ADRC), Khon Kaen Province, indicated that adequate water supply should be maintained in order to get optimum yield and yield decreases due to water stress at different growth stages in order of water stress at seed development > at early pod filling > at early growth > at early pegging (Uthai et al. 1993). The pod yield and quality of groundnut are reduced when less than 30 cm water was received by the crop. Water deficit during seed production affected C_2H_2 and CO_2 production during subsequent germination (Ketring, 1991). The most consistent response of water deficit was reduction in the fraction of rapidly growing seedlings (those with hypocotyl-radical longer than 20 mm at 72 h of germination). Water stress at pod initiation and development phase reduced germinability, vigour, seed membrane integrity, embryo RNA content, and chlorophyll synthesis and dehydrogenase activity in cotyledons during germination, however, moisture stress at early vegetative phase increased 100 kernel wt., embryo wt. and seedling vigour index (Nautiyal et al., 1991). Thus water deficit during seed development affects subsequent growth of seedlings and could pose a problem in establishment for the succeeding crop. Thus a minimum of 500 mm of water was necessary to produce a crop of seeds with high potential for germination and high proportion of vigorous seedlings (Ketring, 1991). In southern Telangana on Alfisols, groundnut generally suffers from mid-season drought reducing crop yields where 18 groundnut genotypes along with a local control (TMV2) crop experienced a 27-day long dry spell from the beginning of pod initiation to full seed development in 1994, and for 16 days from the beginning of peg initiation to the beginning of pod development in 1995, the pod yields ranged from 0.58 (TCGS88) to 2.41 t/ha and only K134 and ICGV86347 were superior genotype with high yield, but, the yield superiority of these two genotypes was not reflected in their ancillary characters (Thatikunta and Durgaprasad, 1996).

7.3.4. Water use efficiency, evapotranspiration and irrigation scheduling

The water use efficiency (W) is g of total dry matter produced kg^{-1} water used. The transpiration efficiency of the leaf is the ratio of CO_2 assimilation rate to transpiration rate. The WUE was high 3.71 g kg^{-1} in Virginia type and low 2.46 g kg^{-1} in Spanish type groundnut (Wright et al., 1988). The quantity of water transpired is proportional to the percentage of soil covered by the crop (KCOV), evaporative demand (EVPAN) and potential transpiration (CROPET) is estimated as CROPET = KCOV*KM*KCROP* EVPAN, where KCROP is equivalent of a crop coefficient. For well irrigated groundnut crop it is estimated as: KCROP = Crop's water requirement/Standardized class A EVPAN (Dan cette, 1981)

The actual water used (Et) from emergence onwards increased to potential use evapotranspiration (E_0) until both become equal about midway when canopy has closed cover and remains equal until harvest. The ICRISAT has developed a novel technique for measuring water use efficiency, partitioning of dry matter to pod and efficient root systems which was successfully used with groundnut by Nageswara Rao et al. (1985) who also computed the seasonal evapotranspiration using the water balance equation:

$ET = (M_i - M_f) + (I + P) - (R + D)$, where ET is evapotranspiration, M_i is initial moisture in 0 to 127 cm profile, M_f is final moisture in 0 to 127 cm profile, I is irrigation, P is precipitation, R is run-off, D is deep drainage (deeper than 127 cm) considered negligible.

A field method for evaluating the sensitivity of groundnut genotypes under various patterns of drought using line source sprinkler technique was developed by ICRISAT (Singh et al., 1991) where water deficit (W_D) is estimated using the amount of water applied during the period of drought and the cumulative class `A' pan evaporation for the same period as:

$W_D = 100 \times (E - I/E)$, Where W_D is water deficient %, E is cumulative pan evaporation for the period of drought and I is cumulative irrigation applied for the period of drought.

The groundnut requires 400-450 mm of water however in sandy soil the water requirement goes to 600-700 mm, but the distinction between kharif and rabi are not made. The evapotranspiration in groundnut varies with crop duration and is nearly 400 mm for 100-110 days crop, 500-600 mm in 120-140 days crop and about 700 mm in 150 days crops. However, the evaporation from the bare soil is 350 mm for the same period. Further, The yield varied with soil types, as it maximum with 75% available soil moisture (ASM) in red loamy soils and only at 50% ASM in black loams (Reddy, 1988), however, in general, the maximum yields are obtained under 50-60% field capacity and -0.3 to -0.4 bars of water tension (Reddy, 1988).

The levels of irrigation have a major effect on the amount of water consumed, and it is 300-350 mm in non irrigated field and 500-600 mm in field irrigated at 40-60 % moisture availability at 30 cm depth. The irrigation given to a depth of 100 mm showed highest yield. More than 70% of the kharif groundnut in India is rainfed where one or two life saving irrigation are required. The rabi groundnut is grown either in residual moisture or with 3-9 irrigations depending upon the soil and climate. But the summer groundnut is mainly irrigated and 6-12 irrigations are required depending upon the soil types, locations and varieties. The use of drip save 30-50% water and produce upto 20-30% more yields than flood irrigation. Most of the scheduling of irrigation in India is based on the depletion of available soil moisture, IW/CPE ratio but mostly the frequency of interval is opted. The maximum yield is at IW/CPE ratio 0.6-0.9. Thorat et al. (1984) obtained highest yield when crop was irrigated at 50 mm CPE (1.0, IW : CPE ratio) and the total number of irrigations was 14 (700 mm-ha water) during rabi season. The irrigation at 15 days intervals during germination to pegging and 10 days during pegging to pod formation and maturity gave highest yield in calcareous soils of Saurashtra, Gujarat during summer season (Dwivedi, 1986b). However, in eastern part of India Khan and Datta (1990) reported that the I/E (irrigation/cumulative pan evaporation) ratio of 0.75 was found optimum irrigation index for potential yield and water use efficiency in SB XI cv. of groundnut, and to ensure adequate moisture in the effective root zone, 6 cm depth of irrigation is considered to be the best irrigation depth.

Reddy (1984) used simple can evaporimeter and established a good relation with class `A' pan and found that irrigation of groundnut when cumulative can evaporation reached 2 cm with a depth of water equal to that lost in evaporation from the evaporimeter gave the highest yield of pods in red soil of A.P. Application of 80 mm depth of irrigation water at 0.40 IW/CPE ratio for first 40 days, at 0.90 ratio from 40-70 DAS and at 0.60 ratio from 70 DAS and onwards produced maximum pod yield in SB XI groundnut (Dhonde et al., 1985). They observed the average consumptive use of 387 mm of water with comsumptive use efficiency of 5.0 kg ha^{-1}-mm and ET/PE ratio of 0.71. However, Patil et al. (1984) reported 5.48 kg ha^{-1}-mm as the comsumptive use efficiency of JL 24 (Phule Pragati) at 3.5 mm day ET, 0.85 ET/PE ratio and 416 mm PE in lysimeter experiment. In medium black calcareous soil of Saurashtra, the field capacity and permanent wilting point were 24.8 and 9.9% soil moisture level in top 0-15 cm layer and irrigation at 1.0 IW/CPW ratio was suitable (Kachot *et al.*, 1984). However, Gajera and Patel (1984) reported that irrigation at IW/CPE ratio of 0.8 yielded at par with than that of ratio 1.0 with total water applied 550 mm, and to maintain this ratio a total of 11 irrigations were provided in summer groundnut variety GAUG-1. At Parbani, Shinde and Pawar (1984) observed that irrigation at 0.8 IW/CPE ratio at all the growth stages with 930-998 mm of water in 14 irrigations increased pod yield, but was detrimental at the ratio of 0.4.

In Eastern India, during summer, pod yield and DM increased with rate of K application (up to 30 kg K_2O ha^{-1}) and frequency of irrigation at 0.3, 0.55 and 0.8 atm. soil water tension increased pod yield by 112, 150 and 159%, respectively, compared with the rainfed treatment (Ghatak et al, 1997). During summer, in Tamil Nadu, at irrigation schedule 0.75 IW/CPE led to highest yield Lourduraj (2000). In sandy loam soil of Tirupati, India, groundnuts irrigated at IW/CPE ratios of 0.5 at 7 cm resulted in early flowering; however irrigation at IW/CPE ratio of 1.0 at 5 cm resulted in more filled pods, a greater volume weight of pods, a higher shelling percentage, and significantly higher pod and kernel weights, highest pod yield and net returns (Sree and Rao,1998). Irrigation at 50% available soil moisture depletion or at 1-week intervals, during summer season, gave pod yields of 4.98 and 4.83 t ha^{-1}, respectively, compared with 4.65, 4.13 and 3.47 t ha^{-1} with irrigation at 50, 75 and 100 mm cumulative pan evaporation, respectively (Babalad and Kulkarni, 1988).

The crop evapotranspiration and growth characteristics of groundnut in the transitional humid zone of Nigeria have shown that the total water used (Evapotranspiration) by the crop during 105 days was 303 mm and more amount of water was used between the vegetative and reproductive growth stages of the crop between 20 and 60 days after planting DAP, the highest mean leaf area (LAI) obtained was 7 at 75 DAP, dry matter accumulation was highest between 75 and 90 DAP when canopy radiation interception was between 70 and 80 percent and there was a positive correlation (p=0.01) between growth parameters and water use (Idinoba et al. 2008). Characterization of agricultural drought is essential prior for undertaking a yield improvement programme in semi-arid zones. Annerose and Diagne (1990) proposed a simplified model combining evapotranspiration and water balance concepts with basic data on plant responses to drought for groundnut in Senegal and demonstrated the applicability of the same for diagnosing drought types. Rao et al (1998), in a remote sensing ground truth experiment to monitor a groundnut crop under non-stressed conditions in Brazil (during Sept- Dec) reported that, the canopy reflectance in the red and near infrared wave bands of the thematic mapper of two vegetation indices, soil adjusted vegetation index (SAVI) and the normalized difference vegetation index (NDVI) were correlated very well with both the LAI and biomass and can be used to estimate LAI and biomass of a groundnut crop. The field experiment during rabi seasons have shown that crop coefficients (Kc) value was low initially, increased linearly with advancement of crop growth, attained peak value at reproductive growth period from flowering through pod initiation, and decreased towards maturity which is useful in developing a methodology for the determination of periodic and peak irrigation requirements (Hemalatha and Rao, 2006). The crop coefficient curve facilitates prediction of groundnut evapotranspiration the seasonal net, gross and peak irrigation requirement of groundnut were determined.

7.3.5. Carbon isotope discrimination and its relationship with WUE and SLA

The desirable traits such as water use efficiency (WUE), partitioning of dry matter to pods and efficient root systems vary with genotypes and are heritable. The groundnut plant, during carbon accumulation, discriminate against ^{13}C which changes the composition of isotopes of CO_2 the $^{13}C/^{12}C$ ratio in dry matter (Hubick et al., 1986). Carbon isotope discrimination of plant dry matter is linearly related in a negative manner to leaf transpiration efficiency via Pi/Pa, the ratio of intercellular CO_2 pressure Pi, to ambient CO_2 pressure Pa (Hubick et al., 1988). There is a strong negative correlation between transpiration efficiency (the ratio of dry matter produced to water used, W) and carbon isotope discrimination, Δ (Hubick, 1990), and also between Δ and total dry matter (Wright et al., 1988). The discrimination against ^{13}C (Δ) in leaf dry matter is calculated as:

$\Delta = (\delta a - \delta p) / (1 + \delta p)$, where δa and δp being the isotope composition of the air and plant materials, respectively relative to PDB (Pee Dee Bele minite).

A high heritability of Δ and its strong relationship with W indicate that a breeding programmes which includes selection for W based on differences in Δ could lead to increased dry matter production and yield of groundnut in water limiting environments. Thus measurement of Δ may prove a useful trait for selecting cultivars with improved W and total dry matter yield under field condition. In a mini-lysimeters study the WUE, ranged 1.81 in Chico to 3.15 g kg^{-1} in Tifton-8, was negatively correlated with Δ (19.1 to 21.8%) and thus Δ is a useful trait for selecting groundnut genotypes with improved WUE under drought conditions in the field Wright et al, (1994). A strong negative relationship also existed between WUE and specific leaf area (SLA, cm^3 g^{-1}) and between Δ and SLA, indicating that genotypes with thicker leaves had greater WUE. Significant correlations amongst WUE, CID in leaf and SLA suggested that CID and SLA could be used to identify genotypes with high WUE (Rao et al, 1994). SLA could therefore be used as a rapid and inexpensive selection index for high W in groundnut where mass spectrometry facilities are not available.

A time-integrated approach based on stable isotope ratios of carbon and oxygen (Delta ^{13}C/Delta ^{18}O) were described by Bindumadhava et al. (2005) using groundnut (NCAC-17090, VRI-4, ICGS-11 and SenNghean) genotypes to identifying crop genotypes with high mesophyll capacity for carbon assimilation as it has specific advantage in crop improvement, since such genotypes besides sustaining productivity under water-limited conditions can also save substantial amounts of irrigation water, this approach would provide a strong impetus to plant breeding efforts with assured success to improve productivity. Experimental evidence is presented to show that the ^{18}O enrichment in the leaf biomass and the mean (time-averaged) transpiration rate are positively correlated in groundnut genotypes (Sheshshayee, 2005). The relationship between oxygen isotope enrichment and stomatal conductance (g_s) was determined by altering g_s through ABA and subsequently using contrasting genotypes of groundnut. The Peclet model for the ^{18}O enrichment of leaf water relative to the source water is able to predict the mean observed values well, while it cannot reproduce the full range of measured isotopic values. As all the genotypes of both species experienced similar environmental conditions, the differences in transpiration rate could mostly be dependent on intrinsic g_s and henc, Delta ^{18}O of leaf biomass can be used as an effective surrogate for mean transpiration rate, further, at a given vapour pressure difference, Delta ^{18}O can serve as a measure of stomatal conductance as well (Sheshshayee, 2005).

Rao and Wright (1994) examined genotype x environment (G x E) interaction for the relationship between SLA and DELTA in four groundnut genotypes (Chico, McCubbin, Shulamit and Tifton-8) with contrasting carbon isotope discriminating characteristics and found that values of DELTA and SLA were significantly influenced by the location, genotype and irrigation treatments, but genotype x location interaction effects on the relationship between DELTA and SLA were not observed. However positive relationship between SLA and DELTA was maintained when data were combined over sites and treatments ($r^2 = 0.87$, $P < 0.01$). SLA was negatively correlated with nitrogen content per unit leaf area (SLN) which in turn was negatively correlated with DELTA. The genotypic and environmental variation in transpiration efficiency (W) and its correlation with carbon isotope discrimination (DELTA) were investigated in 7 groundnut cultivars and *Arachis villosa* and *A. glabrata* where the W was highly correlated with DELTA in leaves, SLA and leaf thickness (Wright et al (1993). Genotype X environmental interaction for W, DELTA and SLA was shown to be very low, while heritability of DELTA was high, indicating that these traits could be used for selecting high W in groundnut breeding programmes.

Carbon isotope discrimination studies made in 21 F1 hybrids of groundnut in Andhra Pradesh, India, during the post rainy season Jayalakshmi, et al., (2002) demonstrated lower values of CID in TMV2-NLM, ICG 2716, Tirupati 1 and ICGV 86031, highest significant heterosis in ICG 2716 x TAG 24 and positive heterosis over better parent was observed in TAG 24 x TMV2-NLM. The ribulose-1, 5-bisphosphate carboxylase-oxygenase (Rubisco) content increase under water deficit and top leaves had a higher Rubisco content and lower DELTA, than bottom leaves Rao et al, (1995). Cultivar x leaf position interaction was observed for DELTA and Rubisco, indicating the importance of leaf position in selecting for water-use efficiency (WUE), using leaf traits in groundnut. Rubisco content and DELTA were negatively related ($r^2 = 0.65$, $P<0.01$). There is a positive correlation between Rubisco content and leaf weight per unit leaf area (rhoL) in the upper leaves ($r^2 = 0.60$, $P<0.01$). And the basis of genotypic variation in DELTA was mostly (>60%) attributable to Rubisco content. In view of the leaf positional effects on DELTA and Rubisco, the upper leaves in the canopy should be used for selecting genotypes for W based on leaf traits like rhoL or DELTA. At Tirupati, India the Under adequately irrigated and simulated drought treatments at Tirupati, Andhra Pradesh with 20 groundnut genotypes differing in their transpiration efficiency and was repeated with 7 genotypes in the second season. Specific leaf area (SLA) and carbon isotope discrimination (CID) exhibited significant positive relationships indicating that SLA can be utilised as a surrogate to CID. (Asalatha, et al., 1999) SLA was negatively related to transpiration efficiency, while it was positively related to partitioning, suggesting that selection for low SLA might result in production of more dry matter with minimal influence on pod weight Asalatha et al (1999). The mineral ash and total chlorophyll contents of leaves were strongly correlated with SLA and due to its simplicity in measurement these has merit considering a screening tools in selection and breeding programmes for higher WUE under limited water environments Reddy et al (2000).

Krishnamurthy, et al. (2007) evaluated the variation for Transpiration efficiency (TE) in a set of 318 recombinant inbred lines (RILs) of groundnut at F8 generation, derived from a cross between a high TE (ICGV 86031) and a low TE (TAG 24) parent, and the value of specific leaf area (SLA), SPAD chlorophyll meter readings (SCMR) and carbon isotope discrimination (Delta ^{13}C) as surrogates of TE were measured. The overall distribution of TE among the RILs indicated that TE was governed by dominant and additive genes, surrogates SLA and SCMR, were measured prior, during and after completion of the drought period, whereas Delta ^{13}C was measured on the dried tissue after harvest. Transpiration efficiency was negatively associated with SLA after the completion of stress treatment ($r^2=0.15$) and Delta ^{13}C in leaves ($r^2=0.13$) was positively associated with SCMR during stress ($r^2=0.17$). Although the heritability of SCMR was relatively higher than that of TE, the stress-dependence of the relationship with TE, and the poor regression coefficients (r^2) with that RIL population, do not confer that these surrogates are adequately robust enough in that population (Krishnamurthy, et al., 2007). Chuni Lal, et al. (2009) evaluated 9 peanut genotypes to investigate the influence of water stress on some phenological, morpho-physiological, and yield traits and found that water saturation deficit (WSD) and epicuticular wax load (EWL) increased in response to water stress and age of the crop, while SLA decreased with water stress and age of the crop. Though, the correlations of WSD, EWL, and SLA with yield traits were fairly weak, WSD in the early stage was positively associated with pod yield and EWL in the early stage was negatively associated with harvest index (HI) under stress. Genotypes that accumulated flowers sooner after initiation showed less yield reduction and the negative association between HI under stress and its reduction deems HI under moisture stress an important criterion of selection for drought tolerance in peanut (Chuni Lal, et al., 2009).

Molecular markers and genetic linkage maps are pre-requisites for molecular breeding in any crop species. In case of peanut or groundnut, an amphidiploid (4X) species, not a single genetic map is, however, available based on a mapping population derived from cultivated genotypes. In order to develop a genetic linkage map for tetraploid cultivated groundnut, a total of 1,145 microsatellite or simple sequence repeat (SSR) markers available in public domain as well as unpublished markers from several sources were screened by Varshney, et al, (2009) on two genotypes, TAG 24 and ICGV 86031 that are parents of a recombinant inbred line mapping population and reported the construction of the first genetic map for cultivated groundnut and demonstrated its utility for molecular mapping of QTLs controlling drought tolerance related traits as well as establishing relationships with diploid AA genome of groundnut and model legume genome specie. As a result, 144 (12.6%) polymorphic markers were identified and these amplified a total of 150 loci. A total of 135 SSR loci could be mapped into 22 linkage groups (LGs). While six LGs had only two SSR loci, the other LGs contained 3 (LG_AhXV) to 15 (LG_AhVIII) loci. As the mapping population used for developing the genetic map segregates for drought tolerance traits, phenotyping data obtained for transpiration, transpiration efficiency, specific leaf area and SPAD chlorophyll meter reading (SCMR) for 2 years were analyzed together with genotyping data. Although, 2-5

QTLs for each trait mentioned above were identified, the phenotypic variation explained by these QTLs was in the range of 3.5-14.1%. In addition, alignment of two linkage groups (LGs) (LG_AhIII and LG_AhVI) of the developed genetic map was shown with available genetic maps of AA diploid genome of groundnut and Lotus and Medicago (Varshney, et al, 2009).

7.4. Hormones and growth regulators

The indigenous growth promoting and inhibiting substances influence apparently to growth of groundnut which is mainly under genetic control, however the flowering, pegs, pods and seeds are influenced greatly by growth regulators. In groundnut there is a good scope to reduce the vegetative growth and increase the reproductive part to increase the pod yield in groundnut and attempts were made to achieve this through growth retardants. Synthetic growth retardant SADH (succinic acid 2,2-dimethylhydrazide) being used with trade names of B-nine, Alar-85, and Kylar and synthetic antiauxin TIBA (2,3,5-triiodobenzoic acid) shortened internodes and reduce shoot dry wt., but increased seed size in groundnut. The growth retardant CCC (2-chloroethyl) trimethyl ammonium chloride had no effect on vegetative growth but increased yield (Das Gupta, 1975). Saini et al. (1984) reported that sequential spray of 5 ppm IAA 40 days after sowing and 25 ppm ethrel 7-10 days after enhanced number of the mature pods, pod yield and shelling out turn. XE-1019, a triazole synthetic plant growth regulator treated in soil at 45 DAS reduced the transpiration due to partial closer of stomata in JL 24 and hence can be used in dry land agriculture (Bora and Mathur, 1991).

Pod yield generally increase by growth retardants, with higher concentrations of CCC having the most effect and maleic hydrazide the least. In a study groundnuts cv. JL-24 sprayed with 100-3000 ppm CCC (chlormequat), 1000 ppm mepiquat chloride, or 500-1000 ppm maleic hydrazide decreased leaf area and LAI, LAD, but specific leaf weight increased, and was highest at higher concentrations of CCC (Phulekar et al, 1998). The SADH applied to the foliage reduced the percentage of fancy pods. (Venkateswarulu et al., 1980) reported that two foliar sprays at 30 and 50 DAS of SADH (1000 ppm) increased pod yield and oil in TMV-2 while MH at 50 ppm improved yield as well as net profit at Tirupati, India. Kylar (SADH) sprayed during early pod set at (79 DAS) at 1 kg a.i. ha^{-1} increased pod yield, 100 seed wt. and shelling percentage. Foliar application of NAA (25-50 ppm), MH (200 ppm) at the initiation of flowering and GA (50 ppm) at peg initiation stage at a rate of 400 l ha^{-1} in 0.5% teepal increased 11.3, 10 and 9.6 % pod yield, respectively (Subba Reddy and Shah, 1984). The M-13 groundnut sprayed with mixture of aliphatic alcohols (C-24 to C-34) at 1 µg ml^{-1} and α-Napthol-1-amino, 4-sulphonic acid at 50 µg ml^{-1} at 30 and 37 DAS (at flowering and gynophore initiation stage) increased the number of flowers produced in initial 3 weeks, pod number and wt., 100 seed wt., harvest index and pod yield (Parmar et al., 1989). These mixture of aliphatic alcohols (C 24 to C 34), tetraconsanol 7-10%, hexaconsanol 12-16%, octacosanol 15-20% triacontanol 24-30%, dotriacontanol 11-14% and tetratriacontanol 4-5% in germinating seeds were also found useful (Parmar et al., 1989).

In Raichur, Karnataka, spray of growth regulators brassinolide at 125 ml/ha and triacontanol at 200 ml/ha increased yield and yield components in groundnut cvs. R-9251 and K-134 during rabi/summer, but Triacontanol was better than brassinollide (1742 kg/ha) (Kabadagi, et al. 2008). Foliar application of 4 % cow urine + 50 ppm NAA increased chlorophyll, nitrogen, potassium content in leaves and oil content in kernels (Pawar, et al. 2008). In another study two foliar sprays of cow urine (4, 6, 8 and 10%) and NAA (50 ppm) alone or in combination enhanced morpho-physiological parameters viz., number and total dry weight of root nodules, plant height, number of branches, leaf area, total dry matter production, RGR, NAR and pod yield hectare (Deotale, et al. 2008). At 45 DAS, spray with 500-1000 ppm cytozyme (hydrolysed protein complex + auxins + cytokinins + activated trace elements in a biological medium), CCC (chlormequat), Vipul (triacontanol) or Paras (a mixture of triacontanol-based long chain alcohols), 50-60 ppm TIBA and 10-20 ppm Planofix (NAA) increased the LAI, DM production, NAR and CGR and gave pod yields of 1.76-2.22 t ha^{-1} compared with 1.75 t in the untreated control with Chlormequat being the most effective, followed by Cytozyme and Planofix (20 ppm) Nawalagatti et al (1991). In Tamil Nadu, India groundnuts cv. Co 1 sprayed with 125 ppm mepiquat chloride at 25, 35 or 45 DAS decreased shoot length and LAI and increased root length, CGR and pod yields (Jayakumar and Thangaraj, 1996).

Spray of IBA at 50 ppm 40 and 60 DAS increased 11.4-28.6 % pod yield and under limited water supply, imposition of water stress by withdrawing two irrigations in the early crop growth, followed by spraying of 50 ppm IBA (400 and 600 l ha^{-1} at 40 and 60 DAS) proved economical (Patel et al., 1988). Under drought condition CCC reduced the rate of permeability and water content of leaves of seedlings (Ling and Rui-chi, 1991). The 150 ppm CCC increased the peroxidase activity and decreased the malonaldialdehyde content and super oxide dismustase activity. The CCC treatment accumulated indigenous ABA content in the leaves of groundnut grown in normal and drought conditions increasing ability of drought resistance. The PP 333 (paclobutrazol) increases the accumulation of endogenous ABA and inhibits GA biosynthesis in the leaves of groundnut (Ling and Rui-chi, 1988). The foliar spray of Lihocin (333 ppm) + Paras (166 ppm) produced maximum number of pods and increased pod yield (NRCG, 1985).

Groundnuts cv. JL-24, sprayed with 100-3000 ppm CCC (chlormequat), 1000 ppm mepiquat chloride, and 500-1000 ppm maleic hydrazide at Dharwad, decreased, the leaf area, leaf area index and leaf area duration by all these growth regulators compared with controls, while specific leaf weight and Pod yield increased and was highest at higher concentrations of CCC (Phulekar, et al.1998). In field trials in Junagadh, groundnuts cv. GG2

2 sprays with 50 ppm IBA twice at 40 and 60 d after sowing increased pod yield, N, P and K uptake and seed oil and protein contents (Patel, et al. 1994). Foliar spray of the mixture of NAA and kinetin increased the pod yield by 20.7% and improved yield components, kernel and haulm yields, and harvest index, and proved more effective than either NAA or kinetin alone (Jat and Singh, 2006). Foliar spray of NAA and 2,4-D increased the yield attributes and yield of Groundnut cv. M-13 (Poonia, et al. 2006).

The effects of various seed treatments on the performance of summer groundnut (cv. TAG-24) studied in Parbhani, Maharashtra, showed that seed germination, field emergence and pod yield were greatest when it was immersed in potassium dihydrogen phosphate, seedling dry weight was greatest when sees was immersed in distilled water and kept at 10 °C for 72 h, however, days to flowering was reduced if seeds were immersed in GA (50 mg) (Shinde, et al. 2007). At Akola, white polythene mulch and foliar spray of cycocel (1500 ppm) recorded maximum growth and yield and harvest index and white and black polythene mulch gave 89 and 66 % higher yield respectively as compared to control (Dambe, et al. 2007). The Presoaking of groundnut seeds cv. TAG 24 in solutions of chlorflurenol and cycocel (both 10^{-6} M) for 6 h resulted in higher yield under drought conditions supported by drought indices like relative water content (RWC), proline accumulation and transpiration the antitranspirant action of these chemicals (Mathew and Pandey, 2006). Field experiments in Tamil Nadu, India, foliar application of brassinosteroid (1.0 mg brassinosteroids/litre at 25 and 35 days after sowing) was beneficial on the growth, physiology, biochemistry and pod yield in groundnut cv. VRI 2 (Prakash, et al. 2006). The paclobutrazol (PB) tended to increase crop growth rate and net assimilation rate. In Japanese groundnut cv. Nakateyutaka, application of PB at the start of the pod formation stage increased chlorophyll content and PHIPSII, resulting in enhanced CO2 assimilation rates which increased the percentage of pod and seed yield mainly by an acceleration of dry matter distribution to the early-bearing pods, which resulted from the inhibition of stem growth by PB (Senoo and Isoda, 2003).

In spite of all these positive results and potential of these chemicals, hormones could not be included in the package of practices of groundnut cultivation in India, because precaution is required to insure that no detrimental effects of growth regulators occur on other plant parts and progenies than the target characters. Kylar is the most widely studied hormone to control the excess vegetative growth. Both auxin and gibberellins are involved in peg growth and pod formation. The growth promoters such as cytokinins had no effect on pod yield. The morphactins inhibited shoot weight but enhanced pegging (Ketring, 1977), reduce stomatal frequency and total chlorophyll content (Umapathi and Swamy, 1978). The ABA, a growth retardant, had no effect on vegetative growth but reduced flowering, ethrel blocked flowering for time being and MH (maleic hydrazide) depending on the concentrations increased and decreased flowering (Ketring (1977).

7.5. Mineral stresses and Salinity

In India, though the groundnut is grown on a wide range of soil across the country in almost all states, it is mainly grown on alluvial, coastal alluvial, red and mixed red, black and laterite soils. Groundnut flourish well on a well drained loamy sand, sandy loam and sandy clay loam soil however, it can be grown over a fairly wide range of soil. In heavier soil there is greater pod loss during harvest. It prefers warm, moist soil and adequate rainfall is necessary during the growth season particularly during fruiting. These soils are well suited for groundnut, but due to continuous cropping and depletion of nutrients show different problems of deficiencies and toxicity of mineral nutrients and heavy metal based on their abundance and availabilities in soil. Though the groundnut, like other crop, require all the macro (N, P, K, Ca, S, Mg) and micro-nutrients (Fe, Mn, Zn, Cu, B, Mo), the Ca, P, S, K, Fe and B are the key nutrients for most of the soils in India and their fertilization is essential (Singh, 1999a). The deficiencies of Ca, P, K and Mo are most common in acid soils, while P, S, K, Fe and Zn in calcareous and alkaline soils and need special attention for the same. The details of the macro and micro-nutrients requirements, functions, deficiency and toxicity symptoms and their rectification measures in groundnut, has been dealt separately in a book mineral disorders of groundnut (Singh et al 2004) and a manual (Singh and Basu, 2005).

7.6. Genotype and environmental interactions

Current phenotype models utilized by plant breeders partition traits, such as reproductive yield (Y), into the 'statistical' components of genetic (G), environmental (E), and genotype X environment (GE) interaction. Traits such as yield commonly have large GE interaction terms. Better knowledge of the physiological basis for the differential responses of genotypes to specific environments should improve the efficiency with which the breeder can characterize material for its G, and GE interaction, and hence increase the speed at which superior genotypes can be identified. Because genotype and environment interactions are often observed adaptation of improved groundnut genotypes to varied environments particularly soil and climate is one of the major problem. However, very little emphasis has been paid on understanding and exploiting variability for specific adaptation. The physiological model, proposed by Passioura (1977) was used to define the yield (Y) as the product T x TE x HI, where T = amount of water transpired, TE = transpiration efficiency and HI = harvest index. Past and current studies have attempted to quantify these components in easily measurable ways. Wright, et al., (1996) in an international collaborative project involving Indian and Australian scientists measured TE in groundnut via carbon isotope discrimination and specific leaf area, T by substituting estimates of Y, TE, and HI and the results from this analysis allowed: (1) additional information to be obtained on GE interactions with very little extra investment in time and resources, since the parameters of the model could be measured simply and economically; (2) facilitate selection of parents/genotypes with specific adaptive traits, and; (3) highlight negative associations between yield determining traits.

The models utilized by plant breeders partition traits, such as reproductive yield (Y), into the 'statistical' components of genetic (G), environmental (E), and genotype x environment (GE) interaction. Traits such as yield commonly have large GE interaction terms. Breeders often have little information concerning the physiological basis of this GE interaction, thus leaving them without a clear idea of how to exploit the material further. Better knowledge of the physiological basis for the differential responses of genotypes to specific environments should improve the efficiency with which the breeder can characterize material for its G, and GE interaction, and hence increase the speed at which superior genotypes can be identified. The heritability of crop growth rate (C), partitioning (p) and duration of reproductive growth (DR), and the relative contribution of genotype (G), environment (E) and G x E interaction were low, 0.11 for yield, 0.03 for C, 0.22 for p and 0.14 for DR (Ntare and Williams, 1998a) however indirect selection for yield via p was estimated to be 22% and more effective than direct selection and p had larger heritability than yield, while C had low heritability of yield. Ntare (1999) determined the potential of selecting for physiological traits where effects of locations were significant for C, p and DR in F_2 and F_3 but non-significant for yield and C in F_4, suggesting that selection for yield and model components in early generation bulks may be ineffective.

Mathur et al (1997) studied 7 Virginia and 7 Spanish varieties of groundnut, at Junagadh, for genotype and environment interactions and found that shelling percentage and 100 pod weight were most stable. Virginia variety M 13 and Spanish variety GG 2 were most stable for most yield traits. In a line x tester design, differences between males and females were observed for days to maturity and interactions were significant for all the characters except three reproductive efficiency (RE) indices(Mathur et al, 2000). For days to maturity, RE_1, RE_2 and RE_3 additive gene action was predominant while for total flowers, days to flower initiation, number of mature pods and sound kernels, mature pod and sound kernel weights, the preponderance of non-additive gene action was noticed. The genotypes ICGV 86325, GAUG 10, Chico and Robut 33-1 could be used in the breeding programmes aimed at the development of suitable cultivars for earliness. ICGV 86325 and Chico would best be used as parents in the breeding programmes on the development of high yielding and reproductively efficient cultivars.

Utilization of exotic germplasm in breeding programs is needed to enhance the diversity of cultivars. Core collections, which generally contain 10% of total accessions and represent the diversity of the entire collection, have been suggested as a means to enhance the use of genetic resources. The groundnut core collection for Asia, consisting of 29 accessions of subsp. fastigiata var. fastigiata, 245 of subsp. fastigiata var. vulgaris, and 230 of subsp. hypogaea var. hypogaea, along with four control cultivars, was evaluated by Upadhyaya, et al. (2005) in multienvironments for 22 agronomic traits to select diverse superior germplasm accessions for use as parents in improvement programs and analysis of data, using the residual maximum likelihood (REML) approach, indicated that variance components due to genotypes were significant for all 22 traits, and genotypes x environment interaction was significant for eight traits. Estimates of broad sense heritability ranged from 35.5% for pod yield per plant to 98.0% for days to cessation of flowering, indicating relative reliability of selection for different traits. On the basis of performance compared to control cultivars in different environments, 15 fastigiata, 20 vulgaris, and 25 hypogaea accessions from 14 countries were selected. The selected accessions and control cultivars were grouped using scores of the first 15 principal components (PCs) in fastigiata, 20 PCs in vulgaris, and 21 PCs in hypogaea. The clustering by Ward's method indicated that the selected accessions were diverse from the control cultivars. These 60 diverse parents will provide the germplasm, which can be used in the improvement programs to broaden the genetic base of groundnut cultivars (Upadhyaya, et al., 2005).

Genotype x environment interactions were highly significant for days to maturity, height of central axis, number of pods/plant, pod yield/plant, shelling percentage and 100 kernel weight and the genotypes could be classified according to their suitability for high, medium and low yielding environment, days to 50% flowering ranged from 21.67 to 33.33, the genotypes Kaushal, ICGS-44 and Chandra were stable for pod/plant, shelling percentage and 100 kernel weight (Singh and Singh, 2001). Nine promising groundnut cv. (TG-24, BG-3, JL-24, GG-2, GG 85-1, TG-22, AK 12-24, Kisan and Gangapuri) studied under 4 environments in Ranchi, the GE interactions were significant for the days to 50% flowering and maturity, shelling percentage, 100 kernel weight and pod yield, all the traits were controlled by non-linear component of environment and among the cultivars, JL-24 and BG-3 were the most stable for pod yield and most of the other characters, and suitable for cultivation in wide range of environmental conditions (Mahto and Mahto, 2000).

Peanut composition is influenced by several groups of factors: environmental, genetic, and their interaction. Isleib, et al. (2008) in a study evaluated the relative contributions of these factors using data from the USDA-ARS quality testing program using samples from the multi-state Uniform Peanut Performance Tests (UPPT). Data were subjected to restricted maximum likelihood estimation of variance components reflecting the main effects of year, production region, location within region, genotype (cultivar or breeding line), and kernel grade ("seed size") within genotype, and the interactions among these main effects. Genetic variation in oil content was low (9% of total variation); however, fatty acid composition of the oil was highly influenced by genotype (34-77%) with the exception of lignoceric acid (1%). Genetic influence on tocopherols was generally less than that of fatty acids. Environmental variation of tocopherols was greater than the variation attributable to genotype-by-environment interaction. The lowest genetic variation was observed in sugar content; however, environmental variation was high (68%). The magnitude of genetic influence on oil content and fatty acid concentrations suggests that these traits are amenable to improvement through breeding (Isleib, et al., 2008).

There is a lot of scope for yield improvement in groundnut by selecting for physiological attributes contributing to yield advantage in a given environment and combining them to enable further identification of genotypes with desirable combinations of traits. Scope also exists to enhance productivity of groundnut by developing varieties with specific traits to match agroclimatic requirements of the region.

7.7. Diseases and pests

The insect pest and diseases play a major role in bringing down the productivity for which utmost care has to taken. Describing the diseases and insect pest is out of scope in this review as the major emphasis is on physiological parameters, nevertheless the diseases nas insect pest alter the physiology of the crop. However, the details diagnosis and remedies of the major and emerging diseases and insect pests of groundnut are mentioned in the book “groundnut Research in India” (Basu and singh, 2004). Here some burning issues are mentioned.

Some members of Arachis section Erectoides have been found resistant to early leaf spot disease caused by *Mycosphaerella arachidis*, but these accessions do not cross with cultivated species. Crossing between one such diploid species, *A. paraguariensis* (ICG8130 and ICG8973) of section Erectoides, and the diploids, *A. batizocoi* and *A. duranensis*, and the tetraploid *A. hypogaea* (groundnut) of section Arachis has helped understand barriers to hybridization between sections (Singh, 1998). These crosses results in the development of normal pegs and pods, but with restricted ovule and embryo development due to cessation of early endosperm development in *A. duranensis* x *A. paraguariensis*, the non-development of endosperm beyond the coenocytic stage in *A. batizocoi* x *A. paraguariensis*, and the overgrowth of nucellar tissue into the embryo sac in case of *A. hypogaea* x *A. paraguariensis*. The weak cross-compatibility between the species of two sections suggest relatively closer phylogenetic relationship between them, than with the other incompatible sections of the genus Arachis (Singh, 1998).

8. Photoperiodism and thermal time

The groundnut is grown from latitute 40ºN to 40ºS under a wide range of temperature and photoperiod combinations, and hence the effect of environmental factor especially on assimilate partitioning will have importance in the adoption of cultivars to a particular region. Temperature is more important factor affecting vegetative growth, while photoperiod is more important during reproductive growth, although significant interaction between these two occur. For the same groundnut cultivar grown under a range of environmental conditions, temperature and irradiance play a major role in determining crop duration and partitioning of dry matter to pods, the latter assessed by harvest index. Groundnuts are indeterminate and their reproductive efficiency and assimilate distribution after flowering can be altered by photoperiod and temperatures. Matching the phenology of the crop to the duration of favorable conditions by selecting the most appropriate sowing dates to avoid periods of stress is crucial for maximum yield as the sowing dates, cultivars and growth durations significantly affect pod yield, number of pod per plant, shelling percentage, 100-seed weight, biomass, harvest index, crop growth rate, and oil and protein content

8.1 Photoperiodism

The photoperiodic effects alter the balance between vegetative and reproductive growth rather than influencing the rate of progression towards flowering. Groundnut is an apparent long-day plant (Bell et al. (1991a) and number of flowers, pegs and pods were reduced under long photoperiod in cv. Robut 33-1 (Bell and Harch, 1991). However, Bagnall and King (1991a) classified groundnut a short-day plant (SDP) as over 14 days as many as twice flower opened in 10 h than 16 h photoperiod. In general the vegetative growth is increased during long day photoperiod and reproductive growth under short day photoperiod. The yield differences between the photoperiod treatments (15-16 h or 11-13 h daylight) were largely explained by changes in CGR, partitioning and the length of the effective pod-filling period (Witzenberger et al., 1988). Long days (15-16 h light) resulted in increased CGR but generally decreased partitioning and the duration of the effective pod-filling phase. The processes more influenced by day-length conditions varied between cultivar. In some cases, partitioning contributed most to yield differences; in others, the duration of the effective pod-filling phase contributed most.

The rate of phenological development increased with increasing mean air temperature. For a Spanish groundnut with about 110 days duration, the 36-72 days period was most sensitive to photoperiod and fruiting potential was highest when short days were given during this period (Emery et al., 1981). The flowering and peg number at 60-70 DAE were doubled by 12-h days compared with plants in 16-h days and pod number was 3-12 times more and hence there was increased yield in plant exposed to short day than long day (Bagnall and King, 1991b). At day/night temperature of 30/25ºC, there was no effect of photoperiod between 10 and 14 h on time to first flower but at 24/19ºC the Spanish, Virginia and Valencia took 85, 64 and 75 % more time to flower (Bagnall and King, 1991a).

The number of pegs and pods and harvest index at 35 and 65 days after flowering correlated with day length during emergence to flowering however, the day length effects could not be separeted into effect of photoperiod, irradiance or heat unit accumulation (Bell et al., 1991b). Bell et al. (1991c) in their further studies contradict the results and reported that the number of pods and pegs and total pod wt were reduced in long (16 or 17 h) photoperiod. In India, the flowering of groundnut occurred in all the photoperiod from 6 to 24 h but maximum was at 10 h and photoperiod shorter or longer than 10 h delayed flowering initiation (Sen Gupta et al., 1977). However the response was cultivar specific and of the 6 cultivars tested, four yielded 38-106 % higher, increased shelling percentage and 100 seed wt. under short-day (11.1-12.6 h) conditions than in long day, while TMV-2 and Robut 33-1 had slightly higher yield under long day (22 h), but Kyler applied at 1 kg a.i. ha^{-1} during early pod set (at 79 DAS) decreased the differences in yield created by the two day-lengths by increasing the 100 seed wt (Witzenberger et al., 1985).

The genotype and environmental interactions are more prominent in the cultivars, which are grown in the environment to which they are not selected. Most of the controlled condition studies showed a difference of only 4 to 5ºC in day and night temperature, however, in field condition the differences are greater (8-16ºC). The TDM in groundnut cultivars was 32-72% higher under LD (12 h, long day) than SD (9 h, short day) photoperiods and pod to peg ratio (PPR) could be used as an indicator of genotypic sensitivity to photoperiod hence temperature x cultivar interaction effects were significant, with the dry matter production being highest at 26/22°C and lowest at 30/26°C and 22/18°C (day/night) Nigam et al (1998). Leaf area (LA) was greater under LD than SD at all temperature regimes and accounted for 76% of the variation in shoot + root dry weight, however, lack of relationship between LA and pod weight or pod numbers suggest that the pod development is controlled by factors other than carbon assimilation. Low temperature (22/18°C) affected the reproductive development by reducing the proportion of reproductive nodes. The conversion of pegs into pods, as indicated by pod to peg ratio (PPR), was lower in LD than in SD conditions.

The effect of photoperiod in groundnut is manifested in post-flowering development including partitioning. The partitioning of assimilates, as measured by harvest index (HI), has the greatest effect on pod yield. The F1 progenies and their parents from a six-parent diallel cross were studied by Dwivedi, et al., (1998) to estimate combining ability for biomass and HI under short day (SD) and long day (LD) conditions, and to identify good combiners with high biomass and HI for use in breeding programmes using two photoperiod treatments SD (defined as normal-day light period) and LD (defined as normal-day light period extended by 4 h using incandescent lamps). The data for combining ability using multi-environment analogue of Griffing's Method 2 - Model 1 reveals that while biomass was controlled by both GCA and SCA effects, HI was predominantly controlled by GCA effects, the GCA and SCA effects for biomass and HI interacted with environments (six factorial combinations of photoperiods and seasons), the SCA effects remained insensitive to variation in photoperiod both for biomass and HI. However, GCA effects for HI were sensitive to photoperiod. ICG2405 was a good general combiner for both biomass and HI across environments. None of the crosses showed positive and significant SCA effects for both biomass and HI. Photoperiod influenced the sensitivity of GCA effects of ICGV86694 and ICG2405 for HI. However, the differences between SCA effects in ICGV86694 X ICG2405 were not significant (Dwivedi, et al., 1998). However there is a need for further studies utilising random genotypes and a range of photoperiods

8.2. Thermal time and heat unit

Although time to first flower was little affected by photoperiod, temperature had a major and positive effect. Several workers have studied the temperature effects, on reproductive development, and data on the temperature dependence of peg and pod formation were obtained. The optimum temperature for peg formation ranged from 20ºC to 32/23ºC. In general, the Spanish cultivars tend to develop reproductive yield component (pegs and pods) sooner than Valencia and Virginia but considerable variation within botanical types especially the Virginia also exist due to different phenology. The base temperature (T_b), the temperature at or below which the rate of progress towards a phenological event is zero and thermal time (θ, ºC d, number of degree-days above the base temprature after which that event will occur) required for emergence θ_s or flowering θ_f of groundnut have positive correlation with mean air temperature. The base temperature (heat unit) T_b for Spanish, Valencia and Virginia types groundnuts were 11.4-13.1, 13.4 and 12.3-15.1 for emergence and 12.3-13.4, 8.8 and 4.6-9.9 for flowering, respectively, and the respective thermal time for these botanical groups were 75-89, 69 and 54-80 for emergence and 212-221, 343 and 342-542 ºC d for flowering, respectively (Bell et al., 1991a). The Spanish types manifested a higher base temperature (13.6ºC) than Valencia (12.5ºC) and Virginia (11.4ºC) types, but the extrapolated base from the quadratic curve were 2-3ºC higher than those from straight-line fits (Begnall and King, 1991a). Using hourly temperature reading to calculate daily heat sum (ºC h) above a base temperature of 10ºC, Bell et al. (1991c) demonstrated that the environment with daily heat unit accumulation >340-350ºC h, showed photoperiod responses.

Thermal time widely describe the temperature response of groundnut. The threshold or base (T_b), optimum (T_o) and maximum (T_m) temperature in groundnut ranged from 8-11.5, 29-36.5 and 41-47ºC, respectively (Ong, 1986). The rate of development increases linearly between a base temperature of 10ºC at which rates were zero and an optimum temperature of 30ºC at which rate are maximum and under non-limiting conditions, developmental events occurred at a fixed interval of thermal time θ (degrees-days, ºC d) defined by the relation: $\theta = t\ (T - T_b)$, where T is the mean daily temperature, and t is the duration of a developmental phase or the time (days) for a discrete event to occur (Leong and Ong, 1983). The T_b vary from various stage of crop growth (Angus et al. 1981) and is highest during the reproductive phase (3-10ºC higher) than during the vegetative phase. However, the T_b (10ºC) of germination could be used to calculate thermal time for further developmental processes for groundnut.

The base temperature and thermal time for differential processes to occur in groundnut are:

Developlmental process	T_b(ºC)	θ (Cºd)	References and remarks
Leaf production	10	56 Leaf^{-1}	cv Robut 33-1 (Leong and Ong 1983)
Branching	9.5	103 branch^{-1}	
Time to first flowering	10.8	538	
Time to first pegging	10.6	670	
Time to first podding	11.4	720	
Time to begin flower		479-534	Hyderabad, India (Harris et al., 1988)
Time to begin peg		813-996	
Time to begin pod		996-1077	
Very early maturity (75 days)		1240	Hyderabad, (Vasudeva et al 1992)
Early maturity (90 days)		1470	
Spanish	13.6		Begnall and King, 1991a
Valencia	12.5		
Virginia	11.4		
Maturity for 'Early Bunch'		1808(± 23)	Bell and Wright, 1998b
Long maturity (160 days)		2400-2500	The Mediterranean climate in Turkey (Caliskan, et al. 2008)

In Japan Awal and Ikeda (2002) reported that in field-grown groundnut cv. 'Chibahandachi' the rate of seedling emergence increased by about 1.4 calendar-days for every 1°C rise in soil temperature. When seeds were exposed to a mean soil temperature of 23.4°C, an air thermal time (Qa) of 49 degree-days (°C d) was required for seedling emergence to start, and emergence was completed within 117°C d but at cooler soil (18.1°C), seedling emergence began at 96°C d and was completed by 237°C d. There were no significant differences among temperature treatments in the soil thermal time (Qs) required for emergence. The rates (d-1) of leaf appearance, branching, flowering, pegging and podding were positive linear functions of soil temperature (Awal and Ikeda, 2002). For the phenological events of 50% seedling emergence, leaf appearance, branching, flowering, pegging, and podding, the base temperature (Tb) of the soil was 9.9, 10.3, 9.7, 10.4, 10.7, or 11.1°C, respectively, and the Qs was 125, 270, 556, 588, 667, or 833°C d, respectively. The mean Tb for the development of all phenophases studied was 10.4 (±0.5)°C. Strong positive correlations (r_0.95) were noticed among the rates of development of the phenophases observed. Rising air thermal times (134-1147°C d) increased the number of main stem leaves (Lf) but decreased the ratio of the number of main stem leaves to the total number of leaves (Lf:TLv) on the plant. Plants grown in warmer soil produced more leaves on their branches than on the main stem, resulting in a lower Lf : TLv ratio (Awal and Ikeda, 2002).

Utilizing published data for the Virginia groundnut cultivar 'Early Bunch' under non-limiting conditions, the accumulation of thermal time using three cardinal temperatures (T_b = 9°C, T_o = 29°C and T_m = 39°C) has considerable potential for predicting crop maturity and Bell and Wright, (1998b) demonstrated that in 16 sowings ranging from the wet tropics in Indonesia to the elevated subtropics in Australia, harvest date for 'Early Bunch' corresponded to the accumulation of 1808 (± 23) degree-days after sowing, and in all sowings this value of thermal time was within eight calendar days of actual harvest maturity. Using total short-wave solar radiation incident during the growing season and calculated values of thermal time, the growing season for each sowing in each location was described in terms of a photo-thermal quotient (PTQ MJ m^{-2} degree-day^{-1}) the values of PTQ ranged from 0.99 (Indonesia) to 2.11 (subtropical Australia). Harvest index varied greatly with both location and sowing date, ranging from 0.31 (Indonesia) to 0.58 (subtropical Australia) which could be explained largely by a curvilinear function of PTQ (R2 = 0.98), provided data were not confounded by the effects of photoperiod and in the semi-arid tropical environment, decreases in photoperiod associated with delayed sowing were the dominant factor controlling harvest index (Bell and Wright, 1998b).

In a 2-year field study the effects of climatic factors on groundnut growth and yield were assessed by Caliskan, et al. (2008) in two cultivars (NC 7 and Com) at various dates of sowing (15 April, 1 May, 15 May, 1 June and 15 June) in a Mediterranean-type environment at Hatay to expose the groundnut plant to a variety of climatic conditions, where very early sowing before 1 May did not have any advantage for earliness and yield due to sub-optimal temperature for vegetative growth, the most suitable period for groundnut sowing was between mid-May and early June for the eastern Mediterranean region since plants expose to suitable temperature regimes during the vegetative and the reproductive growth stages, and receive more solar radiation and sunshine duration during the entire growing period. Lengthening of growth duration had positive effect on yield at early sowings, but satisfactory yield level can be achieved with 140 days growth duration using current cultivars. It is also possible to obtain over 3.0 t ha-1 pod yield, which is considered as acceptable level by the grower in the region with shorter growth duration in double crop production. The Mediterranean climate in Turkey offers a long and suitable environment having at least 160 calendar days or 2400-2500 degrees Cd thermal time for both main and double crop production of the groundnut with acceptable yield levels (Caliskan, et al. 2008)

Estimates of the response of crops to climate change rarely quantify the uncertainty inherent in the simulation of both climate and crops. Challinor, et al. (2009) presented a crop simulation ensemble for a location in India, perturbing the response of both crop and climate under both baseline (12 720 simulations) and doubled-CO_2 (171 720 simulations) climates, where, observed and simulated yields in the baseline climate were compared, the response of yield to changes in mean temperature was examined and compared to that found in the literature and the relative contribution of uncertainty in crop and climate simulation to the total uncertainty in projected yield changes was examined. In simulations without genotypic adaptation, most of the uncertainty came from the climate model parameters, comparison with the simulations with genotypic adaptation and with a previous study suggested that the relatively low crop parameter uncertainty derives from the observational constraints on the crop parameters used in this study. Finally, the simulations were used, together with an observed dataset and a simple analysis of crop cardinal temperatures and thermal time, to estimate the potential for adaptation using existing cultivars and study suggest that the germplasm for complete adaptation of groundnut cultivation in western India to a doubled-CO_2 environment may not exist, however analyses of germplasm and local management practices can identify the genetic resources needed to adapt to climate change (Challinor, et al. 2009).

Groundnut has a great yield potential under the Mediterranean conditions. The growth and development of groundnut are under the influence of complex environmental factors. A two-year field experiment was conducted bt Caliskan et al. (2008) to determine the growth and development response of groundnut genotypes to environmental factors in the eastern Mediterranean region of Turkey where time from sowing to physiological maturity (R8) ranged from 2513 - 2588 Cd while total calendar days varied between 147 -161 depending on genotypes. Dry matter accumulation in each part of the plants continued until maturity although accumulation rate differed depending on plant age. Combination of suitable temperature and photoperiod during the reproductive stages resulted in continuous and abundant reproductive plant parts, which led to delayed harvest and increased unmarketable pods. The slower growth rate due to the cooler conditions during early stages caused slower biomass accumulation in successive stages indicating the importance of initial crop growth for final yield. Therefore, the genotypes having high initial growth rate, less reproductive organs, and shorter growing period should be developed for the Mediterranean conditions by breeders (Caliskan et al. 2008).

In India, the effects of temperature and photoperiod and their interaction on plant growth and partitioning of dry matter to pods were studied in selected groundnut genotypes, at three temperature regimes (22/18, 26/22 and 30/26°C day/night) each under long (12 h) and short (9 h) photoperiods where genotypic variability for photoperiod x temperature interactions were observed which might influence adaptation of groundnut genotypes to new environments (Nigam et al, 1994). The plant growth rates and partitioning of dry matter to pods when estimated on a thermal time basis, the plant growth rate (PLGR) was influenced by temperature, photoperiod and genotype, whereas pod growth rate (PDGR) was influenced primarily by temperature and genotypes (Nigam et al, 1994). Interaction of genotype with photoperiod and with temperature was observed for both PLGR and PDGR and at 22/18°C temperature regime. Partitioning of dry matter to pods (P_f) was also influenced by photoperiod, temperature and genotype, and their interactions where Photoperiod did not affect P_f under the low temperature regime, but at high temperatures partitioning to pods was greater under short days. However, P_f of one genotype was insensitive to photoperiod compared with the other two genotypes.

In Bikaner, Rajasthan, India, thermal units was studied in deciding the best sowing time and pod yield prediction of irrigated groundnut (cv. MA 10) sown on 15 March, 1 April, 15 April, 1 May, 15 May, 1 June, 15 June, 1 July and 15 July where highest pod yield and biomass was recorded in 15 March-sown crops with a decline in later sowings, the cumulative heat unit and photothermal unit values from sowing to flower initiation were low, the thermal use efficiency of 3.043 and 3.143 kg/ha day^{-1} °C was observed for early sowing dates (15 March and 1 April) followed by a decrease in heat use efficiency (Meena and Dahama, 2004). The accumulated heat unit, photothermal unit and heat use efficiency during flower initiation to physiological maturity was significantly and positively correlated with pod yield (Meena and Dahama, 2004). The Groundnuts cv. M 13 and M 335 had late maturity and thus accumulated more growing degree days, helio-thermal units and photo-thermal units in all phenophases than cv. M 522, SG 84 and SG 84 (bunch-type) attained harvest maturity 5-10 days earlier than others 4 genotypes and translocated most dry-matter towards pods at 93 and 114 days, while total dry-matter/plant was maximum in cv. M 522 during both the years (Brar, et al. 1999).

In Vridhachalam, Subrahmaniyan et al. (2008) studied the microclimatic variation in relation to different types of polyethylene film mulch and its effect on the growth and yield of groundnut during the post-rainy seasons. The studu reveals that, plastic film mulch increased the soil temperature by 1.0-1.9 ºC at different crop phenophases from sowing to harvest and was higher under black followed by transparent and white polyethylene film, soil temperature under ridges-and-furrows land configuration was 0.3 ºC lesser than flat-bed and broad-bed furrow methods. Growing degree-days (GDD) and helio-thermal unit (HTU) did not show much variation between the different types of polyethylene films up to 80 days after sowing (DAS), however, heat unit efficiency (HUE) differed with plastic mulches, but there was no such significant difference between the soil temperature, GDD, HTU and HUE. The dry matter production and yield attributes were higher under black polyethylene film mulch, and black polyethylene film mulch with adoption of flat-bed system of land configuration could be an important agricultural practice to augment groundnut productivity besides improving microclimatic conditions (Subrahmaniyan et al. 2008).

Thus, the groundnut physiology is driven primarily by temperature, the reproductive efficiency and assimilate distribution can be modified considerably by photoperiod. In India, there is not much seasonal variation in the length of day, except in a few portion of NE region where short day are observed, however, the plants under high day and night temperatures produce flowers early but under low temperature no flowering occur. By utilizing the data collected from the experiment conducted in the crop weather relationship in groundnut in Anantapur Krishnamurthy, et al. (2007) developed model for prediction of different phenophases for normal and late sown crop, based on the growing degree days with base temperature as 10°C in the variety TMV-2. Peanut sown in early spring often has poor seed germination and seedling development thus cultivar choice and/or genetic improvement of peanut for cold tolerance during emergence and seedling development in regions where cooler soil temperatures persist and/or regions where early sowing is desirable. The groundnut has different heat unit requirement for different cultivars. Since plant development are predominantly controlled by temperature, there are conspicuous differences in the time to flowering, podding and duration of the crop. Depending upon the genotypes, the number of degree-days taken to begin flower, peg and pod production are 479-534, 813-996, and 996-1077 ºC d, respectively at Hyderabad, India (Harris et al., 1988). In India based on the 13-year meteorological record with two predetermined cumulative at ICRISAT, the thermal time 1240 and 1470 ºC d (degree days) equal to 75 and 90-days duration, respectively, was developed as a selection criterion for earliness in groundnut (Vasudeva et al 1992).

9. Seed drying and storage

The drying and storage method significantly affected the germinability, seedling vigour and field emergence. Drying of pods containing 39 % moisture at high temperatures > 50°C adversely affected viability and at 50°C and 60°C temperature showed 92% and 74% germination, respectively (Nautiyal and Zala, 2004). Pods dried under natural field conditions in windrows experienced about 45°C mean temperatures and showed 74% germination which lost about 50% viability, within 3 months of storage on but, pods dried by the NRCG method, which protect pods from the direct exposure of sun rays by the haulm of the plant in a tripod structure, retained >80% germination, even after 9 months of storage and also helped in maintaining the seedling vigour (Nautiyal and Zala, 2004). The Drying of summer season pods of groundnut cv. AK 12-24 by the Directorate of Oilseeds Research (DOR) method and storage in polythene-lined gunny bag with a desiccant ($CaCl_2$ or silica gel) maintained germinability up to 95 % at Bhubaneshwar and 92 % at Bargarh, orissa even after 6 months of storage (i.e. until sowing during the next summer season), while the seeds dried and stored by the conventional method lost its viability completely within 6 months of storage(Nautiyal et al. 2004). The seedling vigour index was higher for seeds stored with $CaCl_2$ than that stored with silica gel in polythene-lined gunny bags (Nautiyal et al. 2004).

Accelerated ageing was associated with a decline in germinability and seedling vigour index. Nautiyal et al. (1997) while studying the physiological and biochemical changes during accelerated ageing in the seeds of a dormant ICGS 11 and a non-dormant GG 2 groundnut genotypes found that in general the concentrations of starch and soluble sugars decreased with ageing and the seeds of the non-dormant genotype had higher protein, total sugars and sucrose contents than non dormant seeds and the dormant genotype had a higher total lipid content. Seeds of the dormant genotype maintained higher germinability, root length and hypocotyl length, and had lower electrical conductivity of the seed leachate than seeds the non-dormant genotype. The concentration of O-dihydroxy phenols was higher from 6 days of ageing in seeds of the dormant genotype (Nautiyal et al. 1997).

The pods of groundnuts cv. GG 2 grown in the dry season were dried using different methods windrow (W, sun-dried in the field), and DOR (Directorate of Oilseeds Research, a method in which plant bundles are positioned to shade pods from direct sunlight in the day, but pods are exposed overnight) for 5 days, stored in polyethylene lined gunny bags with or without desiccant ($CaCl_2$ or silica gel, 10 g kg^{-1} pods) for 12 months and analysed for seed viability, seedling vigour, membrane integrity and field emergence during storage, and crop stand and pod yield. There was quick loss of viability and increase in electrical conductivity of the seed leachate in the W treatment, however the seeds dried by the DOR method and stored with $CaCl_2$ (DOR-C) due to lower drying temperatures showed higher seed viability and vigour and was an effective drying and storage method for retaining acceptable seed viability and vigour till the following years' growing season (Nautiyal and Ravindra, 1996)

Pods of groundnut cultivars GG 2, JL 24, GAUG 10, and GG 20 stored in polyethylene bags, tri-layered aluminium foil pouches, and transparent polyethylene containers under ambient conditions in Gujarat retained high germination rates (over 70%) and seedling vigour up to 18 months of storage as against less than 10 % after 30 months in seeds stored in kraft paper bags. Further the pod stored in tri-layered aluminium foil pouches showed high germination rates (70-80% germination) and seedling vigour up to 30 months in storage, while germination rates of seeds stored in polyethylene bags and containers declined, suggesting that using tri-layered aluminium foil pouches could reduce the frequency of regeneration needed to maintain viability in groundnut germplasm stored under ambient conditions similar to those in Gujarat (Rajgopal and Chandran, 2002).

In a study at Dharwad, Karnataka, pods of Groundnut cv. TMV-2 dried in the shade, sun and by hot air oven drying at 35°C method had germination percentages below the minimum seed certification standard (70%) after 5, 4 and 3 months of storage, respectively, but the pods dried with dehumidified air drying had germination percentages below the minimum seed certification standard immediately after drying, whereas pods dried by DOR method retained 70% seed germination up to 180 days (Jolli et al. 2000a). A decrease in field emergence was observed with the advancement of storage in all the treatments, but was highest in dehumidified air drying. The highest field emergence was observed in the DOR method and shade drying. The decrease in seedling vigour index during storage was highest in dehumidified air drying and hot air drying due to thermal injury to the seed. Irrespective of drying methods, electrical conductivity of seed leachate increased with the advancement in storage period. The electrical conductivity of seed leachate recorded was least in DOR method of drying followed by shade drying and was highest in dehumidified air drying (Jolli et al. 2000a).

The electrical conductivity of six groundnut genotypes (Oira, Tupa, Poitara, Caiapo, Branco and Tatu) seeds (24 h imbibition of 25 seeds in 75 ml deionized water at 20°C) with initial seed moisture content approximately 7% when evaluated it was concluded that comparing the physiological quality among groundnut genotypes with different seed sizes by electrical conductivity can be difficult (Vanzolini and Nakagawa, 1998). In another study the newly harvested groundnut pods of cv. TMV-2 when subjected to different drying methods, sun drying took 100 h, shade drying took 200 h, hot air drying at 35°C air temperature and dehumidified air drying took 130 h and DOR method took 130 h to achieve 9% moisture content and the highest germination (95%), field emergence (91.5%), root length (24 cm), shoot length (8.38 cm), seedling vigour index (3056) and dry weight (2.70 cm) were recorded with DOR method, which was at par with shade drying, but the electrical conductivity of seed leachate was highest with hot air drying (0.158 mMhos/cm) and lowest with the DOR method (Jolli et al. 2000b).

The optimum storage period regarding seed germination and seedling vigour in cloth bags was 3-7 months in freshly harvested pods of groundnut cv. DH-330, JL-24, DH-40, TMV-2, ICGS 76 and Mardur Local, (Kurdikeri, et al. 1996). The 6-monthly recording of seed germination and seedling vigour index (root length x germination percentage) of the pods of groundnut cultivars J 11, GG 2, GAUG 10 and GG 20 stored immediately after drying in five packaging media kraft paper bags (KRB), tar-coated kraft paper bags (TKB), polyethylene bags of 700-gauge thickness (PB), tri-layered aluminium foil pouches (TLP) with 12 µm each Al and polyester and 250 gauge polylamination and transparent polyethylene containers with screw caps (PCN) at temperature 11.3- 40°C and RH 30.8-90% during storage period recorded highest viability (72.9 %) at 30 months in seeds stored in TLP while seeds stored in KRB and TKB lost both viability and seedling vigour at a faster rate than other packaging irrespective of genotype (Rajgopal and Chandran, 2000).

Pods of groundnut Cv. KRG-1 produced during rabi or summer season stored in Poly lined (300 gauge) gunny bag (PLGB) alongwith silica gel (30 g kg^{-1} pod) maintained highest germination (72%) in pods at 8 months after storage (MAS) and showed high seedling vigour and field emergence which were comparable with PLGB + Calcium chloride (10 g kg^{-1} pod), whereas only 63% germination was recorded in pods stored in gunny bag (Gowda and Reddy, 2008). Thus to use rabi or summer produce for seed purpose, farmers are advocated to dry the produce to 7% moisture content and store in the gunny bags lined with polythene (300 gauge) with desiccant, either silica gel (30 g kg^{-1} pod) or Calcium chloride (10 g kg^{-1} pod) to achieve proper crop stand and productivity. In Raichur and Dharwad for storing dried pods (7% moisture) of groundnut cv. KRG-1 polylined gunny bags (PLGB) was the most appropriate container and PLGB + silica gel (30 g/kg of pods) or PLGB + $CaCl_2$ (10 g/kg) stored for 7 months under ambient conditions recorded higher germination percentage (64.4 and 63.4%, respectively) and seedling vigour index (1002 and 996) mainly due to low maintenance of low pod moisture content (7.14%), while the pod moisture content was highest in gunny bag (9.04%) where loss of viability was fast (Rashmireddy et al. 2006).

10. Conclusions and Future Research Strategies

For optimal yield, in an environment, the life cycle of the crop should match to the length of growing season as introduction of an improved genotypes into new region is largely determined by temperature and phenology particularly the rate of development. The groundnut being grown from 40ºN to 40ºS under a wide range of temperature and photoperiod combinations, soils and other edaphic factors, the effect of environmental factors especially on assimilate partitioning will have importance in the adoption of cultivars to a particular region. In groundnut both perennial and annual species occur and harvesting of the crop is rarely determined by physiological maturity. The rate of developmental process is usually expressed as number or amount per day whereas events, which occur once in life cycle, are generally expressed as the duration and more recently as thermal time. The cropping season strongly influence phenology, growth and productivity. The kharif (June-Oct.) is the major groundnut-growing season, besides, it is also grown by sowing the same during September-October (rabi) and January-February (Summer) with high productivity. The CGR is higher in kharif crop than rabi season crop, but the average per day dry matter production is more or less similar in both the seasons. Due to longer duration (10-14 days more) and more sunshine hours, the rabi-summer season crop received more PI and PAR and hence produced more yield than the kharif crop, but the energy harvesting capacity of groundnut is similar during both of these seasons.

The runner cultivars showed higher chlorophyll content in leave, produced more pod and haulm yield than erect types. The growth rate on the other hand is faster in the erect varieties and they attain high dry matter earlier than in the spreading ones, but in runner the growth continue for a longer period and hence accumulate more dry matter. The average crop growth rate of groundnut varieties varies from 32-255 kg ha^{-1} day^{-1} in India. The dry matter accumulation in groundnut crop follows the growth pattern characterized by (i) a lag phase in early growth (up to 40 DAE), (ii) exponential increases in weight from vegetative to flowering stage (40-60 DAE), (iii) a linear and maximum growth rate during late vegetative to early pod filling (60-80), and (iv) leveling of weight during late pod filling stage. The leaf and stem dry weight increases in sigmoidal fashion up to maximum value, which occur 90 to 100 days after planting. However, the growth is a genotypic character, largely influenced by seasonal and environmental conditions.

The canopy development at peak flowering is most important and the high yield could be achieved through development of canopy towards compaction in Virginia runners and more pronounced in case of Spanish genotypes. To have sufficient size of the photosynthetic sink, the maintenance of high LAI is advantageous and it is worth while maintaining high LAI during pod filling period as the yields were limited by the low leaf area and less efficient leaves during the final filling period which is a critical stage. The leaf area duration (LAD) during later stage of growth had positive effect on pod filling, resulting in higher number of pods per plant. In India, the Spanish cultivars, as in case of TAG 24, TG 37A, GG 2, and GG7 cultivars and Virginia cultivars as in case of GG 20, 21 have reached a critical genetic balance for canopy development and further compaction might result in low reproductive efficiency. The breeder should concentrate the canopy development at peak flowering as one of the selection criterion. The ideal canopy development occur in FeESG 10 in Spanish and GG 20 and ICGS 76 Virginia bunch groundnut.

The expansion, podding and filling are the three major phenophases in groundnut. A rapid expansion, short podding, long filling coupled with high partitioning of assimilates to pods is the main desirable characters. In groundnut, the flowering and fruiting are of an indeterminate type, which generally has an effect on pod yield and quality. The flowering commences 20-40 DAE (20-35 days in Spanish and 30-40 days in Virginia runner) depending upon genotypes and environment and most of the flowers appear in between 30-70 DAE. Runner produced more flowers (40-250) per plant and also had a longer duration of flowering than in bunch types (100-150). It is desirable to initiate early branching, which increase the total flower bearing areas and the chances of pod formation because the flower borne at the basal part of the plant has greater chance to develop into pods. The ideal type of groundnut would be one that sets all its young fruits within 7 days and spends the rest of the growing season filling them.

Maximum leaf apparent photosynthesis (AP) is at about 30°C in groundnut, which decreases above and below this optimum temperature. The AP increases linearly as the light intensity increase from 500 to 1600 µE m^{-2} S^{-1}, was saturated only at 1600 µE m^{-2} S^{-1} (near full sun light) and remain constant after increasing it further. The minimum of 500 µE m^{-2} S^{-1} of irradiance is necessary for photosynthesis to compensate for respiration by the canopy and on this the AP was zero. The AP of well-developed canopies may reach values of 6 to 8 g CO_2 m^{-2} h^{-1}. The canopy AP increased from about 1g CO_2 m^{-2} h^{-1} at 3 weeks after emergence (WAE) to a value of more than 6 at 8 to 9 WAE and thereafter it drops nearly to 1 g CO_2 m^{-2} h^{-1} at 14 to 15 WAE. However, screening for high net photosynthesis (P_N) has to be made at the pod-filling phase in between 0900-1000 of the day. The CO_2 enrichment from 400 to 800 µmol mol^{-1} had positive effects on growth and yield, but not above 800 µmol mol^{-1}. The solar energy conversion efficiency of groundnut ranged from 0.7-1.67% of total solar radiation and 1.79-2.92% of PAR. As the light interception is about 95% complete at an LAI of 3, the extinction coefficient for visible radiation was about 1. The groundnut has mechanism to optimize energy interception by changing in leaf orientation when water is freely available. The yield improvement in groundnut, is mainly due to partitioning of assimilates between vegetative and reproductive parts, length of grain-filling period and rate of fruit development. The rate of translocation is positively correlated with net photosynthetic rate and the translocation of photosynthates involves movement of metabolites from mesophyll cells to phloem tissue, phloem loading, translocation in phloem, unloading and metabolism of photosynthates in the site of utilization. Quicker cessation of the vegetative growth makes more photosynthates available for pods and is a desirable character.

The high yield appears to be associated with rapid increase in pod number, duration of pod fill and near cessation of vegetative growth during pod filling. The attributes required for high solar energy-harvest and yields are erect thick leaves, synchronised flowering, emergence of flower and peg very close to soil, low photorespiration rate and CO_2 compensation point and efficient partitioning. It takes about 60 days from the time of fertilization to full maturity, however the pod attains its maximum size within 3 weeks. The improvement in yields by newly evolved cultivars over the old one are mainly due to, more efficient carbon fixation, better canopy geometry, greater leaf area duration, better partitioning factor, and duration of fruit growth. The harvest index increases linearly during the entire pod fill period. The potential reproductive growth rate (R) of a good groundnut crop is about 100 kg ha^{-1} day^{-1}.

The yield among groundnuts varieties differs mainly because of differences in their ability to develop the reproductive sink rather than differences in their leaf area or crop growth rate (source) and, once the reproductive sink is established, the yield differences are most closely related to the partitioning of assimilates between vegetative and reproductive parts when maximum fruit numbers are being established. There is a linear increase in fruit numbers until fruit utilization of assimilates equals the genetically determined level of assimilates partitioned to fruit growth. At the initiation of seed growth, reproductive growth becomes dominant and subsequent partitioning is determined by environmental influences. Some times the peg production increases out of proportion to pod production indicating that these two processes (peg and pod formation) are influenced differently by assimilate supply. The yield advantages due to moderate water deficit during the pre-flowering phase are associated with greater pod synchrony after the release of water stress, resulting in production of more mature pods as the plant try to set more fruiting sites with the existing assimilates as the vegetative site demanding assimilate supply are reduced. Studies on the heritabilities of groundnut yield components, ie. crop growth rate (C), reproductive duration (DR) and partitioning (p) and their predictive value in early generations show that none of the yield-model traits had larger heritability than yield and that selection for these traits in segregating bulk populations is difficult.

The temperature is more important factor affecting vegetative growth, while photoperiod is more important during reproductive growth, although significant interaction between these two occur. The reproductive efficiency and assimilate distribution of dry matter between vegetative and reproductive plant parts can be altered by photoperiod and temperatures. Temperature has major influence on growth and development and in groundnut growth ceased at daily mean temperature below 15ºC. The plants are very sensitive to temperature during early growth stages, but less sensitive as become older. Though the optimum day/night temperature for growth of whole plant are reported to be 25/25 to 35/25ºC, the optimum mean daily temperature is 30ºC and production of flowers is maximum at 20-25ºC. Pod growth is better at slightly less temperature than that of vegetative growth and was optimum at 26/22ºC day/night temperature and 31-33ºC soil temperature. The flowering, pegging and peg growth rate at 30ºC increases with RH from 50 to 97%. However, the temperature optima are different for each growth phases. The concept of thermal time is widely used for describing the temperature response of groundnut and under non-limiting conditions, developmental events occurred at a fixed interval of thermal time θ (degrees-days, ºC d). The T_b (10ºC) of germination could be used to calculate thermal time for further developmental processes for each genotype. The number of degree-days taken to begin flower, peg , pod production and maturity should be used in varietal selection. Matching the phenology of the crop to the duration of favorable conditions by selecting the most appropriate sowing dates to avoid periods of stress is crucial for maximum yield.

The period of reproductive growth stages in groundnut occurs over a period of nearly two months and moisture stress durind this period has a depressing effects on yield. No flowering occurs during the stress, but once the stress is removed, there is a flush of flowering depending on the growth stages and sometimes it results in more flowers than produced in unstressed one. Water stress depresses flowering, stem growth and nodulation delayed pod initiation, and the major cause of variability in pod yield and harvest index was the delay between peg initiation and onset of rapid pod growth. Under water stress there is poor pod filling that reduced kernel size, shelling percentage, SMK % and lipid content of kernel. The genotype and environmental interactions are more prominent in the cultivars, which are grown in the environment to which they are not selected. Genotype x environmental interaction for transpiration efficiency (W), carbon isotope discrimination (DELTA) and SLA are very low, while heritability of DELTA was high, indicating that these traits could be used for selecting high W in groundnut breeding programmes. Selection for low DELTA or SLA may be appropriate in certain water-limiting cropping systems where both pod and fodder yields need to be maximized.

The flowering, pegs, pods and seeds in groundnut are influenced greatly by growth regulators and there is a good scope to reduce the vegetative growth and increase the reproductive part in certain commercial cultivars having no genetic control over vegetative growth. Kylar has been commercially used to control the excess vegetative growth. Now a days several formulations and combinations are being recommended, however it may be insured that no detrimental effects of these growth regulators occur on other plant parts and progenies than the target characters. Seed quality, especially the germinability and vigour is essential to establish adequate plant stand for crop production, which are affected by environmental factors while seeds are still maturing on the plant, during harvest or in post-harvest handling or storage condition. Pod maturity is an important factor determining seed size and seed size is an important factor determining market quality and crop value. During seed development, high temperature (>30ºC) and water deficit affect seed quality by reducing photosynthates and other metabolites required for seed formation. Due to fungal invasion, the field emergence of groundnut seeds is always less than their laboratory germination and this reduction is more pronounced with large size seeds than with small size seed.

Groundnut is a very photosynthetically efficient crop, and in theory its potential yield can reach as high as 17.3 t ha^{-1}. In few part of the world, groundnut yields of 10 t pods ha^{-1} are obtained over a small area under intensive cultivation. The theoretical basis for obtaining high yields need to be discussed in detail and implemented with reference to photosynthetic efficiency, accumulation and distribution of biomass and structure and appearance of high-yielding plants their cultivation methods a suitable soil structure, balanced fertilizer application, optimum plant populations, strengthening field management, and use of sustainable methods to create ecological conditions that ensure high and stable yields.

11. References

Abd Alla, M.M.S., El Mandoh, M.E., 1996. Laboratory evaluation of peanut seed quality. *Annals of Agric. Sci*., Moshtohor, 34, 79-92.

AICRPG., 1993. Annual Progress Report, Rabi/Summer groundnut. 1992-93. DOR, Hyderabad, India.

Agriculture statistics at a glance, 2009. Department of Agriculture Research and cooperation. Ministry of Agriculture.

AICRPG., 2009. Annual Progress Report, Kharif groundnut. 2008. DGR, Junagadh, India.

AICRPG., 2010. Annual Progress Report, Kharif groundnut. 2009. DGR, Junagadh, India.

Annerose, D.J.M., Diagne, M., 1990. Characterization of agricultural drought in Semi-arid zones I. Description of a single assessments model applied to cultivataed groundnut in Senegal. *Oleagineux* 45, 547-557.

Arjunan, A., Srinivasan, D.S., Vindiyavarman, P., 1988. Physiological aspects of drought tolerance in groundnut. *Madras Agric. J.* 75, 5-8.

Asalatha, M., Reddy, P.V., Rao, R.D.V.,1999. Relationship of specific leaf area and carbon isotope discrimination with dry matter production and pod yield in groundnut genotype under moisture stress. *Indian J. Plant Physiol*. 4, 161-166.

Ashleg, J.M., 1984. Groundnut. In, Goldswarthy, P.R., Fisher, N.M., (eds). *The physiology of Tropical field crops.* Wiley, New York, pp. 453-494.

Awal, M.A., Ikeda, T., 2002. Effects of changes in soil temperature on seedling emergence and phenological development in field-grown stands of peanut (*Arachis hypogaea*). *Environ. and Experi. Botany*. 47: 01-113.

Bagnall, D.J., King, R.W., 1991 a. Response of peanut (*Arachis hypogaea*) to temperature, photoperiod and irradiance. 1. Effect on flowering. *Field Crop Res*. 26, 263-277.

Bagnall, D.J., King, R.W., 1991b. Response of peanut (*Arachis hypogaea*) to temperature, photoperiod and irradiance. 2. Effect on peg and pod development. *Field Crop Res*. 26, 279-293.

Basha, S.M., 1990. Protein as an indicator of peanut seed maturity. *J. Agric. Food Chem*. 38, 373-376.

Baskaran, R., Solaimalai, A., Subburamu, K., 2003. Effect of water harvesting techniques and IPM practices on productivity of rainfed groundnut. *Crop Res.*, Hisar, 26, 424-428.

Basu, M.S., Reddy, P.S., 1989. Technologies for increasing groundnut production. Technical Bulletin, NRCG, Junagadh, pp. 18.

Bell, M.J., 1986. Effect of sowing date on growth and development of irrigated peanuts, (*Arachis hypogaea* L. cv. early bunch in a monsoonal tropical environment. *Aust. J. Agric. Res*. 37, 361-373.

Bell, M.J., Hasch, G., 1991. Effect of photoperiod on reproductive development of peanut (*Arachis hypogaea* L.) in a cool subtropical environment. I. Field studies. *Aust. J. Agric. Res*. 42, 1133-1149.

Bell,M.J., Shorter R and Mayer R1991a. Cultivar and environmental effects on growth and development of peanuts (*Arachis hypogaea* L.) I. Emergence and Flowering. *Field Crop Res.* 27, 17-33.

Bell, M.J., Shorter, R., Mayer, R., 1991b. Cultivar and environmental effects on growth and development of peanut (*Arachis hypogaea* L.) II. Reproductive development. *Field Crop Res*. 27, 35-49.

Bell, M.J., Wright, G.C., 1998a. Groundnut growth and development in contrasting environments. 1. Growth and plant density responses. *Exp. Agric*. 34: 99-112.

Bell, M.J., Wright, G.C., 1998a. Groundnut growth and development in contrasting environments. 1. Growth and plant density responses. *Exp. Agric*. 34: 99-112.

Bell, M.J., Wright, G.C., 1998b. Groundnut growth and development in contrasting environments. 2. Heat unit accumulation and photo-thermal effects on harvest index. *Exp. Agric.* 34: 113-124.

Bellm M.J., Bagnall, D.J., Hasch, G., 1991 c. Effect of photoperiod on reproductive development of Peanut (*Arachis hypogaea* L.) in a cool subtropical environment II. Temperature interaction. *Aust. J. Agric. Res.* 42, 1151-1161.

Bhagat, N.R., Devi Dayal, Acharya, D., 1992. Performance of Spanish Peanuts during winter-summer season at two locations in India. *Trop. Agric*. 69, 93-95.

Bhagat, N.R., Taslim Ahmad, Lalwani, H.B., Patil, S.A., Patra, G.J., Acharya, D., 1988. Screening of bunch peanut (*Arachis hypogaea* L. ssp. *fastigiata*) germplasm for cold tolerance in India. *Trop Agric*. 65, 109-112.

Bhagsari A S 1974. Photosynthesis in peanut (*Arachis*) genotypes. Ph.D diss. Univ. of Ga. Athens. Diss. Abstr. Intl. 35, 4747 B.

Bhagsari, A.S., Brown, R.H., 1976. Relationship of net photosynthesis to carbondioxide concentration and leaf characteristic in selected peanut (*Arachis*) genotypes. *Peanut Sci*. 3, 10-14.

Billaz, R., Ochos, R., 1961. The stage of susceptibility to drought in groundnut. *Oleagineux* 16, 605-609.

Bin, J.H., Shen,Y., Fu, J.R., 1996. Purification and characterization of cysteine endopeptidase in cotyledons of germinated peanut (*Arachis hypogaea* L.) seeds. J. *Tropical and Subtropical Bot*. 4, 66-73.

Bindumadhava, H., Sheshshayee, M.S., Shashidhar, G., Prasad, T.G., Udayakumar, M., 2005. Ratio of stable carbon and oxygen isotope discrimination (Delta 13C/ Delta 18O) reflects variability in leaf intrinsic carboxylation efficiency in plants. *Curr. Sci*. 89, 1256-1258.

Boote, K.H., Jones, J.W., Smerage, G.H., Barfield, C.S., Berger, R.D., 1980. Photosynthesis of peanut canopies as affected by leafspot and artificial defoliation. *Agron. J*. 72, 247-252.

Bora, K.K., Mathur, S., 1991. Effect of XE-1019 on transpiration of excised groundnut (*Arachis hypogaea* L.) leaves. *Indian J. Exp.Biol*. 29, 494-495.

Bourgeois, G., Boots, K.J., 1992. Leaflet and canopy photosynthesis of peanut affected by late leaf spot. *Agron. J*. 84, 359-366.

Brar, A.S., Dhingra, K.K., Kaul, J.N., 1999. Phenological behaviour and heat unit requirement of groundnut (*Arachis hypogaea*) genotypes under two dates of sowing during summer season. *Indian J. Agric. Sci.* 69: 419-423.

Bunting, A.H., Elston, J., 1980. Ecophysiology of growth and adaptation in the groundnut, an easy on structure, partition and adptation In, R.J. Summerfield and A.N. Bunting (eds.). Advances in Legume Science, Proc. Int. Legume Conf. Kew, Great Britain. Royal Botanical Gardens, Kew, pp. 495-500.

Caliskan, S., Caliskan, M.E., Arslan, M., Arioglu, H., 2008. Effects of sowing date and growth duration on growth and yield of groundnut in a Mediterranean-type environment in Turkey. *Field Crops Res.* 105: 131-140.

Calskan, S., Calskan, M.E., Arslan, M., 2008. Genotypic differences for reproductive growth, yield, and yield components in groundnut (*Arachis hypogaea* L.). *Turkish J. Agric. Forestry* 32, 415-424.

Cao, T.H., Isoda, A., 2008. Dry matter production of Japanese and Chinese high-yielding peanut cultivars under planting in terms of intercepted radiation and its use efficiency. *Japanese J. Crop Sci.* 77: 41-47.

Cavazzoni, J., Volk, T., Tubiello, F., Monje, O., Lieth, J.H., (ed.), Oki, L.R., 2002. Modelling the effect of diffuse light on canopy photosynthesis in controlled environments. Proceedings of the 4th International Symposium on Models for Plant Growth and Control in Greenhouses: Modeling for the 21st Century Agronomic and Greenhouse Crop Models, Beltsville, Maryland, USA, 25-29 March, 2001. *Acta Horticulturae* 593, 39-45.

Challinor, A.J., Wheeler, T., Hemming, D., Upadhyaya, H.D., 2009. Ensemble yield simulations: crop and climate uncertainties, sensitivity to temperature and genotypic adaptation to climate change. *Climate Res.* 38: 117-127.

Chen, J.J., Sung, J.M., 1990. Gas exchange rate and yield response of Virginia type peanut to CO_2 enrichment. *Crop Sci*. 30, 1085-1089.

Chhonkar, A.K., Kumar, A., 1987. Correlation and regression studies between different physiological attributes and pod yield in groundnut. *J. Oilseeds Res*. 4, 132-135.

Chuni Lal, Hariprasanna, K., Rathnakumar, A.L., Misra, J.B., Samdur, M.Y., Gor, H.K., Chikani, B.M., Jain, V.K., 2009. Response of peanut genotypes to mid-season moisture stress: phenological, morpho-physiological, and yield traits. *Crop and Pasture Sci*. 60, 339-347.

Chuni Lal., Hariprasanna, K., Rathnakumar, A.L., Gor, H.K., Chikani, B.M. 2006. Gene action for surrogate traits of water-use efficiency and harvest index in peanut (*Arachis hypogaea*). *Annals of App. Biol*. 148, 165-172.

Das Gupta, D.K., 1975. Effect of cycocel on crop plants in Sierra Leone I. Groundnut (*Arachis hypogaea* L.). *Exp. Agric*. 11, 209-213.

Dayal, D., Basu, M.S., Reddy, P.S., 1989. Water management in groundnut. National Research Centre for Groundnut, ICAR, Junagadh, India, pp. 11.

De Vries, J.D., Bennett, J.M., Albrecht, S.L., Boote, K.J., 1989. Water relations, nitrogenase activity and root development of three grain legumes in response to soil water deficits. *Field Crop Res*. 21, 215-226.

Delecaux, D., 1987. Effects of cool temperature on the germination of seeds from four (*Arachis hypogaea* L.). Cultivars. *Oleagineux* 42 , 197-205.

Deotale, R.D., Pawar, S.B., Kalamkar V., Sable, N.H., Lende, S.R., 2008. Effect of foliar sprays of cow urine and NAA on morpho-physiological parameters and yield of groundnut. *J. Soils and Crops* 18: 221-227.

Devi Dayal, Ghosh, P.K., Ravindra,V., 1999. The influence of seed maturity variation on crop establishment, growth, and yield of groundnut (*Arachis hypogaea* L.). *Tropical Agric*. 76, 151-156.

DGR 2009. Annual Report, Directorate of Groundnut Research (ICAR), Junagadh, India.

Dhonde, P.W., Shinde, S.H., Patil, B.B., Pawar, A.D., 1985. Irrigation scheduling for kharif groundnut. *J. Maharashtra Agric. Univ*. 10, 28-30.

DOR, 1983. Simple and efficient post-harvest techniques for increasing seed viability of Rabi/Summer groundnut. Directorate of Oilseeds Res. Newsletter Hyderabad, India, 2, 1-5.

DOR, 1985. Groundnut sesamum, niger, sunflower and castor. In, Package of practices for increasing productions. Extension Bulletin No.2, Directorate of Oilseeds Research (ICAR), Hyderabad, India. pp. 1-39

Dreyer, J., Duncan, W.G., Mc Cloud, D.E., 1981. Fruit temperature, growth rates and yield of peanuts. *Crop Sci*. 21, 686-688.

Duncan, W.G., Mc Cloud, D.E., Mc Graw, R.L., Boote, K.J., 1978. Physiological aspects of peanut yield improvement. *Crop Sci*. 18, 1015-1020.

Dwivedi, R.S., 1986 b. Drought resistant plant attributes and breeding for drought resistance in groundnut. Ibid. pp. 60-67.

Dwivedi, R.S., 1986a. Plant architecture for higher solar energy harvest and yield. In, Dwivedi, R.S., (ed.), Recent Advances in Groundnut Productivity Research, Proceeding Summer Institute, NRCG (ICAR), Junagadh, India.

Dwivedi, R.S., Joshi, Y.C., Nautiyal, P.C., Singh, A.L., Ravindra, V., Thakkar, A.N., Koradia, V.G., Dhapwal, G.S., 1986. Detection of drought resistance in peanut (*Arachis hypogaea* L.). *Oleagineux* 41, 281-285.

Dwivedi, R.S., Saha, S.N., Joshi, Y.C., 1985. A comparative study of the solar energy conserving efficiency of groundnut (*Arachis hypogaea* L., wheat *Triticum aastivum* L. and Cynodon dactylon Press, *Oleaginueux*, 40, 79-83.

Dwivedi, S.L., Nigam, S.N., Chandra, S., Ramraj, V.M., 1998. Combining ability of biomass and harvest index under short and long day conditions in groundnut. *Annals of Appl. Biol*. 133, 237-244.

Emery, D.A., Sherman, M.E., Vickers, J.W., 1981. The reproductive efficiency of cultivated peanuts. The influence of photoperiods on the flowering, pegging, and fruiting of Spanish type peanuts. *Agron. J*. 73, 619-623.

Enyi, B.A.C., 1977. Physiology of grain yield in groundnut. *Exp. Agric*. 13, 101-110.

FAO, 2010. FAOSTAT, FAO Statistics Division 2010 | 05 May 2010

Forestier, J., 1973. Vegetative characters growth and yield of early groundnuts in a forest region. *Caharstom Biologic*. 19, 43-62.

Frimpong, A., Nyarko, G., Bayor, H., Apeliga, J.A., 2004. Effects of different seed treatment methods on the percent germination, seedling vigor and biomass production of groundnuts in Ghana. *Pakistan J. Biolo. Sci*. 7, 1024-1028.

Fu, J.M., Su, F., Zhang, G.L., 1995. Developmental dynamics and diurnal changes of canopy photosynthesis rate in groundnut (*Arachis hypogaea* L.). *China's Fibre Crops* 17, 17-21.

Gajera, M.S., Patel, J.C., 1984. Response of summer groundnut to irrigation scheduling based on cumulative irrigation under varying fertility levels. *Ind.J.Agron*. 29, 394-395.

Ghosh P.K., Mandal, K.G., Hati, K.M., 2000. Allelopathic effects of weeds on groundnut (*Arachis hypogaea* L.) in India - a review. *Agric. Rev*. 21, 66-69.

Ghosh, P.K., Devi Dayal, Bandyopadhyay, K.K., Manna, M.C., 2003. Organic vis-a-vis polyethylene mulch to boost up productivity of irrigated post-rainy season groundnut in India. *J. Food, Agric. Environ*. 1, 213-214.

Golombek, S.D., Sultana, A., Johansen, C., 2001. Effect of separate pod and root zone temperatures on yield and seed composition of three Spanish cultivars of groundnut (*Arachis hypogaea* L). *J. Sci. Food and Agric.* 81: 1326-1333.

Gowda, B., Reddy, Y.A.N., 2008. Storage of rabi or summer groundnut with desiccants to prolong seed viability and seedling vigour. *Karnataka J. Agric. Sci.* 21, 353-356.

Gregory, W.C., Krapovikas, A., Gregory, M.P., 1980. Structure, variation and evolution and classification in Arachis. In, Advances in Legume Science pp. 469-481. Summerfield, R.J., Bunting, A.H., (eds.), Royal Botanical Garden, Kew, England.

Grewal, M., Parmar, U., Singh, P., Bhatia, D.S., Malik, C.P., 1989. Increasing assimilates transport from cotyledons to axis in germinating *Arachis hypogaea* L. seeds through aliphatic alcohols treatments. *J. Nuclear Agric. Biol.* 18, 166-169.

Guerra, L.C., Hoogenboom, G., Garcia-y-Garcia, A., Banterng, P., Beasley, J.P.Jr., 2008. Determination of cultivar coefficients for the CSM-CROPGRO-Peanut model using variety trial data. *Transactions of the ASABE* 51, 1471-1481.

Guo, X.F., Yan, H.Y., He, J., Li, L.J., Tao,Y., Cao, J.J., 2006. Localization analysis of ABI3 homologous gene in peanut. *J. Wuhan Bot. Res*. 24, 22-26.

Harris, D., Matthews, R.B., Nageswara Rao, R.C., Williams, J.H., 1988. The physiological basis for yield differences between four genotypes of groundnut (*Arachis hypogaea*) in response to drought III. Developmental process. *Expl. Agric*. 24, 215-226.

Hemalatha, S., Rao, V.P., 2006. Crop coefficients for prediction of irrigation requirements of groundnut. *J. Res.*, ANGRAU 34, 1-7.

Henning, R.J., Brown, R.H., Ashley, D.A., 1979. Effect on leaf position plant age on photosynthesis and translocation in peanut. I. Apparent photosynthesis and C translocation. *Peanut Sci.* 6, 46-50.

Hubick, K.T., 1990. Effect of nitrogen sources and water limitation on growth, transpiration efficiency and carbon isotope discrimination in peanut cultivars. *Aust. J. Plant. Physiol*. 17, 413-430.

Hubick, K.T., Farquhar, G.D., Shorter, R., 1986. Correlation between water use efficiency and carbon isotope discrimination in diverse peanut (*Arachis*) germplasm. *Aust. J. Plant Physiol*. 13, 803-816.

Hubick, K.T., Shorter, R., Farquhar, G.D., 1988. Heretibility and genotype environment interaction of carbon isotope discriminate and transpiration efficiency in peanut (*Arachis hypogaea* L.). *Aust. J. Plant Physiol*. 15, 799-813.

IBPGR/ICRISAT, 1981. Groundnut Descriptors. International Board of Plant Genetic Resources Rome and International Crop Research Institute for the Semi-Arid Tropics, Patancheru, A.P., India. pp. 1-23.

ICRISAT. 1986. Annual Report, 1985. ICRISAT, Patancheru, A.P. 502 324, India.

ICRISAT. 1990. Annual Report, 1989. ICRISAT, Patancheru, A.P. 502 324, India.

Idinoba, M.E., Idinoba, P.A., Gbadegesin, A., Jagtap, S.S., 2008. Growth and evapotranspiration of groundnut (Arachis hypogaea) in a transitional humid zone of Nigeria. *African J. Agric. Res*. 3, 384-388.

Inanaga, S., Yanagigawa, T., Naka, Y., Yamanokuchi, K., 1996. The effect of light on the accumulation of lipids in seeds. *Soil Sci. Plant Nutrition* 42, 845-852.

Isleib, T.G., Tillman, B.L., Pattee, H.E., Sanders, T.H., Hendrix, K.W., Dean, L.O., 2008. Genotype by environment interactions for seed composition traits of breeding lines in the uniform peanut performance test. *Peanut Sci*. 35, 130-138.

Jain S., Padmaja, G., 2004. Induction of maturation proteins in germinating seeds of groundnut by exogenous application of ABA and sodium chloride. *Indian J. Plant Physiol*. 9, 343-347.

Jakkula, L.R., Knauft, D.A., Gorbet, D.W., 1997. Inheritance of a shriveled seed trait in peanut. *J. Heredity* 88, 47-51.

Jayalakshmi, V., Reddy, P.V., Rao, R.C.N., Reddy, G.L.K., 2002. Carbon isotope discriminations studies in groundnut hybrids. *Agric. Sci. Digest* 22, 39-41.

Jayaramaiah, R., Thimmegowda, S., 1998. Correlation studies in groundnut. *Curr. Res*., University of Agriculture Science, Bangalore, 27, 34.

Jolli, R.B., Shashidhar, S.D., Vyakarnahal, B.S., 2000a. Studies on the effect of different methods of drying on storability of groundnut pods. *Karnataka J. Agric. Sci*. 13, 158-162.

Jolli, R.B., Shashidhar, S.D., Vyakarnahal, B.S., 2000b. Comparative study of different methods of drying groundnut pods with respect to seed quality. *Karnataka J. Agric. Sci*. 13, 163-165.

Joshi, Y.C., Nautiyal, P.C., Ravindra, V., Dwivedi, S., 1988. Water relation in two cultivars of groudnut (*Arachis hypogaea* L.) under soil water deficit. *Trop. Agric.* 65, 182-184.

Joshi, Y.C., Ravindra, V., Nautiyal, P.C., 1993. Cold tolerant groundnut genotypes. Groundnut News 5, 2.

Jun, S.Y., Anke, 1988. Effect of controlling peg growth at the stant of groundnut (*Arachis hypogaea* L.) flowering. *Oleagineux*, 43, 127-134.

Ketring, D.L., 1975. Physiology of oilseeds. V.Germination of NC-13 Virginia type peanut seeds in the presence of inhibitors and ethylene. *Peanut Sci*. 2, 73-77.

Ketring, D.L., 1977. Effect of plant growth regulators on reproduction of "Starr" Spanish type peanuts. *Agron. J*. 69, 110-114.

Ketring, D.L., 1979. Light effects on development of an indeterminate plant. *Plant Physiol*. 64, 665-667.

Ketring, D.L., 1986. Physiological response of groundnut to temperature and water deficits - Breeding implications. In, Agronometeorology of groundnut. Proceeding of an international symposium, ICRISAT Sahelian Centre Niger, ICRISAT, Patancheru, India. pp. 135-143.

Ketring, D.L., 1991. Physiology of oilseeds, IX Effects of water deficit on peanut seed quality. *Crop Sci.* 31, 459-463.

Ketring, D.L., Brown, R.H., Sulliven, G.A., Johnson, B.B., 1982. Growth physiology In, Pattee, H.E., Young, C.T., (Ed.), Peanut Science and Technology. American Peanut Res. Edu. Soc. Yoakum, Texes, pp. 411-457.

Ketring, D.L., Erickson, P.I., Stone, J.F., 1990. Apparent sap velocity in peanut genotypes under control and stress conditions. *Peanut Sci*. 17, 38-44.

Khan, A.A., Akosu, F.I., 1971. The physiology of groundnut I. An auto radiographic study of the pattern of distribution of 14 carbon products. *Physiologia Plantarum* 24, 471-475.

Khan, A.R., Datta, B., 1990. Response of peanut to moisture stress and irrigation. Agroclimica 24, 15-23.

Khistaria, M.K., Patel, J.S., Parmar, M.T., Patel, Y.C., 1985. Pod distribution in bunch groundnut under rainfed conditions. *Madras Agric. J*. 72, 455-456.

Kim, N.K., Hung, Y.C., 1991. Mechanical properties and chemical composition of peanuts as affected by harvest date and maturity. *J. Food Sci*. 56, 1378-1392.

Krishnamurthy, L., Vadez, V., Devi, M.J., Serraj, R., Nigam, S.N., Sheshshayee, M.S., Chandra, S., Aruna, R., 2007. Variation in transpiration efficiency and its related traits in a groundnut (*Arachis hypogaea* L.) mapping population. *Field Crops Res*. 103, 189-197.

Kurdikeri, M.B., Giriraj, K., Danapur, H.N., Hiremath, N.V., Hanumaratti, N.G., 1996. Groundnut seed viability under ambient storage conditions of Dharwad (Karnataka). *Karnataka J. Agric. Sci.* 9, 363-365.

Leong, S.K., Ong, C.K., 1983. The influence of temperature and soil water deficit on the development and morphology of groundnut (*Arachis hypogaea* L.). *J. Expl. Bot*. 34, 1551-1561.

Li, X.D., Guo, L.J., Zhang, G.Y., Wan, Y.S., 2002. The changes in photosynthetic properties during groundnut leaf senescence. *International Arachis Newsletter* 22, 54-57.

Lin, L., Fu, J.R., 1997. Differences in BAPAase activity between the cotyledon and hypocotyl of groundnut embryos during seed development and germination. *Acta Phytophysiologica Sinica* 23, 29-33.

Lin, L., Fu, J.R., 1996b. Formation of groundnut seed vigour. *Acta Scientiarum Naturalium Universitatis Sunyatseni* 35, 23-27.

Lin, L., Fu, J.R., 1996c. Relationship between the accumulation of storage proteins and formation of vigour of groundnut seeds. *J. Tropical and Subtropical Bot*. 4, 57-60.

Lin, Lu, Fu, J.R., 1996a. Changes of endogenous ABA content and their relation to the vigour of groundnut seeds. *Acta Botanica Sinica*, 38, 209-215.

Ling, L., Rui-chi, P., 1988. Effect of pp 333 on endogenous ABA and GA levels in the leaves of *Arachis hypogaea* L. seedlings. 2, 36-39.

Ling, L., Rui-chi, P., 1991. Studies on CCC increasing the drought resistance in peanut seedling. *Acta Botanica Sci.* 33, 55-60.

Lu, C.B., Huang, S.Z., Tang, X.J., Fu, J.R., 2000. Composition of amino acid in storage proteins and changes in 17.5 kDa polypeptide synthesis during peanut seed development. *J. Tropical and Subtropical Bot*. 8, 339-345.

Lu, C.B., Huang, S.Z., Tang, X.J., Fu, J.R., 2000. Composition of amino acid in storage proteins and changes in 17.5 kDa polypeptide synthesis during peanut seed development. *J. Tropical and Subtropical Bot*. 8, 339-345.

Mahto, R.N., Mahto, D., 2000. Stability analysis in groundnut (*Arachis hypogaea* L.). *J. Res.*, Birsa Agril. Uni. 12, 171-174.

Main, C.L., Ducar, J.T., MacDonald, G.E., 2002. Response of three runner market-type peanut cultivars to diclosulam. *Weed Technol*. 16, 593-596.

Maity, S.K., Giri G., Deshmukh, P.S., 2003. Effect of phosphorus, sulphur and planting methods on growth parameters and total yield of groundnut (*Arachis hypogaea* L.) and sunflower (*Helianthus annuus* L.). *Indian J. Plant Physiol*. 8, 377-382.

Manivel, P., Mathur, R.K., Gor, H.K. and Chikani, B. M., 1997. Effect of cutting groundnut seed for ELISA on seed germination and seedling vigor. *Inter. Arachis Newsletter*, 17, 53-54.

Matthews, R.B., Harris, D., Nageswara Rao, R.C., Williams, J.H., Wadia, K.D.R., 1988a. The physiological basis for yield differences between four genotypes of groundnut (*Arachis hypogaea*) in response to drought I. Dry matter production and water use. *Exp. Agric.* 24, 191-202.

Matthews, R.B., Williams, J.H., Nageswara Rao, R.C., 1988b. The physiological basis for yield differences between four genotypes of groundnut (*Arachis hypogaea*) in response to drought II. Solar radiation interception and leaf movement. *Expl. Agric*. 24, 203-213.

McCloud, D.E., 1974. Growth analysis of high yielding peanuts. Proceedings Soil and Crop Science Society of Florida 33, 24-26.

Meena, R.P., Dahama, A.K., 2004. Relevance of thermal units in deciding sowing time and yield prediction of groundnut (*Arachis hypogaea* L.) under irrigated condition of western Rajasthan. *J. Agrom.* 6: 62-69.

Meisner, C.A., Karnok, K.J., 1991. Root hair occurrance and variation with environment. *Agron. J*. 83, 814-818.

Meisner, C.A., Karnok, K.J., 1992. Peanut root response to drought stress. *Agron. J*. 84, 159-165.

Misra, J.B., Nautiyal, P.C., Chauhan, S., Zala, P.V., 1992. Reserve mobilization and starch formation in cotyledons of germinating groundnut seeds. In Nigam, S.N., (ed.), Groundnut - a global perspective , Proc. of an International Workshop, 25-29 Nov. ICRISAT, Patancheru, India, (In,En. Abstracts.), pp. 451.

Misra, J.B., Nautiyal, P.C., Ravindra, V.,Yadav, S.K., 1995. Diurnal variations in photosynthesis and activities of enzymes of sucrose metabolism in groundnut. Plant Physiology and Biochemistry New Delhi, 22, 187-191.

Misra, J.B., Yadav, S.K., 1993. Groundnut, A source of protein Groundnut News 5, 5.

Misra, J.B., Yadav, S.K., Chauhan, S., 1993. Inverse relationship between oil content and specific gravity of groundnut kernels. *J. Sci. Food Agric*. 61, 231-234.

Mohammed Ali, Mohan, J.S., Shanta, R., 1974. Response of groundnut to different moisture regimes and farmyard manure. *Madras Agric. J*. 67, 472-476.

Morgan, P.W., Ketring, D.L., Beyer, E.M. Jr., Lipe, J.A., 1970. Functions of naturally produced ethylene in abscissian, dehiscence and seed germination In, Carr, D.J., (ed.), Plant growth substances. Proc. 7th Int. Symp. Plant growth substances, Canberra, Australia, Springerverlog Berlin, Heidelberg-New York, pp. 502-509.

Mortley, D.G., Bonsi, C.K., Hill, W.A., Morris, C.E., 2004. Temperature influences yield, reproductive growth, harvest index, and oil content of hydroponically grown 'Georgia Red' peanut plants. *HortScience* 39, 975-978.

Murty, U.R., Rao, N.G.P., Kirti, P.B., Bharati, M., 1980. Fertilization in groundnut, *Arachis hypogaea* L. *Oleagineux*, 36, 73-76.

Nagaraj, G., Chauhan, S., Ravindra, V., 1989. Peanut composition and oil quality as influenced by genotype and harvest stagaes. JOTAI. 21, 60-63.

Nagaswara Rao, R.C., Williams, J.H., Singh, M., 1989 b. Genotypic sensivity to drought and yield potential of peanut. *Agron. J*. 81, 887-893.

Nageswara Rao, R.C., Simmonds, L.P., Azan Ali, S.M., Williams, J.H., 1989a. Population, growth and water use of groundnut maintained on stored water. I. Root and shoot growth. *Exp. Agric*. 25, 51-61.

Nageswara Rao, R.C., Singh, A.K., 1993. Prospects for utilization of genetic variability for yield improvement in groundnut. In Oilseeds Research and Development in India, Status and Strategies Extended Summaries of National Seminar, DOR, Hyderabad pp. 8.

Nageswara Rao, R.C., Singh, S., Sivakumar, M.V.K., Srivastava, K.L., Williams, J.H., 1985. Effect of water deficit and different grwoth phases of Peanut I. yield responses. *Agron. J.* 77, 782-786.

Nageswara Rao, R.C., Wadia, K.D.R., Williams, J.H., 1990. Intercropping short and long duration groundnut (*Arachis hypogaea*) genotypes to increase productivity in environments prone to end of season droughts. *Exp. Agric*. 26, 63-72.

Nageswara Rao, R.C., Williams, J.H,, Sivakumar, M.V.K., Wadia, K.D.R., 1988. Effect of water deficit at different growth phases of peanut. II. Response to drought during pre-flowering phase. *Agron. J.* 80, 431-438.

Nageswara Rao, R.C., Williams, J.H., Rao, M., Wadia, K.D.R., 1992. A red-infrared reflectometer for measuring radiation interception by cropcanopies. *Field Crop Res*. 29, 353-360.

Narayanan, A., Chand, K.K., 1986. The nature of leaf-senescence in groundnut (Arachis hypogaea L.) genotypes. *Indian J. Plant Physiol*. 29, 125-132.

Narayanan, A., Murthy, S.R.K., 1979. Studies on the yield potential of pods in groundnut (*Arachis hypogaea* L.). *Indian Agric*. 23, 85-95.

Narayanan, A., Reddy, B., Murthy, S.R.K., 1984. The effects of peg removal on the vegetative and reproductive parts of groundnut. *J. Oilseeds Res*. 1, 63-69.

Narayanan, A., Reddy, C.B., Murthy, S.R.K., 1981. Growth and yield analysis of two contrasting groundnut (*Arachis hypogaea* L.) cultivars. *Indian Agric*. 25, 173-180.

Nautiyal, P.C., Ravindra, V., Vasantha, S., Joshi, Y.C., 1991. Moisture stress and subsequent seed viability, Physiological and biochemical basis for viability differences in spanish groundnut in response to soil moisture stress. *Oleagineux*, 46, 153-158.

Nautiyal, P.C., Bandyopadhyay, A., Misra, R.C., 2004. Drying and storage methods to prolong seed viability of summer groundnut (*Arachis hypogaea*) in Orissa. *Indian J. Agric. Sci.* 74, 316-320.

Nautiyal, P.C., Bandyopadhyay, A., Zala, P.V., 2001. In situ sprouting and regulation of fresh-seed dormancy in Spanish type groundnut (*Arachis hypogaea* L.). *Field Crops Res*. 70, 233-241.

Nautiyal, P.C., Joshi, Y.C., 1991. Storage of rabi/summer groundnut (*Arachis hypogaea* L.) with calcium chloride for prolonged seed viability and vigour. *Tropical Sci*. 31, 21-26.

Nautiyal, P.C., Rajgopal, K., Zala, P.V., Pujari, D.S., Basu, M., Dhadhal, B.A., Nandre, B.M., 2008. Evaluation of wild Arachis species for abiotic stress tolerance: I. Thermal stress and leaf water relations. *Euphytica* 159, 43-57.\

Nautiyal, P.C., Ravindra, V., 1996. Drying and storage method to prolong seed viability and seedling vigour of rabi-summer-produced groundnut. *J. Agron. Crop Sci*. 177, 123-128.

Nautiyal, P.C., Ravindra, V., Joshi, Y.C., 1989. Germination and early seedling growth of some groundnut (*Arachis hypogaea* L.) cultivars under salt stress. *Indian J.Plant Physiol*. 32, 251-253.

Nautiyal, P.C., Ravindra, V., Joshi, Y.C., 2002. Dry matter partitioning and water use efficiency under water-deficit during various growth stages in groundnut. *Indian J. Plant Physiol*. 7: 135-139.

Nautiyal, P.C., Vasantha, S., Suneja, S.K., Thakkar, A.N., 1988. Physiological and biochemical attributes associated with the loss of seed viability and vigour in groundnut (*Arachis hypogaea* L.) *Oleagineux*, 43, 459-463.

Nautiyal, P.C., Zala, P.V., 1991. Effect of drying methods on seed viability and seedling vigour in spanish groundnut (*Arachis hypogaea* L.) *Seed Sci. Technol*. 19, 451-459.

Nautiyal, P.C., Zala, P.V., 2004. Influence of drying method and temperature on germinability and vigour of groundnut (*Arachis hypogaea*) seed harvested in summer season. *Indian J. Agric. Sci*. 74, 588-593.

NRCG. 2007. Annual Report, National Research Centre for Groundnut (ICAR), Junagadh, India.

NRCG. 2008. Annual Report, National Research Centre for Groundnut (ICAR), Junagadh, India.

Ntare, B.R., 1999. Early generation testing for yield and physiological components in groundnut (*Arachis hypogaea* L.) *Euphytica*. 1999, 107, 141-147.

Ntare, B.R., Williams, J.H., 1998a. Heritability and genotype X environment interaction for yield and components of a yield model in segregating populations of groundnut under semi arid conditions . *Arican Crop Sci. J*. 6, 119-127.

Ntare, B.R., Williams, J.H., Ndunguru, B.J., 1998. Effects of seasonal variation in temperature and cultivar on yield and yield determination of irrigated groundnut (*Arachis hypogaea*) during the dry season in the Sahel of West Africa. *J. Agric. Sci.* 131: 439-448.

Oliveira Junior, J.O.L., de, Tavora, F.J.A.F., Barbosa, F.M., 2004. Phenology of peanuts cultivars submitted to water stress. *Cientifica Jaboticabal* 32, 25-29.

Ong, C.K., 1984. The influence of temperature and water deficient on the partitioning of dry matter in groundnut (*Arachis hypogaea* L.). *J. Exp. Bot*. 35, 746-755.

Ong, C.K., 1986. Agroclimatological factors affecting phenology of groundnut. In Agrometerology of groundnut. Proc. of an International Symposium, ICRISAT Sehalien Centre Niger, ICRISAT, Patancheru, India, pp. 115-125.

Ono, Y., 1979. Flowering and fruiting of peanut plants. JARQ. 3, 226-229.

Ono, Y.K., Nakayama, Kubota, M., 1974. Effect of soil temperature and soil moisture in podding zone on pod development of peanut plants. *Proc. Crop Sci. Soc.* Japan 43, 247-251.

Pachepsky, L.B., Ferreyra, R.A., Collino, D., Acock, B., 1999. Transpiration rates and leaf boundary layer parameters for peanut analyzed with the two-dimensional model 2DLEAF. *Biotronics* 28, 1-12.

Padmalatha, Y., Reddy, S.R., Reddy, T.Y., 2002. Influence of dates of sowing and irrigation schedules on total dry matter production, its partitioning and yield of winter groundnut (*Arachis hypogaea*). *Indian J. Agron*. 47: 98-104.

Pae, S.B., Oh, K.W., Kim, J.T., Park, C.K., Kwack, Y.H., 1998. The evaluation of relationships between peanut growth and yield by mulching and nonmulching cultivation in southern region of Korea. *RDA J. Industrial Crop Sci*. 40, 1-6.

Pallas, J.E.Jr., Samish, Y.B., 1974. Photosynthetic response of Peanut. *Crop Sci*. 14, 478-482.

Parmar, U., Malik, C.P., Grawal, M., Bhatia, D.S., Singh, P., 1989. Flowering pattern and pod development responses in a spreading type of groundnut (cv. M 13) to a monophenol and aliphatic alcohols mixture. *Proc. Ind. Acad Sci. (Plant Sci.)* 99, 147-153.

Parvathi R., Rajasekharan, R., 2002. Developmentally regulated dual-specificity kinase from peanut that is induced by abiotic stresses. *Plant Physiol.* 130, 380-390.

Patel, D.P., Munda, G.C., Mokidul, I., 2005. Dry matter partitioning and yield performance of HPS groundnut. *Crop Res*. Hisar. 30: 156-161.

Patel, M.S., Gundalia, J.D., Davaria, R.L., Vadher, P.G., 1988. Yield and quality of summer groundnut (Arachis hypogaea) as influenced by growth retardents and promoters. *Indian J. Agric. Sci*. 58, 773-735.

Penning, de Vries, F.W.T., Van Laar, H.H., eds, 1982. Simulation of plant growth and crop production. Wageningen, Netherlands PUDC (Centre for Agricultural Publishing and Documentation) pp. 308.

Phulekar, C.S., Chetti, M.B., Nalini, A.S., Patil, A.B., 1998. Relationship of leaf characters with total dry matter and yield in groundnut as influenced by growth retardants. *Indian J. Agric. Res*. 32: 195-200.

Ponnuswamy, A.S., 1986. Influence of seed size on pod and haulm production and yield in groundnut (*Arachis hypogaea* L.) cv. POL 1 and TMV 2. *Madras Agric. J.* 73, 313-316.

Poonia, B.S., Shanwal, A.V., Rajput, O.P., Singh, J., Dharmveer, 2006. Effect of sulphur fertilization, phosphorus solubilizing micro-organism (PSM) and growth regulators on groundnut (*Arachis hypogaea* L.). *Annals Biol*. 22: 19-22.

Prakash, M., Saravanan, K., Kumar, B.S., Sabesan, T., Gokulakrishnan, J., Suganthi, S., Ganesan, J., 2006. Response of brassinosteroids on growth and pod yield of groundnut. *Crop Res*. Hisar, 31: 419-423.

Prasad, M.V.R., 1993. Genetic enhancement of groundnut for higher productivity based on canopy development. Oilseeds Research and Development in India, Status and Strategies. Extended summaries of National Seminar 2-5 August 1993, DOR, Hyderabad, India, pp. 2-5.

Prasad, P.V.V., Craufurd, P.Q., Summerfield, R.J., 2000. Effect of high air and soil temperature on dry matter production, pod yield and yield components of groundnut. *Plant and Soil* 222: 231-239.

Prasad, P.V.V., Boote, K.J., Thomas, J.M.G., Allen, L.H. Jr. Gorbet, D.W., 2006. Influence of soil temperature on seedling emergence and early growth of peanut cultivars in field conditions. *J. Agron. Crop Sci.* 192: 168-177

Prathap, S., Reddy, S.S., Swamy, G.N., 2006. Effect of water stress on germination and seedling growth of groundnut genotypes. *Crop Res*., Hisar, 31, 58-60.

Promchote, P., Duangpatra, J., Chanprasert, W., 2008. Seed composition and physiological changes in Thai peanut cv. Kaset 1 and Tainan 9 during maturation. *Kasetsart J. Natur. Sci*. 42, 407-416.

Rajendrudu, G., Singh, M., Williams, J.H., 1983. Hydraulic press measurements of leaf water potential in groundnuts. *Exp. Agric*. 19, 287-291.

Rajendrudu, G., Williams, J.H., 1983. Effect of gypsum and drought on crop yield in early maturing groundnut (*Arachis hypogaea* L.). *Exp. Agric*.

Rajgopal, K., Chandran, K., 2000. Storability of groundnut seeds in different packaging media. Inter. *Arachis Newsletter* 20, 11-13.

Rajgopal, K., Chandran, K., 2002. Influence of packaging media on the storability of groundnut (*Arachis hypogaea* L.) germplasm. *Plant Genetic Resources Newsletter* 130, 62-64.

Rajgopal, K., Chandran, K., Bhagat, N.R., Bhalodia, P.K., 1997. Morphological characterization of Valencia and Virginia bunch peanut (*Arachis hypogaea* L.) germplasm. *Plant Genetic Resources Newsletter* 109, 27-29.

Ramnath Rao, V., 1988 Botany. In, Reddy, P.S., (Edt.), Groundnut, pp. 24-64.

Rao, P.V., Subba Rao, I.V., Reddy, P.R., 1986. Influence of moisture stress at different stages on growth and productivity of groundnut (*Arachis hypogaea* L.). *The Andhra Agric. J.* 33, 48-52.

Rao, K.V., 1999. The combined effect of elevated CO$_2$ levels and temperature on growth characteristics of groundnut (*Arachis hypogaea* L.) *Indian J. Plant Physiol*. 4: 297-301.

Rashmireddy, P., Basavegowda, Shekharagouda, M., Malligawad, L.H., 2006. Influence of storage containers and locations on storability of rabi/summer groundnut seeds. *Karnataka J. Agric. Sci.* 19, 400-402.

Ravindra, V., Vasantha, S., Joshi, Y.C., Nautiyal, P.C., Singh, A.L., 1990. To develop ideotype concept and to identify genotypes with high physiological efficiency for high productivity in Spanish bunch and Virginia runner forms of groundnut. Technical Report of Milestone. 8. under Micromission-I on crop technology of the Technology Mission on Oilseeds. Govt. of India. NRCG, Junagadh.

Reddy, L.J., Nigam, S.N., Nageswara Rao, R.C., 1993. Progress in breeding for drought tolerant groundnut varieties at ICRISAT Centre. Oilseeds Research and Development in India. Status and Strategies. Extended summaries of National Seminar, 2-5 August 1993, DOR, India, pp. 50-51.

Reddy, P.R., 1988. Physiology In, Groundnut. Reddy, P.S., (Ed), Indian Council of Agricultural Research, New Delhi, pp. 77-118

Reddy, P.S., 1988. Genetics, Breeding and Varieties. In, Groundnut (Reddy, P.S., edt.) ICAR, New Delhi pp. 200-317.

Reddy, P.V., Asalatha, M., Babhita, M., 1999. Soil water extraction and root growth in five groundnut genotypes under different soil moisture regimes. *Legume Res*. 22, 94-98.

Reddy, S.R., 1984. Scheduling irrigation with can evaporation for groundnut. *Ind. J. Agron*. 29, 51-54.

Reddy, Y.M., Reddy, M.V., Reddy, K.R., 1990. Effect of growing period on reproductive efficiency in genotypes of groundnut (*Arachis hypogaea*). *Ind. J. Agril.Sci*. 60, 56-60.

Saha, S.N., Dwivedi, R.S., 1981. Seed germination behaviour in groundnut. *Seed Res.* 9, 144-147.

Saini, J.S., Jolly, R.S., Dhillon, A.S., 1984. Effect of some growth regulaters on the pod yield and quality in peanut. *Crop Improv*. 11, 61-63.

Sakr, M.M.EL S Abd EL H., Baz, A g I.O., Ibrahim, M.A.M., 1997. Comparative studies on some peanut genotypes. 1. Growth behaviour. *Annals of Agric. Sci*., Moshtohor, 35, 243-261.

Sarma, P.S., Sivakumar, M.V.K., 1989. Response of groundnut to drought stress in different growth phases. *Agricultural Water Management* 15, 301-310.

Sastry, K.S.K., Sashidhar, V.R., Mekhri, A.A., Parameshwara, G., 1980. Final report of the scheme for drought tolerance studies on groundnut castor and safflower. 1974-1979. Univ.of Agri.Sciences, Bangalore, India.

Scandaliaris, J., Hemsy, V., Rodrignez, M.E., Munoz, H.L., Cajal, J.A., 1978. Flowering cycle in groundnut and factors which influence it. San Migeneddi tacuman, Argentina.

Sengupta, U.K., Sirohi, G.S., Pokhriyal, T.C., Kaim, N.S., 1977. Photoperiodic control of flowering in groundnut (*Arachis hypogaea* L.). *Curr. Sci*. 46, 271-272.

Senoo, S., Isoda, A., 2003. Effects of paclobutrazol on podding and photosynthetic characteristics in peanut. *Plant Production Sci*. 6, 190-194.

Senthil, N., Kalaiselvi, K., Raveendran, M., Vindhiyavarman, P., 1997. Ontogenetic variability of isozymes and proteins in groundnut. *Tropical Agric. Res*. 9, 381-387.

Seshadri, C.R., 1962. Groundnut. Indian Central Oilseeds Committee, Hyderabad, India, pp. 274.

Sheshshayee, M.S., Bindumadhava, H., Ramesh, R., Prasad, T.G., Lakshminarayana, M.R., Udayakumar, M., 2005. Oxygen isotope enrichment (Delta^{18}O) as a measure of time-averaged transpiration rate. *J. Exp. Bot*. 56, 3033-3039.

Shinde, G.G., Pawar, K.R., 1984. Effect of water stress at critical growth stages on growth and yield of groundnut in summer season. *J. Maharashtra. Agric. Univ*. 9, 26-28.

Singh, A.K., 1998. Hybridization barriers among the species of Arachis L., namely of the sections Arachis (including the groundnut) and Erectoides. *Genetic Resources and Crop Evol*. 45, 41-45.

Singh A.L. and M.S. Basu, 2005. Integrated nutrient management in groundnut-a farmer's manual. National Research center for groundnut (ICAR), Junagadh India p 54.

Singh A.L., M.S. Basu and N.B. Singh, 2004. Mineral Disorders of Groundnut. National Research center for groundnut (ICAR), Junagadh India p 85

Singh, A. L. 2004. Mineral nutrient requirement, their disorders and remedies in Groundnut. pp 137-159. In: Groundnut Research in India (Eds. M.S. Basu and N. B. Singh) National Research center for groundnut (ICAR), Junagadh, India.

Singh, A.L. 2003. Phenology of Groundnut. In: Advances in Plant Physiology (Ed. A. Hemantranjan), Vol. 6 pp.295-382. Scientific Publishers (India), Jodhpur, India.

Singh, A.L. 2004. Growth and physiology of Groundnut. Pp.178-212. In: Groundnut Research in India (Eds. M.S. Basu and N.B. Singh) National Research center for groundnut (ICAR), Junagadh, India.

Singh, A.L., Davada, P., Chaudhori, V., 2004. Role of pod and seed size in P and Ca nutrition of groundnut, In current trends in groundnut research, NRCG, Junagadh.

Singh, A.L., Joshi, Y.C., 1993. Comparative studies on chlorophyll content, growth, N uptake and yield of groundnut varieties of different habit groups. *Oleagineux*, 48, 27-34.

Singh, A.L., M.S. Basu and N.B. Singh, 2003. Potential of Groundnut in North-eastern States of India. National Research center for groundnut (ICAR), Junagadh, India 76 p.

Singh, A.L., Nautiyal, P.C., Zala, P.V., 1998. Growth and yield of groundnut (*Arachis hypogaea* L.) varieties as influenced by seed size. *Tropical Sci*. 38, 48-56.

Singh, M., Nageswara Rao, R.C., Williams, J.H., 1991. A statistical assessment of genotypic sensitivity of groundnut (*Aracis hypogaea* L.) to drought in line source sprinkler experiments. *Euphytica* 57, 19-25.

Singh, P.K., Jadhav, A.S., Varshneya, M.C., 2002. Effect of intercropping on reflected photo-synthetically active radiation in rainfed crops. *J. Agrometeorology* 4, 187-190.

Singh, S.B., Singh, J.P., 2001. Genotype environment interaction effects in groundnut (Arachis hypogaea) tested in mid-western plain zone of Uttar Pradesh. *Indian J. Agril. Sci*. 71, 126-127.

Sreenivas, A., Sastry, P.S., 1995. A soluble preparation from developing groundnut seeds (Arachis hypogaea) catalyzes de novo synthesis of long chain fatty acids. *Indian J. Biochem. Biophy*. 32, 213-217.

Stanciel, K., Mortley, D.G., Hileman, D.R., Loretan, P.A., Bonsi, C.K., Hill, W.A., 2000. Growth, pod, and seed yield, and gas exchange of hydroponically grown peanut in response to CO2 enrichment. *HortScience* 35, 49-52.

Stirling, C.M., Black, C.R., 1991. Stages of reproductive development in groundnut (*Arachis hypogaea* L.) most susceptible to environmental stress. *Trop. Agric*. 68, 296-300.

Subba Reddy, C., Shah, C.B., 1984. Effect of growth regulation on Spanish bunch and Virginia runner groundnut (*Arachis hypogaea* L.) cultivars. *Indian J. Agron*. 29, 516-521.

Subbaraman, R., Selvaraj, J.A., 1989. Effect of pre-sowing treatment on seed yield and quality in groundnut cv. JL 24. *Seeds and Farms* 14, 5-9.

Subrahmaniyan, K., Kalaiselvan, P., Balasubramanian, T.N., 2008. Microclimate variations in relation to different types of polyethylene-film mulch on growth and yield of groundnut (*Arachis hypogaea*) *Indian J. Agron.* 53: 184-188.

Subrahmaniyan, K., Kalaiselvan, P., 2005. Flowering behaviour and reproductive growth of polyethylene film-mulched groundnut (*Arachis hypogaea*) intercropped with cotton (*Gossypium hirsutum*) under irrigated situation. *Indian J. Agron*. 50, 126-128.

Sun, Y.H., Tao, S.X., Wang, C.B., Gowda, C.L.L. (ed.), Nigam, S.N. (ed.), Johansen, C., (ed.), Renard, C., 1996. Achieving Theoretical foundations for high yield of groundnut in China. : Proceedings of an International Workshop, Laixi, Shandong, China, 25-29 August 1995, 129-139.

Taksina S., Somsak, I., Sa-ngobphai, N., 1993. Growth and development of groundnut in different planting dates. 11. Thailand National Groundnut Meeting. Ranong (Thailand). 17-21 May 1993. Department of Agricultural Extension, Bangkok (Thailand). Proceedings of the eleventh Thailand national groundnut meeting. Raingan kan sammana thua-lisong haeng chat khrang thi 11 na rongraem Chansomthara, Ranong 17-21 Phrusaphakhom 2536. Bangkok (Thailand). 568 pp. 311-331.

Talwar, H.S., Rao, R.C.N., Nigam, S.N., 2002a. Influence of canopy attributes on the productivity of groundnut. *Indian J. Plant Physiol*. 7: 215-220.

Talwar, H.S., Soni, M.L., Beniwal, R.K., Tomar, R.K., Nigam, S.N., 2002b. Evaluation of short-duration groundnut genotypes for the arid zone of northwest Rajasthan, India. *Inter. Arachis Newsletter* 22: 15-18.

Talwar, H.S., Takeda, H., Yashima, S., Senboku, T., 1999. Growth and photosynthetic responses of groundnut genotypes to high temperature. *Crop Science* 39, 460-466.

Thatikunta, R., Durgaprasad, M.M.K., 1996. Identifying groundnut genotypes for the Southern Telangana Zone in India. *Inter. Arachis Newsletter* 16, 19-20.

Thorat, S.T., Kalra, G.S., Pawar, A.B., 1984. Responses of groundnut varieties to different irrigation schedules. *Indian J. Agron*. 29, 43-45.

Tingem, M., Rivington, M., Bellocchi, G., Azam-Ali, S., Colls, J., 2008. Effects of climate change on crop production in Cameroon. *Climate Res.* 36: 65-77.

Trachtemberg, C.H., Mc Cloud, D.E., 1976. Net photosynthesis of peanut leaves at varying intensities and leaf ages. *Proc. Soil and Crop Sci. Soc.* Florida 35, 54-55.

Truman, C.C., Williams, R.G., 2001. Effects of peanut cropping practices and canopy cover conditions on runoff and sediment yield. *J. Soil and Water Conser.*, Ankeny, 56, 152-159.

Umapathi, P., Swamy, P.M., 1978. Influence of morphactin on stomal, characters, total chlorophylls and net and gross productivity of peanut leaves. *Indian J. Exp. Biol*. 17, 225-226.

Upadhyaya, H.D., Swamy, B.P.M., Goudar, P.V.K., Kullaiswamy, B.Y., Singh, S., 2005. Identification of diverse groundnut germplasm through multienvironment evaluation of a core collection for Asia. *Field Crops Res*. 93, 293-299.

Uthai A., Nakara T.N., Sukakit S., Boonyoung B., 1993. Effect of water stress at different growth stages on yield of groundnut. Department of Agricultural Extension, Bangkok (Thailand). Proceedings of the eleventh Thailand national groundnut meeting, pp. 273-278.

Vaghasia, P.M., Khanpara,V.D., 2008. Response of groundnut (Arachis hypogaea L.) to moisture conservation practices and sulphur nutrition under rained conditions. *Inter. J. Agric. Sci*. 4, 523-526.

Vanzolini, S., Nakagawa, J., 1998. Electrical conductivity test in peanut seed genotypes. *Revista Brasileira de Sementes* 20, 178-183.

Vara-Prasad, P.V., Craufurd, P.Q., Kakani, V.G., Wheeler, T.R., Boote, K.J., 2001. Influence of high temperature during pre- and post-anthesis stages of floral development on fruit-set and pollen germination in peanut. *Austr. J. Plant Physiol*. 28: 233-240.

Varisai Muhammad, S., Ramnathan,T., Ramachandran, M., Mohanbabu, G., 1973. Variation in kernel weight and shelling out- turn in Arachis hypogaea L. *Madras Agric. J*. 60, 1394-1398.

Varshney, R.K., Bertioli, D.J., Moretzsohn, M.C., Vadez, V., Krishnamurthy, L., Aruna, R., Nigam, S.N., Moss, B.J., Seetha, K., Ravi, K., He, G., Knapp, S.J., Hoisington, D.A., 2009. The first SSR-based genetic linkage map for cultivated groundnut (*Arachis hypogaea* L.). *Theor. Appl. Genet*. 118, 729-739.

Venkateswarlu, M.S., Ram Rao, R.C., Shanker Reddy, G.H., 1980. Effect of growth regulators and plant density on groundnut oil production. *J. Res.* APAU. 8, 76-78.

Vithlapuru, V.M., Mandavia, C., 1991. Reproductive physiology of Spanish bunch groundnut (*Arachis hypogaea* L.) cultivars sown under different stand densities and its relationship with yield. In. Physiological strategies for crop improvement. Proc. Intl.Conf. Plant Physiol. Tyagi et al.(edts.) BHU, Varanasi, India, pp. 1-15.

Walls, R., Tin, B., Anderson, W.F., Wyne, J.C., 1991. Peanut yield as a result of fifty years of breeding. *Agron. J*. 83, 957-961.

Wan, Y.S, Fu, J.M., Li, X.D., Tan, Z., Fan, H., 1996. Fatty acid composition of developing groundnut seed, Shandong, China. *Inter. Arachis Newsletter* 16, 55.

Wang, C.B., Sun, Y.H., Chi, Y.C., Cheng, B., Tao, S.X., Chen, D.X., In: Gowda, C.L.L., Nigam, S.N., Johansen, C., Renard, C., (Eds.), 1996. Studies on light interception, photosynthesis, and respiration in high-yielding groundnut canopies. Achieving high groundnut yields: Proceedings of an International Workshop, Laixi, Shandong, China, 25-29 August 1995, 171-180.

Wang, C.B., Zheng, Y.P., Cheng, B., Sha, J.F., 2004. Studies on the canopy characters and efficiency for solar energy utilization of super high-yielding peanut. *Acta Agriculturae Boreali Sinica*, 19: 40-43.

Watanake, I.,1975. Transformation factor from carbon dioxide net assimilation to dry weight in crops. II. Peanut. *Proc. Crop Sci. Soc.* Japan, 44, 403-408.

Wheeler, R.A., Smith, R.L., Knauft, D.A., 1994. Microsomal polypeptide comparisons between high and normal oleic acid isogenic peanut lines using two-dimensional gel electrophoresis. *Peanut Sci*. 21, 75-78.

Williams J H 1979 a.The influence of shading during the pre-flowering phase of groundnuts (Arachis hypogaea L.) on subsequent growth and development. Rhod. *J. Agric. Res*. 17, 31-40.

Williams, E.J., Wase, G.O., Lai, J.Y., Drexler, J.S., 1987. Effect of pod maturity and plant age on pod and seed size distributions of florunner peanuts. *Peanut Science* 14, 79-83.

Williams, J.H., 1979 c. The physiology of groundnuts (*Arachis hypogaea* cv.Egret.) 3. The effect of thinning at different stages of development on reproductive growth and development. Rhod. *J.Agric. Res*. 17, 57-62.

Williams, J.H., 1979 d. The physiology of groundnuts (*Arachis hypogaea* L. cv. Egret.) 4. The growth of groundnut fruit set at the stand and end of pod setting. Rhod. *J. Agric. Res*. 17, 63-66.

Williams, J.H., 1979b. The physiology of groundnuts (*Arachis hypogaea* L. cv. *Egret*.) 1. General growth and development. Rhod. *J. Agric. Res*. 17, 41-48.

Williams, J.H., Hilderbrand, G.L., Tattersfield., J.R., 1978. Effects of weather and genotype x environment interaction on yields of groundnut (*Arachis hypogaea* L.) Rhod. *J. Agric. Res.*16, 193-204.

Williams, J.H., Nageswara Rao, R.C., Matthews, R., Harris, D., 1986. Responses of groundnut genotypes to drought. In. Agrometrology of groundnut, Proceedings of an International Symposium 21-26 August 1985. ICRISAT Sahelian Centre, Niger, ICRISAT, Patancheru, India, pp. 99-106.

Williams, J.H., Wilson, J.H., Batle, G.C., 1975a. The growth of groundnuts (*Arachis hypgaea* L.) cv. Makalu Red at three altitude in Rhodesia. *Rhodesian J. Agric. Res*. 13, 33-43.

Williams, J.H., Wilson, J.H.H., Batle, G.C., 1975b. The growth and development of four groundnut (*Arachis hypogaea* L.) cultivars in Rhodesia. *Rhodesian J. Agric. Res*. 13, 131-144.

Witzenberger, A., Williams, J.H., Lenz, F., 1985. Yield, components of yield and quality responses of groundnut cultivars (*Arachis hypogaea* L.) as influenced by photoperiod and a growth regulator. *Field Crop Res*. 12, 347-361.

Wright, G.C., Bell, M.J., 1992. Plant population studies on peanut (Arachis hypogaea L.) in subtropical Australia. 3. Growth and water use during a terminal drought stress. *Aust. J.Expl. Agric*. 32, 197-203.

Wright, G.C., Hubick, K.T., Farquhar, G.D., 1988. Discrimination in carbon isotopes of leaves correlates with water use efficiency of field grown peanut cultivars. *Aust. J.Plant Physiol*. 15, 815-825.

Wright, G.C., Hubick, K.T., Farquhar, G.D., 1991. Physiological analysis of peanut cultivar response to timing and duration of drought stress. *Aust. J. Agric. Res*. 42, 453-470.

Wright, G.C., Rao, R.C.N., Basu, M.S., 1998. Selection for water-use efficiency in food legumes - extension phase report. ACIAR Food Legume Newsletter, 27: 4-6.

Wynne, J.C., Gregory, W.C., 1981. Peanut breeding. *Adv. Agron*. 34, 39-72.

Yadav, S.K., Singh, A.L., Misra, J.B., Mathur, R.S., 1993. Effect of protrected moisture stress on biochemical constitutents of groundnut leaves. International Conference on Biotechnology in Agriculture and Forestry. February 15-18 1993. New Delhi India. pp. 65.

Yang, X.Q., Jiang, X.C., Fu, J.R., 1998. Heat-stable proteins and acquisition of desiccation tolerance in peanut seeds. *Acta Botanica Sinica* 40, 337-342.

Zhang, B., Zhang, T.L., Zhao, Q.G., 1999. Relationship between water potentials of red soil and crop leaves under five farming systems and their responses to drought stress in the dry season. *Acta Pedologica Sinica* 36, 101-110.

Zhou, S.M., Ma, S.Q., Li, W., Zhang, S.T., 1998. Analysis of superiority of maize and groundnut row intercropping. *Acta Agric*., Universitatis Henanensis 32, 17-22.