CROP GROWTH AND DEVELOPMENT OF CASTOR CULTIVARS UNDER OPTIMAL AND SUB-OPTIMAL WATER AND NITROGEN CONDITIONS IN TELANGANA REGION.

BY

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CERTIFICATE

This is to certify that the thesis entitled **"CROP GROWTH AND DEVELOPMENT OF CASTOR CULTIVARS UNDER OPTIMAL AND SUB-OPTIMAL WATER AND NITROGEN CONDITIONS IN TELANGANA REGION"** submitted in partial fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY IN AGRICULTURE** of the **Acharya N.G.Ranga Agricultural University**, Hyderabad, is a record of the bonafide research work carried out by **Ms.C.SUDHA RANI** under my guidance and supervision. The subject of the thesis has been approved by the student's Advisory committee.

No part of the thesis has been submitted for any other degree or diploma or has been published. The published part has been fully acknowledged. All the assistance and help received during the course of investigations have been duly acknowledged by the author of the thesis.

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DECLARATION

I **C. SUDHA RANI** hereby declare that the thesis entitled **CROP GROWTH AND DEVELOPMENT OF CASTOR CULTIVARS UNDER OPTIMAL AND SUB-OPTIMAL WATER AND NITROGEN CONDITIONS IN TELANGANA REGION** is a result of original research work done by me. I, further declare that the thesis or any part thereof has not been published earlier in any manner.

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ABSTRACT

A field experiment was conducted at ICRISAT, PATANCHERU, during *kharif* season of 1997-98 and 1998-99, to study the crop growth and development of castor cultivars under optimal and sub-optimal water and nitrogen conditions in Telangana region.The investigation was carried out in Split-plot design with 16 treatment combinations comprising of two water regimes (Rainfed and irrigated at 0.75 IW/CPE ratio) constituting the main plots, two nitrogen levels (10 and 60 kg N ha^{-1}) assigned to sub plots and four varieties (Aruna, DCS-9, GAUCH-1 and GCH-4) in sub-sub plots and replicated four times.

Biometric observations on growth and physiological parameters, yield and yield attributes and light interception were recorded by Tube Solarimeter. Plant chemical analysis was done to determine the nutrient uptake. Oil and protein content was also estimated.

Results of the investigation indicated that irrigation at 0.75 IW/CPE, ratio increased the plant height of castor cultivars when compared with rainfed situation. The LAI and dry matter production by irrigated castor was significantly higher than the rainfed castor. Flowering was delayed by 4-5 days under irrigated condition than in rainfed condition. Longer spikes, spikes per plant, capsules per spike and maximum100 seed-weight were obtained from irrigated castor than rainfed ones. Compared to rainfed castor, maximum seed and stalk yield and harvest index was obtained under irrigation. Irrigated castor continued its growth for longer period than rainfed castor, and hence the growing crop accumulated more number of growing degree-days under irrigation. The maximum amount of dry matter was partitioned into sink portion (spike) under irrigated

condition than the rainfed condition. Uptake of N, P and K were found to be higher under irrigated condition.

N application @ 60 kg ha^{-1} resulted in taller plants with greater leaf area, and more dry matter production. The highest N level (60 kg ha^{-1}) produced longer spikes more spikes per plant, capsules per spike and larger seeds. Maximum seed and stalk yields were obtained at 60 kg N ha^{-1}. Improved nitrogen nutrition as a result of fertilizer application permitted extended growth and hence more accumulation of growing degree-days. GCH-4 gave the higher seed and stalk yields compared to GAUCH-1, DCS-9 and Aruna. Higher partitioning lead to higher harvest index in GCH-4 over other cultivars. The interaction effect due to water regimes, nitrogen levels and cultivars, W & N, C & W, N & C in terms of seed yield were found significant.

Out of the six dates of sowings between November and September, GCH-4 sown during the first week of June gave the highest seed yield. Out of the three planting densities, 17,000 plants ha^{-1} recorded the highest seed yield than 55,000 plants ha^{-1} and 1,30,000 plants ha^{-1}.

Thus the study indicated the superiority of irrigating the castor at 0.75 IW/CPE ratio over rainfed cultivation. Under the existing agro-climatic condition of Telangana region of Andhra Pradesh, irrigation based on IW/CPE ratio is recommended. Application of nitrogen @ of 60 kg N $ha^{-1}$is recommended (1/2 basal and remaining half in two equal splits at 30 and 60 DAS) for higher castor yields. Cultivation of castor with cultivars having higher yield potential like GCH-4 was recommended for Telangana region of Andhra Pradesh. The data collected on castor finally combined with the data collected by others, could be the basis of developing a castor simulation model.

LIST OF SYMBOLS AND ABBREVIATIONS USED

@	: at the rate of
^0C	: degree celsius
CD	: critical difference
cm	: centimetre (s)
CV	: Co-efficient of variation
DAS	: days after sowing
dSm^{-1}	desi siemens per metre
EC	: electrical conductivity
Fig	: figure
g	: gram
ha^{-1}	: per hectare
K_20	: potassium
kg m^{-2}	: Kilogram per square metre
kg N ha^{-1}	: Kilogram nitrogen per hectare
kg P ha^{-1}	: Kilogram phosphorous per hectare
kg K ha^{-1}	: Kilogram potassium per hectare
LAI	: leaf area index
m	: metre
m^{-2}	: per square metre
m ha	: million hectare
mm	: milli metre
N	: nitrogen

P_2O_5	: phosphorous
S.Ed.+-	: standard error of difference
t ha^{-1}	: tonnes per hectare
MSL	: mean sea level
RUE	: radiation use efficiency
PAR	: photosynthetically active radiation
DMP	: dry matter production
%	: per cent
g MJ^{-1}	: grams per mega joule
SVPD	: saturated vapour pressure deficit
CO_2	: carbondioxide
IW / CPE	: Irrigation water depth / cumulative pan evaporation

INTRODUCTION

CHAPTER I

INTRODUCTION

Castor (*Ricinus communis* L.) is an important non-edible oilseed crop grown in India. Today castor oil finds application in the manufacture of an ever-expanding range of industrial products such as nylon fibres, jet engine lubricants, hydraulic surfactants, coating, greases, fungistats, pharmaceuticals, cosmetics, polyesters and polymers. India occupies a distinct position in the world's annual vegetable oilseeds production scenario, not only in terms of cropped area, but also in terms of diversity in cultivated oilseeds. The country is blessed with the agro-ecological conditions favorable for growing nine annual oilseeds including seven edible oilseeds, groundnut, rapeseed- mustard, sesamum, sunflower, soybean and safflower and two non-edible sources castor and linseed. In the Indian agricultural economy, oilseeds hold an important position next to food grains, accounting for about 10 per cent of gross cropped area and contributing nearly 5 per cent to the gross national product. With an area of 8.4 lakh hectares, the country accounts for about 61.1 per cent (13.74 lakh ha) of the total area under castor oilseeds in the world (FAO, 1997).

India currently produces 0.8 million tonnes of castor seed annually compared to world Castor seed production of 1.274 million tonnes (FAO, 1997). Andhra Pradesh holds the premier position in the country in terms of area (2.69 lakh ha), but ranks second in production (0.9 lakh tonne) and the per hectare yields are low (335 kg ha^{-1})

(Directorate of Oilseed Research, 1995). Most of the area within the state is confined to the chalka (Red sandy loam) soils of Nalgonda, Mahaboobnagar and Ranga Reddy districts of Telangana region. Other important castor growing states are Gujarat, Karnataka, Orissa and Tamilnadu.

Castor is the most preferred crop for rainfed farming in the semi-arid tracts because of the crop's drought-hardy nature. However its productivity does fluctuate with the aberrations in weather. As it is a long duration crop (more than 150 days) it often encounters terminal drought due to early withdrawal of the south-west monsoon and occasionally encounters early and mid-season droughts due to break in the monsoon conditions. Because it is a foreign exchange earner through its exports, farmers will use irrigation as and when required. Yields as high as 2900 kg ha^{-1} can be obtained under irrigation.

Despite a phenomenal increase in the production and productivity of castor over the last ten years or so, there still exists wide range of regional disparities in per hectare yields of castor. The Government of India established "Oilseed Technology Mission" in 1986 to stimulate the production of crops like groundnut, sunflower and castor. The aim of the mission was to achieve self-sufficiency in oilseeds production. Recently new varieties of castor have been developed.

One way of stimulating castor production is by expansion of the area grown which can be achieved by utilizing the genetic diversity within the crop. In that way castor cultivars are better adapted to the soils and climates of the region. It is also important to overcome constraints to production, which are generally believed to be water deficit and nitrogen deficiency.

These cultivars differ in their response to agronomic practices like irrigation and fertilizer application in respect of flowering and maturity, harvest index and seed oil content. Since little information is available on above aspects, so there is a need to study the response of castor cultivars to water and nitrogen. A better understanding of the growth and development of castor, and of how castor responds to water and nitrogen, may provide avenues for improving production of castor.

The specific objectives are:

1. To determine the relationship between light interception, leaf area development and seed yield.
2. To study the effect of sowing dates on growth and development of castor cultivars.
3. To understand the effects of water and nitrogen on growth and productivity of castor cultivars.
4. To quantify the partitioning of assimilates to castor seeds in different cultivars.

Growing castor in submarginal and marginal lands under rainfed conditions with practically a little or no inputs, use of poor quality of seed etc., are some of the reasons identified for low yields. The primary environmental constraint is that of water deficit, with much of the production being on sandy soils, and with the crop having a relatively long duration, crops well frequently experience water stress, particularly towards the end of the season.

Primary spikes mature in about 55 days after flowering. The spikes of the secondary, tertiary and latter orders appear from October and thereafter. Since moisture becomes frequently a limiting factor beyond the month of October, the development of the subsequent spikes frequently suffers rendering the yields low and unpredictable. So provision of irrigation to the crop will help in harvesting higher yields. In the absence of irrigation, there is need to improve the efficiency of utilization of water under rainfed conditions.

The soils are invariably low in nitrogen. The castor responds well to fertilizer application. Tremendous scope exists for increasing the production through efficient fertilizer use of these dryland crops. Fertilizer management in rainfed oilseeds assumes special importance with improved varieties and dryfarming practices. Use of fertilizers in these crops under rainfed cultivation is very low though there is ample scope for increasing production through their use. Application of major nutrients such as nitrogen was found to increase the number of capsules, bean yield per plant, 100 seed-weight and productivity.

This thesis therefore addresses the need to develop a quantitative understanding of castor growth and development as affected by growth duration, available water and nitrogen.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

The purpose of this chapter is to review the existing knowledge on growth and development of castor, and its yield and yield components, with special emphasis on effects of water and nitrogen. The available literature on "Crop growth and development of castor cultivars under optimal and sub optimal water and nitrogen conditions in Telangana region" are presented under the following sub heads

2.1 Growth and development of castor cultivars

2.2 Effect of sowing dates on castor cultivars

2.3 Effect of nitrogen on yield and yield components of castor cultivars

2.4 Effect of irrigation on yield and yield components of castor cultivars

2.5 Interaction effect of irrigation and nitrogen on yield and yield attributes of castor cultivars

2.6 Nutrient uptake, oil and protein content.

2.7 Effect of planting density on castor yields

CASTOR PRODUCTION IN INDIA

Castor is widely grown in India, particularly in Andhra Pradesh, as a low input dryland crop on poor soils, where its drought-hardy characters help it to provide a cash crop for farmers. The major objective is to consider castor as it is grown in Andhra Pradesh, with growth severely limited by water and nitrogen supply. Its importance as an irrigated, fertilized crop in Gujarat is recognized, and the responsiveness of improved and traditional castor cultivars to irrigation and added nitrogen is also reviewed.

Based on past agronomic, site-specific studies, nitrogen requirements and responsiveness to supplemental water have been established, although most of the production comes under dryland without fertilizer input. Castor crop is cultivated between 40°S to 52°N and from sea level to 2000 m above sea level (Weiss, 1983). It cannot tolerate frost. Castor requires a moderately high temperature of 20°-26°C with low humidity throughout the growing season to produce maximum yields. In India, it is usually raised as a rainfed crop in areas with 600-900 mm rainfall, but is very hardy and drought resistant and can thrive well even with 500 mm rainfall. In India and Pakistan, the rainfed castor crop is grown in Kharif season and a partially irrigated crop in the *rabi* season mainly in Gujarat state. In Andhra Pradesh on red loams, a rainfall of 500-600 mm will produce a good crop. Maximum rainfall prior to planting will lower soil temperature and in these circumstances sowing should be delayed until the soil warms up.

Castor is a crop that can be cultivated on many soils including sandy loams, laterites, alluvial, etc. It would not, however grow well on heavy clay soils particularly when they are poorly drained. Saline soils are not suitable for growth of castor since a majority of the castor varieties are sensitive to salinity. On most soils castor crop responds well to fertilizers because of the high nutrient requirements during the early stages of growth. With production of 1500 kg per hectare of seed, nutrient removal is 45 kg N, 18 kg P_2O_5 and 15 kg K_2o ha^{-1}. The castor yields can be improved considerably if supplemental irrigation is given along with the fertilizer application. The judicious application of fertilizer may increase yield under limited resource conditions. Moreover, there are complementary and supplementary relationships between irrigation and fertilizer application that have a considerable impact on the yield of a crop. Compared with the major crops such as paddy, wheat, sorghum, sunflower etc., quantitative knowledge on the growth and development of castor is meager.

2.1 GROWTH AND DEVELOPMENT OF CASTOR CULTIVARS

Knowledge on growth and development of castor is meager. The castor plant varies greatly in its growth habit, color of foliage, stems, seed size, color and oil content, so that varieties often bear little resemblance to each other. The period from emergence to maturity varies with variety, and is greatly influenced by environment.

The term growth is defined as a permanent and irreversible change in the size of a cell, organ or whole organism usually accompanied by an increase in dry weight. Growth is attained mainly by photosynthesis. Development is, therefore applied to the whole series of changes, which an organism goes through during its life cycle. The development is nearly always associated with morphogenesis and differentiation. The development of a plant from germination to maturity can be considered as a series of discrete periods, each identified by an accompanying process of change in the structure, size or weight of specific organs. Developmental processors relate to varying degrees of expansion or growth in weight of an organ.

Castor seed of some varieties may have a dormancy period of several months and the modern hybrids are not dormant and freshly harvested seed germinates without special treatment. Germination is epigeal, the two cotyledons acting as suctorial organs absorbing the endosperm and are carried above the surface and expands as green leaves. The soil should be moist up to 150-200 mm and seed planted at least 50 mm deep. Seedling which emerge from a depth of 300 mm, but are usually shorter and less vigorous than those planted less than 100 mm deep. When planted at 350 mm deep, seed germinated and produced hypocotyls varying to emerge (Weiss, 1983). A seedbed temperature of 17 ° C is normally necessary for uniform germination. A soil moisture range of 15-20 per cent usually ensures good germination at optimum temperature below 11 per cent impairs and above 25 per cent inhibits. Heavy rain just after planting, unless followed by warm sunny days, can seriously reduce emergence. Water logging will lead to seed rotting and affects germination and emergence.

High soil temperatures decrease the time from sowing to emergence and low soil temperature extends it. Thus temperature and time of sowing are closely related but the factors influencing both vary regionally. The main temperature effects of importance to growers are those of low temperature in seedbed and high temperature at flowering. Low temperature first extends the time of emergence and by prolonging the period seeds are in the ground before and after germinating, render them more liable to attack by fungal disease and insects. (Weiss, 1983)

Dwarf types have root systems which reflect the particular variety or cultural systems i.e. rainfed or irrigated, and the taproot is less apparent. The well-developed secondary root system is much branched and often deeply penetrating to take maximum advantage of soil moisture, a major factor in the plant resistance to drought. In arid areas where the plant has only rainfall for subsistence, aerial growth tends to be slower in relation to root growth than under less arid conditions, and the rate of root growth of locally adapted cultivars was more than in other varieties. An added advantage of quick root growth (seed priming) is increased ability to follow the moisture front down into the subsoil, which in many dry areas is often better supplied with nutrients than in more temperate regions.

The stem is round, glabrous, frequently glacous and covered with a waxy bloom' which gives red or green stems a bluish appearance in the field. Varieties with a heavy, waxy bloom are more resistant to jassids or leafhoppers. Conversely, bloomless types (Brar *et al.*, 1977) are more resistant to mites (Chadrasekharan, 1964). The stem of dwarf varieties generally becomes hollow with age, but is usually solid to a considerable height in wild, tree like types. The node at which the first raceme appears is an important agronomic characteristic, since it is associated with quick maturity.

In its natural state, castor is a multi-branched crop, a sequence that continues over the life of the plant. This is an unfavorable characteristic for commercial production and mechanical harvesting, since the fewer the branches the lower the number of racemes and hence a shorter period and more even maturity. Topping at 300-600 mm can reduce height and increase branching, but usually decreases yield.

The very large leaves are usually dark glossy green, palmate, with 5-11 lobes and prominent veins on the under surface. Leaves are alternate, except for two opposite leaves at the node immediately above the cotyledons. Growth and expansion of castor leaves do not appear to be checked by prolonged sunlight, provided there is ample moisture for transpiration. It is not until water deficit has been built up that growth and leaf expansion were affected. Leaf growth curves obtained in California indicate that temperature and water stress were more important than sunlight in control of growth (Loomis *et al.*, 1968). LAI was an important determinant of the partitioning of evapotranspiration between evaporation and transpiration. (Ritchie and Burnett, 1971 and Cooper *et al.*, 1983).

The inflorescence which forms a primordial raceme also known as the spike or candle is born terminally on main and lateral branches, and the node at which the first one originate is a varietal characteristic. The inflorescence can reach a length of 100 cm, but since there is a wide variation in distance between flowers, yield is not necessarily correlated with length. The lower portion of the raceme bears male flowers, the upper female, the ratio between them being a varietal characteristic, but it is also strongly influenced by climate. High temperature favour maleness, as does plant age and short day length and vice-versa. Pollen is shed readily between 26-29°C with a relative humidity of 60 per cent, but a temperature of 15°C delays shedding and lower temperature can injure pollen grains. Prolonged periods of high humidity adversely affect pollen grains, this interference with normal pollen production was a major factor influencing the lower yields. The lowest flowering raceme on the plant is usually the first to mature, and the other following in sequence up the stem. There is a distinct variation in yield of seed and their oil content between inflorescence, primary racemes generally producing the greatest number and largest seeds.

The fruit is a globular capsule, spiny to some degree, which becomes hard and brittle when ripe. Cultivated varieties known as thorn less have been developed and these often have rudimentary spines. The capsules contain three seeds, a flattened oval in shape with shiny brittle tests enclosing a white, highly oleaginous kernel. There is also a difference in rate of germination between seed from different racemes, the first to flower having greater viability than the last. The 100 seed weight may vary from 10 g to 100 g but most of the dwarf internodal variety average some 30 g. in general, the weight of individual seeds increases as the total number of seeds produced per plant decreases. However, the increase in 100 seed-weight does not fully compensate for the decrease in number and total yield is less. This applies particularly to the yield obtained from different times of planting, since yield normally decreases after the optimum sowing period.

If the temperature stays above 38°C for an extended period or if excess soil moisture supply is available the seed may fail to set. It needs a hot dry climate for proper development of fruits for harvesting. High temperature (above 35°C) will reduce oil content and protein content. Temperature below 15°C will reduce oil content and alter the oil characteristic (Veda, 1975). The most important seed constituent is the oil, usually between 40 and 60 per cent in commercial varieties.

The radiation penetration within the crop canopy to a larger extent depends on the extinction co-efficient of the crop (Monteith, 1973). According to Goudrian (1977) the fraction of radiation intercepted by a layer with certain leaf area is proportional to the average projection and inversely proportional to the sine of the inclination of the incident radiation. Biomass accumulation of different species growing in different environments can be analyzed in terms of the amount of solar radiation intercepted and its efficiency of use in biomass production, termed the radiation-use efficiency (RUE) (Monteith, 1977). The RUE is a measure of the photosynthetic performances of field-grown crops. By comparison with baseline values of RUE obtained under optimal growth conditions, the extent of environmental and management limitations can be assessed and the potential for yield improvement can be determined. The baseline RUE is a key parameter for crop growth simulation models, which are powerful tools for assessing crop performance, particularly in environment where climate is variable and relatively unpredictable. For a given species, RUE is widely regarded as a stable quantity in the absence of limitations due to water deficits, inadequate nutrition and pests and diseases (Monteith and Elston, 1983). In the field experiments Rawson *et al.* (1984) recorded LAI values between 3 and 4 for maximum light interception.

On vertisols of peninsular India, Siva Kumar and Virmani (1984) observed that photosynthetically active radiation (PAR) interception in the sole pigeonpea crop showed low values up to about 70 days after planting, where Leaf area index (LAI) was only about 0.9. Interception increased up to 93 per cent with the steady increase in LAI up to about 130 days, after which increasing leaf senescence contributed to a steady decrease.

Hughes *et al* (1987) observed a linear relationship between the maximum amount of biomass accumulation by pigeonpea and the amount of solar radiation intercepted by the foliage during crop growth. Moisture stress adversely affected radiation interception, photosynthetic efficiency and harvest index. In Northern Australia, Muchow and Davis (1988) studied the influence of nitrogen on radiation interception and biomass accumulated (RUE) by sorghum and maize under irrigated conditions. It was observed that RUE was more responsive to nitrogen supply than radiation interception. RUE increased with higher rate of applied nitrogen (0 to 50 g m^{-2}), maximum RUE was greater in maize than in sorghum and RUE declined more during grain filling in maize than in the sorghum crop. It was concluded that RUE, may not be stable across environments as it was previously thought, but it rather depended on the balance of leaf growth, nitrogen uptake and allocation to leaves and nitrogen mobilization from leaves to grain. Muchow *et al.* (1990) reported that leaf area development as influenced by ambient temperature determines the LAI of the crop and also the proportion of the incident radiation that was intercepted. The higher light interception represents the poor transmittance of the light to the lower canopy in turn decides the efficient utilization of light for photosynthesis (Arjunan *et al.*, 1992). Steer *et al.* (1993) observed that the LAI per day was the function of number of leaves produced and the rate and duration of each leaf. The higher light interception represents the poor transmittance of light to the lower canopy and it will in turn decides the efficient utilization of light for photosynthesis. Duration of sunshine and incidence of solar radiation have direct bearing on the growth and development especially on the photosynthetic activity of the plant.

At, Hisar, mustard grown during the post-rainy cropping season produced dry matter which was linearly related to the amount of solar radiation intercepted by crop canopy (Raj Singh *et al.*, 1993). The average value of radiation use efficiency of both the cultivars was 3.15 ± 0.30 gMJ^{-1} of absorbed PAR. Cumulative dry matter production of crops supplied with adequate moisture and nutrients has been shown to be linearly related to cumulative intercepted PAR [Gallagher and Biscoe (1978), and Gossee *et al.*, (1986); Hamdi *et al.* (1987)]. Variability in RUE was explained in terms of both physical parameters like temperature (Hammer and Vanderlip, 1989) water stress (Ong & Monteith, 1985) and biological factors like plant phenology (Spitters 1990; Giauffret *et al.*, 1991), CO_2 exchange rate and leaf nitrogen content. (Sinclair & Horie, 1989).

The RUE of castor, worked out for different dates of sowing in different years ranged from 0.77 to 1.0 (Vijaya Kumar *et al.*, 1997). It is lower than that of sorghum (2.74 g MJ^{-1}) reported by Siva Kumar and Huda (1985), Maize (3.8 g MJ^{-1}) reported by

Siva Kumar and Virmani (1984), pearl millet (1.5 to 1.7 g MJ^{-1}) reported by Marshall and Willey (1983), Squire *et al.* (1984) and Azam Ali *et al.*, (1984) and higher than chickpea (0.55 to 0.67 g MJ^{-1}) reported by Singh and Sri Rama (1989).

According to Vijaya Kumar *et al.* (1997) RUE may vary from year to year and also were influenced by the planting dates. Variations in RUE ranged from 0.79 to 1.19 g MJ^{-1}.The variability in RUE before and after flower initiation were quite contrasting. The variability in RUE was associated with saturated vapour pressure deficit (SVPD), drought index, temperature and wind velocity. RUE was related positively with SVPD and wind velocity and negatively with drought index and temperature.

Weather parameters individually influence the physical and physiological processes of the crops. With increase in temperature, duration of canopy decrease, aging of leaves is faster, senescence will be more and dry matter accumulation will be less. The saturation vapour pressure deficit affects growth by affecting the rate of leaf expansion, leaf conductance and rate of photosynthesis. Drought stress enhances senescence and reduces dry matter accumulation. Wind velocity increases boundary layer conductance, transpiration rate, facilitates better supply of CO_2 and increases the rate of photosynthesis and decreases the canopy temperature and alters the energy budget of the leaf.(Weiss, 1983)

From this we can conclude that in sole cropping system, with increase in LAI there will be proportional increase in PAR interception. With the increase in senescence of leaves there will be decrease in PAR interception. Moisture stress adversely affected radiation interception, photosynthetic efficiency and harvest index. RUE increases with nitrogen application. RUE increases with crop growth and decreases with grain filling phase. The relative difference in RUE increased with crop development between nitrogen applied plots and without nitrogen applied plots. Further there is relatively little information available on LAI, dry matter production, partitioning and RUE under optimal (irrigated) and sub-optimal (rainfed) water and nitrogen conditions.

2.2 EFFECT OF SOWING DATES ON CASTOR CULTIVARS

Yield potential of a crop can be explored by the use of agronomic techniques. Among the agronomic techniques, time of sowing is an important non-monetory input. When sowing date variations are used, effects of day length and temperatures interact to influence growth, yield and quality. Castor in dry lands of Andhra Pradesh is sown at times early with the onset of monsoon or late due to uncertain rainfall. Sowing time can play an important role in boosting the yields, with efficient use of available resources.

In North East India, Turkhede *et al.*, (1982) conducted a trial on the performance of three castor cultivars (Aruna, GCH-3 and local) under four dates of sowing at monthly intervals starting from end July. The dates of seeding had a profound influence on the seed yield. The best yields were recorded when the crop was sown in the end of July or end of August. The yield dropped from 1900 kg ha^{-1} in July or August sowing to 700 kg ha^{-1} when sown at the end of September. End October sown crop failed to produce any seed. This decrease in the yielding ability of the plant was due to a reduction in plant height, the length of panicle and a large proportion of unfilled capsules. The crop sown in end October flowered in late December and the flowers were killed due to low temperature in December and January. Though seeding later than the end of August, usually reduced seed yield, there are examples of different reaction of the varieties to seeding dates. The two varieties GCH-3 and Aruna were adversely affected by delayed sowing beyond August.

Ganga Saran and Gajendra Giri (1987) conducted a study at Indian Agricultural Research Institute (IARI), New Delhi and reported that one month delay in sowing of GAUCH-1 (10^{th} April) resulted in 58% more leaf dry matter and 67% more whole plant dry matter to that of crop sown on 10^{th} March. They also stated that growth and yielding ability of the castor appeared to be conditioned by the temperatures prevailing not only at the time of sowing but also at various phenological stages. In summer season hot and desiccating winds adversely affected flower fertilization and development of seed as would be evident from the reduced seed size and capsules per spike. Seed yields of castor were higher in 10^{th} March sowing (1066 kg ha^{-1}) when compared with 10^{th} April sowing (733 kg ha^{-1}). Increased dry matter per leaf or plant does not seem to divert more photosynthates for more production in the hot and desiccating environment of summer season with maximum temperature ranging between 40 and 45°C in the late sown crops.

Ankineedu *et al.*, (1975) observed that under rainfed conditions delay in sowing of Aruna variety from June to September in Telangana region of Andhra Pradesh results in progressive reduction in yield. The reduction in seed yield ranged from 11 % (July planting) to 74 % (September planting) compared with June planting. Early planted crop (June planting) was able to complete flowering up to the forth order spike i.e. before the end of October and was able to elevate and stabilize yields. Inspite of uncertain weather conditions and fluctuating rains, delay in sowing will affect even the flowering of primaries and secondaries and will result in drastic reduction in yield. The proportion of female to male flowers (sex ratio) is influenced by environment. Temperature of 31-32^{0} C will promote interspersed male flowers while lower order temperature result in fully female racemes. However studies on sowing dates and newly released hybrids are very scanty.

In Telangana region of Andhra Pradesh castor yield stability over the years can be judged from the fact that the yield of this crop was not much affected by variations in rainfall in different years. For the best results the crop should be sown not later than the end of August. By delayed seeding the flowering or capsule development period coincides with the relatively low temperatures of November and December month which adversely affect fertilization (Juang,1975).

In Palem Telangana region of Andhra pradesh, Baby Akula and Bapi Reddy (1998) studied the effect of dates of sowing on yield of castor cultivars GCH-4, Kranthi, DCS-9 and Aruna during kharif season on medium fertile sandy soils and observed highest yields during 15th June sowing. It was observed that with delay in sowing, the period of moisture availability will be reduced resulting in shortening of vegetative period, ultimately reducing the yield. Moshkin (1986) has reported similar findings. Sowing on 18th August gave higher yield over 30th July sowing. Heavy rains occurred during the month of October (180.3 mm) coupled with high relative humidity which caused severe incidence of Botrytis grey rot in 30th July sowing, coinciding with the development of primary spikes and also formation of secondary spikes, ultimately resulted in lower yields. In 18th August sowing, though primary spikes were affected, secondary spikes escaped Botrytis incidence. The higher yields of castor with 15th June sowing can be attributed to more lengthy primary spikes and also favorable female to male flower ratio in primary spike, probably due to favorable soil moisture regime during entire growth period caused by the rainfall received during the succeeding month. GCH-4 gave significantly higher yield (1600 kg ha^{-1}) compared to other cultivars under test. DCS-9 and Aruna were at par. Primary spike length, number of capsules per spike and test weight of GCH-4 contributed to perceptible increase in yield. Thus it can be indicated that sowing castor during first fortnight of June under rainfed conditions, increased the yield since the crop had favorable rainfall during entire growth period.

Vijaya Kumar *et al.*, (1997) in Telangana region of Andhra Pradesh reported that high castor bean yield can be achieved by planting the crop on an early date i.e. in June, and that delay in planting by three weeks significantly reduced the yield. The end of July planting resulted in a much reduced castor bean yield due to biotic stress i.e. Botrytis mould and moisture stress. The critical factor appeared to be a rainless period for one month during the active flowering stage. Date of sowing also influences the yield components. The percentage contribution of different spike orders (primary spike, secondary spike and tertiary spike) differs with different dates of planting. The moisture adequacy index is the ratio of the actual to potential evapotranspiration. The studies revealed that primary spikes are mostly influenced by photoperiod (61 %) and to a lesser extent by moisture adequacy index (39 %). Secondary spikes were mainly influenced by moisture adequacy index (83 %) whereas tertiary spikes were not found to be influenced independently by any weather parameter but were inversely influenced by the interaction of moisture adequacy index and degree days. The moisture adequacy index (63%) and degreedays (37%) during the total reproduction period positively influenced total bean yield (initiation of primary spike to maturity of tertiary spikes).

Subba Reddy *et al.* (1996) reported that timely sowing is a critical factor in stepping up the seed yields of castor in rainfed environment. Sowing of castor in farmer's field in second fortnight of June gave on an average bean yield of 672 kg ha^{-1} over the years. While castors sown in first and second fortnight of July and first fortnight of August recorded 9, 30 and 40 per cent reduction in bean yield than the second fortnight of June. Thus, castor can be sown in the farmer field up to first fortnight of July. Early sowing of castor was found advantageous in the years of normal distribution of rainfall and also in case of early withdrawl of monsoon.

From the above literature it was learnt that June sown crop recorded highest yields followed by July and then by September sowings in Telangana region of Andhra Pradesh. In *kharif* season, delay in sowing reduces the bean yield due to reduced water availability. For rainfed castor June sowings is the best for higher yields because of favourable soil moisture during entire crop growth. July planting reported that reduced yields due to Botrytis mould and also rainless period during flowering. In North East India March sowings are better than April sowings because the hot and desiccating winds adversely affected flower fertilization and development of seed. Little information is available on the performance of different cultivars(GCH-4, DCS-9, Aruna and GAUCH-1) on very early sowings such as January, April and very late sowings such as November sowings.

2.3 EFFECT OF NITROGEN ON YIELD AND YIELD COMPONENTS

Response of castor to nitrogen application in the seedbed or as top-dressing, tends to be erratic, and yield increases are frequently more due to the variety selected and soil type rather than the fertilizer. It was noted that the application of nitrogen promoted the development of male flowers without however causing a reduction in female flowers, and that there was a great improvement in seed yields. Trails on forty cultivar plots in Hyderabad, Andhra Pradesh, showed good responses to nitrogen in the presence of phosphate and potash. The combination N_{20}, P_{10}, K_{10} gave the highest yields, ranging from 361 to 604 kg seed per hectare (Giroti, 1964).

Sarma (1985) conducted a study at Rajendranagar, Andhra Pradesh and stated that highest seed yield of 1500 kg ha^{-1} was recorded with GAUCH-1 which was significantly higher than Aruna (13.69 %) and Bhagya (24.98 %).

According to Ankineedu *et al.* (1975) the mean yield data across locations and seasons indicated that highest bean yield (1400 kg ha^{-1}) due to GAUCH-1 followed by the variety Aruna with regard to nitrogen application. The response was obtained up to 80 kg N ha^{-1} and it should be applied either as basal or 40 kg N as basal and equal amount top dressed at 25 and 45 days after sowing depending on the availability of soil moisture. Application of 40 kg N ha^{-1} in split dose recorded significantly higher yields (25 to 75 %) in Telangana region of Andhra Pradesh (Sarma 1985).Split application of 40 kg Nha^{-1} in equal splits at sowing and 25 DAS proved effective in increasing the yield of castor at the same level of its application as basal dose.

Top dressing of urea at 30 to 60 days after sowing @ 20 kg N ha^{-1} along with basal (10-30-0-NPK kg ha^{-1}) as critical input recorded an additional average seed yield of castor by, 170 Kg ha^{-1} compared to the normal practice adopted by the farmers (average of 5 years). Additional application of 40 kg N ha^{-1} gave increased bean yields of castor by 190 kg in 1992 and 360 kg in 1993. Castor with 50-30-0 NPK kg ha^{-1} gave higher seed yields under rainfed conditions in favorable environment in sole and inter cropping with clusterbean (Venkateswarlu and Reddy, 1989).

Ganga Saran and Gajendra Giri (1987) conducted a study on sandy loam soils of IARI, New Delhi and stated that application of 50 kg N ha^{-1} increased spike length, capsules per spike and 100 seed weight over no nitrogen application in GAUCH-1 cultivar.

Madhusudana Rao and Venkateswarlu (1988) conducted a trial at Rajendranagar, Andhra Pradesh and reported that the total bean yield increased with increase in N level up to 60 kg N ha^{-1}. Beyond this level the yield increase was of lesser magnitude. The lack of adequate response to N application might be due to medium level of organic matter in the soil.

The average castor bean yield could be increased from 300 to 700 kg ha^{-1} by adopting high-level management such as application of optimum dose of fertilizer (50 kg N +30 kg P_2O_5 ha^{-1}) and improved weed management (four times blade harrowing and two times hand weeding) and pest management in Hyderabad, Andhra Pradesh (Vishnumurthy, 1998).

Patel *et al.* (1991) conducted a study and reported that application of 75 kg N ha^{-1} in three splits (50% as basal the remaining 50% in two equal splits at 40 and 70 DAS) gave the highest seed yield of 2440 kg ha^{-1}, but was on par with treatments N_{100} (4 equal splits), N_{75} (4 equal splits) and N_{75} (2 equal splits). The increase in seed yield may be attributed to greater length of main spike and number of effective spikes per plant. Three or four irrigation in the post-rainy season during crop growing period is required in well-drained soils of North Gujarat. Urea being highly soluble and rapidly leachable, hence 3 splits of 75 kg N ha^{-1} (N_{75} ½ +¼+¼) gave 7.16 % higher yield over N_{75} ½ + ½ and 14.14 % higher yield over N_{75} as basal. Mathukia and Modhwadia (1993) also observed that nitrogen application in three equal splits was found advantageous over full dose as basal. Thus application of 75 kg N ha^{-1} in three splits appeared to be optimum. Days to 50% flowering of castor varieties was delayed by 2 to 9 days at the highest level of nitrogen, but was unaffected by no nitrogen in Andhra Pradesh (Vijaya Kumar Bhosekar, 1990). Early flowering by 4.2 days recorded in Bhagya variety than in Aruna. This difference could be due to their varietal character and also due to agronomic manipulations.

Vijay Kumar and Shiva Shankar (1992) stated the total bean yield of castor varieties increased with increase in N level but nitrogen levels (30, 60, 90 kg ha^{-1}) were found to be on par with each other and only 60 and 90 kg N ha^{-1} were significantly superior over control. The lack of adequate response to nitrogen application might be due to medium N status of the soil. They also stated that the number of capsules per plant significantly increased with increase in nitrogen up to 60 kg ha^{-1} and it was 25 % more than no nitrogen

Rao *et al* (1995) conducted a trial in Rajasthan and stated that application of 75 kg N ha^{-1} and 22 kg P_2O_5 ha^{-1} gave significantly higher seed yield by 12 per cent compared with unfertilized control when sown during 2^{nd} fortnight of July. As the soil was poor in N and medium in phosphorus, early application of fertilizer to the crop might have helped in formation of primordia for its reproductive growth and stimulated seed setting. However, application of fertilizer did not affect the 100-seed weight and oil content. Significantly higher seed yield by 12 % was noticed by fertilizer application compared with unfertilized control. GCH-4 showed significantly higher seed yield at harvest (240

DAS) by 46 %, 100-seed weight by 76 % and oil content by 3 % compared with Aruna when sown during 2nd fortnight of July. Aruna did not respond significantly to N fertilizer application. However, GCH-4 responded significantly to fertilizer application for seed yield by 17 % and oil yield by 19 % compared with unfertilized control. Lack of response of Aruna to fertilizer application may be attributed to its yield potential (2720 kg ha^{-1}), being well below the productivity level of GCH-4 (3690 kg ha^{-1}) sustained by the initial soil fertility (high N and medium P).

Ashok Kumar *et al.* (1995) conducted a trial at IARI, New Delhi under rainfed conditions and stated that application of farmyard manure proved superior to control but inferior to that of fertilizer and bio-fertilizer. A linear trend was observed in each case, with superiority of $N_{40}P_{80}$ to other fertility treatments. In Dharwad (Karnataka) Ramji Bind and Patil (1997) conducted a trial on castor during kharif and found that GCH-4, recorded higher seed yield as compared to other genotypes TMV-5 and SH-41. This is attributed to higher values of yield components like number of spikes per plant, spike length, number of capsules per plant and 100-seed weight.

Baby Akula and Bapi Reddy (1998) conducted a trial in Southern Telangana zone and reported that split application of 40 kg N, half as basal and half at 30-35 DAS, gave more yield than application of 40 kg N in a single dose. Split application of nitrogen has increased the nitrogen use efficiency by 64 % and produced 4.3 kg of more castor seed per kg of nitrogen applied than applying entire 40 kg N in single dose as basal. The mean castor yield over locations and season revealed highest yield of GAUCH-1 (1400 kg ha^{-1}) was 17.7 % per cent higher than the variety Aruna and 20.2 per cent over local (DOR, 1983).

From the literature it is concluded that GCH-4 hybrid was found to be having the highest yielding ability than other varieties. Some studies indicated that there was response up to 80 kg N ha^{-1}. Split application of nitrogen had improved the castor yields to a greater extent than application of entire nitrogen as basal. Some others stated that response to nitrogen was up to 60 kg N ha^{-1}. Beyond that there was no response, which was likely due to medium level of organic matter. Some others stated that castor yield can be improved if nitrogen is applied at the rate of 60-80 kg N ha^{-1} in three splits. Since the risk bearing capacity of farmers is very poor it is better to go for split application than entire dose as basal. 40-60 kg N ha^{-1} is found to be optimum i.e. half as basal and remaining half as top-dressing at 30-35 DAS. Application of N fertilizers under irrigated conditions will help to boost the yield components and finally the bean yield. Literature pertaining to different cultivars like DCS-9, GAUCH-1 and GCH-4 was lacking.

2.4 EFFECT OF IRRIGATION ON YIELD AND YIELD COMPONENTS

Improved varieties and hybrids require a total of 750 to 1250 mm of water, depending on local conditions. Castor uses soil moisture more effectively when N P and K fertilizers are given (Singh and Ramakrishna, 1975). Time of irrigation is important for there should be no water stress, once the primary raceme had flowered. Adequate soil moisture during flowering is essential, especially when temperatures are likely to rise above 35°C for any period. Shortage of moisture during this period will result in high proportion of lighter seed. Irrigation is not required once majority of capsules had been formed, or 21-28 days prior to harvest. Irrigation can also increase absorption of PAR of leaves, due to an increase in total leaf area. This activity has been shown to be highest in the morning and evening, and lowest at midday. Adequate moisture supplies promoted the development of both male and female flowers without altering the sex ratio.

The castor crop quite often faces fluctuating rainfall resulting in periods of moisture stress thus responsible for fluctuating yields. During the rainy season in semi-arid tropics, there can be periods of decreased or no rainfall. Under such conditions the degree of reduction in yield is dependent on duration and intensity of intermittent drought and stage of the crop that experiences moisture stress. The ill effects of moisture stress in dryland crops can be mitigated by selection of suitable varieties and also evolving suitable agronomic techniques.

Wali *et al.* 1988 conducted a study during Kharif in Red loam soils of Raichur and reported that irrigated castor produced significantly higher seed yield (2130 kg ha^{-1}) than rainfed castor. This was attributed due to higher values of yield attributing characters like yield per plant and 100 seed weight. Irrigated castor gave 57 % higher seed yield than rainfed treatment. In Gujarat, it was reported that capsules per plant is the only character which is positively correlated with seed yield, irrespective of the management practices (Patel and Jaimini, 1991)

Subba Reddy *et al.*, 1996 conducted a pivotal trial in Telangana region of Andhra Pradesh and stated that vegetative stage, formation of primary spikes and secondary spikes were the most sensitive stages for moisture stress in reducing the bean yield of castor. Castor under stress-free environment i.e., protective irrigation of 50 mm each during early stress (0-45 DAS), mid stress (45-90 DAS) and terminal stress periods recorded 42 % additional bean yields over the rainfed environment. Supplemental irrigation of 5cm either at early or mid stress period gave 26 % additional bean yield than rainfed crop followed by extra nitrogen fertilizer application after relief from early stress period. Increased bean yield of castor under varied management practices at different moisture stress periods were attributed to enhancement of yield components such as spike length, number of capsules and test weight of beans.

The favourable soil water balance of 0.8 IW/CPE ratio (Irrigation water depth/cumulative pan evaporation) aided the crop plants to increase their heights and branches per plant in castor grown in Telangana region of Andhra Pradesh (Sudhakar and Praveen Rao, 1998). Irrigation in turn helped to put forth more LAI, thus contributing to more dry matter per plant at 0.8 IW/CPE ratio over 0.2, 0.4 and 0.6 IW/CPE ratio. The improved growth performances by castor under 0.8 IW/CPE might have been responsible for significantly higher yield attributes. Irrigated castor recorded higher yield and yield attributing characters than when compared with rainfed crop. Irrigating the castor crop during flowering of primaries gave higher yield than the rainfed castor crop. Confirming studies indicated that irrigating the castor crop at 0.8 IW/CPE had recorded more dry matter per plant and thus contributing for significantly higher yield and yield attributes.
It helps us to increase the efficiency of applied N P and K. Both the N application and irrigation are able to hasten the yield and yield components, which will finally promote the yield. Literature on performance of various castor cultivars suited to Telangana region under irrigated conditions was lacking. Dry matter production, partitioning to various plant parts was also lacking.

2.5 INTERACTION EFFECT OF IRRIGATION AND NITROGEN ON YIELD AND YIELD COMPONENTS OF CASTOR CULTIVARS

According to Kittock Williams, (1967) nitrogen application to irrigated castors in Nebraska reduced the incidence of leaf spot, and increased the yield. But at high levels of nitrogen application i.e. 180 kg per hectare adversely affected oil content. However oil formation in the seed is most active between 20-70 days after flowering and throughout this period nutrient supply must be adequate. Information on the performance of high yielding varieties and hybrids of castor at different levels of nitrogen is limited under the agroclimatic conditions in the castor growing belt of Telangana region of Andhra Pradesh.

Highest seed yield of 2130 kg ha^{-1} and stalk yield of 2470 kg ha^{-1} was recorded by GCH-4 with application of 100 kg N ha^{-1} but these were at par with 75 kg N ha^{-1} (Thadoda *et.al.*,1996). However, both these levels were found significantly superior than application of 50 kg N ha^{-1}. The highest seed and stalk yields obtained under higher level of nitrogen was probably due to improvement and development of growth and yield attributes viz. plant height, number of spikes per plant, number of capsules per spike, length of main spike and 100 seed weight.

Assured irrigation increased the yield by 18.9 per cent over rainfed castor in Telangana region. Timing of irrigation is important. Irrigation on 85^{th} day (flowering of primary spikes) had helped in the formation of more spikes (Vijay Kumar and Shiva Shankar, 1992). The number of capsules per plant significantly increased with an increase in the level of N up to 60 kg ha^{-1} and it was nearly 25 % more than without N. The lack of adequate response to N application might be due to initial medium N level (Vijaya Kumar Bhosekar, 1992).

2.6 NUTRIENT UPTAKE, OIL AND PROTEIN CONTENT

It is important to say about rapeseed as it helps us to conclude regarding oil content on N application. Applied nitrogen increased the formation of N containing protein precursors so that protein formation competes more strongly for photosynthates. As a result, less of the photosynthates are available for fat synthesis. In rape-seed, oil content decreased with increase in the nitrogen level. The oil content increased up to N_{100} and later showed a declining trend.

At Rajendranagar, Hyderabad, Madhusudana Rao and Venkateswarlu (1988) conducted a trail and reported that oil content of castor bean increased with increase in fertility level up to 30 kg N ha^{-1} and further increase in dose of N reduced the oil content progressively. In general oil yield increased due to irrigation and nitrogen levels. Assured irrigation and application of 30 kg N ha^{-1} registered higher oil yield over rainfed and no nitrogen respectively. Same authors reported that N and P uptake by castor was significantly higher under assured irrigation than the rainfed conditions. This may be due to the higher dry matter production with irrigation. The uptake of potassium was significantly varied due to irrigation and plant density but not due to nitrogen levels. Higher N content at harvest in seed samples than that of plant samples was noticed in Aruna castor sown during first week of August in Telangana region of Andhra Pradesh. It was due to higher demand of nutrients by seeds and translocation of nutrients into reproductive parts from vegetative parts (Uma Devi *et al.*,1991). Nitrogen content in both plant and seed sample is not significantly influenced by either nitrogen levels or tillage. Nitrogen application at the rate of 80 kg ha^{-1} recorded higher mean P content (0.38 %) in seed samples but lower mean P content in plant samples (0.15 %). Among N levels N_{80}

recorded lower mean K content (1.87 %) in plant samples in contrast to phosphorus content. Lower K content in seed samples (0.66 %) were recorded in control (N_0). Uptake by the whole plants at harvest was 11 to 48 kg N ha^{-1}, 1.0 to 6 kg P ha^{-1} and 12 to 43 kg K ha^{-1}. Among the N levels, successive increments of N levels up to 80 kg N ha^{-1} significantly increased N, P and K uptake progressively over control.

Mathukia and Modhwadia (1995) reported higher N P K contents and uptake due to N fertilization in castor crop and stated that P content was maximum without N application by N_{40} and N_{80}. The contents of N, P and uptake of N P K increased with increase in level of N application.

Castor producing an average seed yield of 1700 kg ha^{-1} had removed about 50 kg N, 20 kg P_2O_5 and 16 kg K_2o (Jacob and Vexkull, 1958) and 80 kg N, 18 kg P_2O_5, 32 K_2O kg were removed at seed yield of 2000 kg ha^{-1}.

Excess nitrogen application to oilseed crops reduces the oil percentage. In case of castor there was no increase in oil percentage up to 100 kg N ha^{-1}. Further with the increase in nitrogen dose there was decrease in oil percent. Irrigation and nitrogen applied castor crop recorded higher percentage of oil content than when compared with rainfed crop without nitrogen application. However, there is paucity of information on N P and K uptake at different crop growth stages by various plant parts.

2.7 EFFECT OF PLANTING DENSITY ON CASTOR YIELDS

Spacing between plants adapted for planting castor plays an important role in boosting the yields. Closer spacing can result in considerable damage to branches and shallow lateral roots during cultivation. Closer spacing also tends to reduce the height and promote more even growth. Branching may also be suppressed and ripening becomes more even. The optimum population density is largely determined by the amount of rainfall received in a given area.

Purshotam Rao *et al.*, (1989) conducted a trial at Haryana under rainfed conditions and found that the average yield of castor was highest when it was planted at a row spacing of 100 x 30 cm (33,000 plants ha^{-1}) with two rows of green gram. Similarly Singh and Singh (1988) reported that inter cropping of castor with green gram produced higher total seed yield compared to sole castor. Under conditions of drought the inter crop of green gram failed in all the treatments due to severe moisture stress. However, castor seed yield was highest (1630 kg ha^{-1}) when it was planted at a spacing of 100 x 50 cm (20,000 plants/ha). It is because of lack of competition between plants and between rows for moisture, nutrients and space for root growth and sunlight. Vijaya Kumar Bhosekar (1992) stated that the increase in spikes by 27 %, capsules by 49 % and test weight by 3.3 % at wider spacing (60 x 45 cm) compared with closer spacing (60x30 cm) may be due to less competition for nutrients, light and moisture among the plants at wider spacing.

Ashok Kumar *et al.*, (1995) conducted a trial at IARI New Delhi, on sandy loam soils under rainfed conditions and stated that castor as a sole crop (100 cm between rows) proved superior to the pearl millet and castor inter crop in growth and development. Castor as a sole crop sown at wider spacing and without any inter crop proved to be the best. Subba Reddy *et al.* (1996) conducted a trial in rainfed alfisols of Central Research institute for dryland Agriculture (CRIDA) farm, Hyderabad with castor (GAUCH-4) during kharif seasons and stated that castor with 75,000 plants per hectare recorded the highest bean yield of 1153 kg ha^{-1} in 1990 and 1350 kg ha^{-1} in 1991. There was no variation in bean yields of castor between plant densities of 75 to 38 thousands per hectare in 1990 and also within plant densities of 75 to 50 thousands per hectare in1991. The highest bean yield of castor at 75 to 50 thousands plants per hectare over other range of populations was due to increased production of growth components such as dry matter and leaf area index, consequently resulting in higher nitrogen up take and rainfall use efficiency of seed and total biomass during different crop growth stages. Thus castor with 50 to 75 thousands plants per hectare is found optimum for getting stabilizing bean yields under rainfed conditions.

Thadoda *et al.*, (1996) conducted a study on response of castor GCH-4 to planting geometry under rainfed condition on clayey soils sown during August. They stated that the spacing 90 x 60 cm gave the highest seed yield of 2380 kg ha^{-1} and stalk yield of 2790 kg ha^{-1} but remained statistically similar with 60 x 60 cm and 90 x 45 cm. The lowest seed and stalk yields were obtained at 120 x 60 cm spacing. The appreciable increase in seed and stalk yields in favor of 90 x 60 cm spacing was probably due to adequate interception of sunlight by the crop canopy even at low level of illumination, consequently higher rates of photosynthesis and ultimately increase in yield.

Narkheda *et al.*, (1983) stated that the higher values of yield attributes under widely spaced plants, could not increase the yield as against the narrow spaced plants. The reason for reduction in seed and stalk yields under closer spacing of 60 x 45 cm would be the narrow planted crop invariably had lower values of growth and yield contributing characters under study.

It was concluded that 60 x 45 cm spacing recorded higher yield and yield attributes than 60 x 30 cm, which was due to less competition for nutrients, light and moisture among the plants at wider spacing. It is very difficult to confirm the results due to confounding between density and row spacing. However there is little information available regarding the performance of castor at various spacing under stress free moisture conditions (irrigated conditions). Partitioning of dry matter studies on castor is also scanty.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

The field experiments on "Crop growth and development of castor cultivars under optimal and sub-optimal water and nitrogen conditions in Telangana region" was carried out at ICRISAT center Patancheru, Hyderabad to study the following aspects.

1. "Effect of water regimes and nitrogen levels on castor cultivars" during *kharif* season of 1997 and 1998.

Initially the project was planned with a view to develop a castor model and extra experiments on sowing dates and planting density were carried out. So the dates of sowing and planting density experiments were carried out for one year for data generation and to develop model. Extra data will be used for model development in near future. Due to lack of special programme on castor the title of the project was changed and model development part was deleted from the project work.

2. "Effect of dates of sowing on castor cultivars" from later part of *rabi* season 1996 to later part of *rabi* 1997.

3. "Effect of planting density on castor yields" during *rabi* season of 1997.

The farm is located at an altitude of 545 m above mean sea level, 17^{0} 19^{1}N latitude and $78^{\circ}23^{1}$ East longitude.

3.1 WEATHER DURING THE CROP PERIOD

The meteorological data from November 1996 to January 1999 was recorded in a class 'A' meteorological observatory situated at ICRISAT,

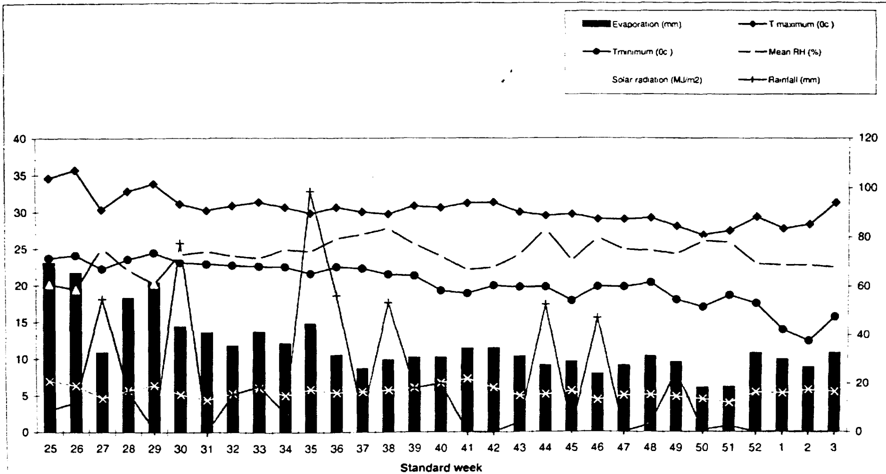


Fig : 3.1 Weekly meteorological data during *Kharif* season 1997 - 1998

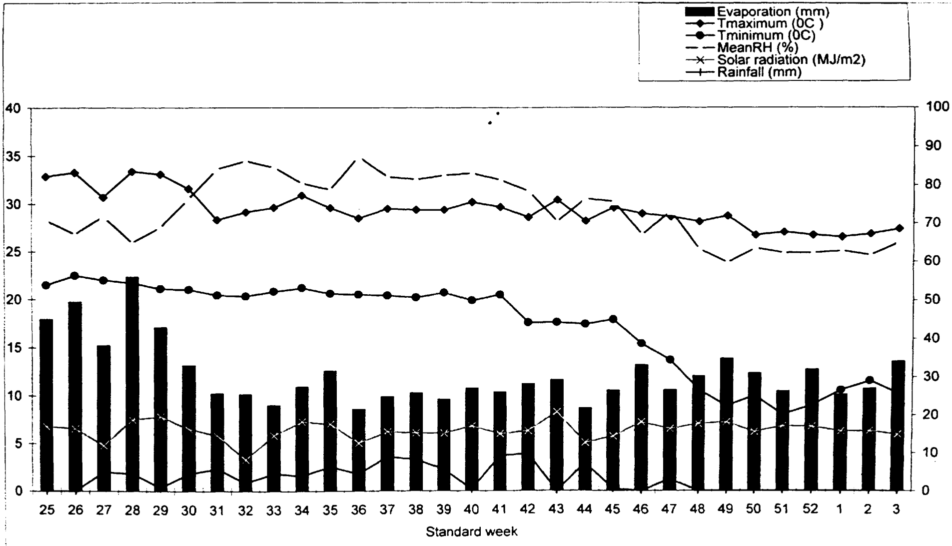


Fig : 3.2 Weekly meteorological data during Kharif season 1998 - 1999

Patancheru, 1.5 km from the experimental site. Weekly means for the period are presented in Figure 1-2 and Appendix-I & II.

Rainfall

There was 598.8 mm of rainfall during in first year (*kharif* 1997-98) while it was 946.2 mm during the subsequent year (*kharif* 1998-99). The mean maximum and minimum temperatures recorded during the first year's study were 35.7 ^{0}C and 12.5 ^{0}C and were 33.4 ^{0}C and 8 ^{0}C respectively during the second year. The mean relative humidity ranged from 58 to 83 percent during first year, whereas it varied from 59 to 87 percent during second year.

3.2 EXPERIMENTAL DETAILS

3.2.1 Layout of the Experiment

The dates of sowing experiment, which was started during late *rabi* season 1996 was laid-out in completely randomised block design with twenty four treatment combinations, replicated four times (Fig. 1). The treatments include six dates of sowing and four cultivars as given below

TREATMENT DETAILS

Effect of sowing dates on castor cultivars

Six dates of sowing:	D1	: 07-11-1996
	D2	: 06-01-1997
	D3	: 03-04-1997
	D4	: 04-06-1997
	D5	: 10-07-1997
	D6	: 04-09-1997

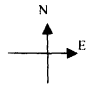
Four cultivars :	C1	:	Aruna
	C2	:	DCS-9
	C3	:	GAUCH-1
	C4	:	GCH-4

Fig 3.3 LAYOUT OF DATES OF SOWING EXPERIMENT

R4	D2C4	D3C1	D2C2	D3C4	D4C1	D5C3	D1C4	D1C2	D5C4	D1C3	D5C2	D6C4
	D4C2	D2C3	D6C3	D1C1	D4C4	D3C2	D2C1	D4C3	D5C1	D6C2	D6C1	D3C3
R3	D5C4	D2C2	D3C3	D5C2	D3C2	D4C4	D2C3	D1C1	D6C2	D4C3	D5C3	D6C4
	D6C3	D6C1	D5C1	D1C4	D2C1	D1C3	D2C2	D3C4	D4C1	D2C4	D4C2	D3C1
R2	D1C4	D4C3	D3C1	D5C3	D6C3	D6C4	D1C2	D2C3	D3C4	D1C3	D4C4	D4C2
	D2C2	D1C1	D2C4	D5C2	D4C1	D3C2	D5C4	D6C1	D5C1	D6C2	D3C3	D2C1
R1	D4C1	D5C2	D4C4	D2C1	D5C1	D4C2	D3C4	D6C1	D1C1	D1C2	D1C4	D3C1
	D2C3	D2C4	D6C2	D6C3	D5C4	D4C3	D5C3	D3C2	D6C4	D3C3	D2C2	D1C3

C1 = Aruna
C2 = DCS-9
C3 = GAUCH-1
C4 = GCH-4

D1 = 07.11.1996
D2 = 06.01.1997
D3 = 03.04.1997
D4 = 04.06.1997
D5 = 10.07.1997
D6 = 04.09.1997



Rainfed

N2	N2	N1	N1
C1	C4	C2	C3
C2	C3	C1	C4
C4	C3	C4	C3
C1	C2	C1	C2
C2	C1	C1	C2
C4	C3	C3	C4
C2	C4	C3	C2
C3	C1	C1	C4

Irrigated

N1	N1	N2	N2	
C4	C2	C4	C3	R4
C1	C3	C1	C2	
C2	C4	C3	C1	R 3
C3	C1	C2	C4	
C2	C1	C1	C2	R2
C4	C3	C3	C4	
C2	C4	C3	C2	R1
C3	C1	C1	C4	

Fig : 3.4 LAY OUT PLAN OF KHARIF 1997

Main plot treatments : Water regimes (2) (i) W1: Rainfed
(ii) W2 : Irrigated at 0.75 IW/CPE ratio

Sub Plot : Nitrogen level (2) (i) N1=10 kg N/ha
(ii) N2=60 kg N/ha

Cultivars in factorial set up
C1 : Aruna
C2 : DCS-9
C3 : GAUCH-1
C4 : GCH-4

Gross Plot Size : 9 x 10 = 90 m^2

N

→ E

Irrigated

C3	C2	C1	C3
C1	C4	C4	C2
C2	C1	C1	C2
C4	C3	C4	C3
C4	C3	C3	C4
C1	C2	C2	C1
C3	C1	C2	C4
C2	C4	C1	C3
N2	**N2**	**N1**	**N1**

Rainfed

C4	C2	C2	C1
C1	C3	C4	C3
C3	C1	C1	C4
C2	C4	C3	C2
C1	C4	C3	C1
C3	C2	C2	C4
C2	C1	C4	C2
C4	C3	C1	C3
N1	**N1**	**N2**	**N2**

R2

Fig: 3.5 LAY OUT PLAN OF KHARIF 1998

Design	:	CRBD		
Replications	:	4		
Plot Size	:	Gross plot	:	9.0 x 10.0 m
		Net plot	:	7.5 x 5.0 m
Spacing	:	75 x 25 cm		

Effect of water regimes and nitrogen levels on castor cultivars *Kharif* – 1997 and *Kharif* – 1998

Main Plot	:	Water Regimes	-	W1 - Rainfed
			-	W2 - Irrigated at IW/CPE ratio 0.75
Sub-Plot	:	Nitrogen Levels	-	N_1 - 10 kg N ha^{-1}
				N_2 - 60 kg N ha^{-1}
Sub-Sub-Plot	:	Cultivars	-	C1 - Aruna
				C2 - DCS-9
				C3 - GAUCH-1
				C4 - GCH-4

Design	:	Split plot		
Replications	:	4		
Plot size	:	Gross plot	:	9.0 x 10 m
		Net plot	:	7.5 x 5.0 m
Spacing	:	75 x 25 cm		
Sowing date	:	26-6-1997 & 26-6-98		

Effect of planting densities on castor yields

Cultivar	:	GCH-4		
3 Densities	:	75 x 25 cm	=	5.5 plants/m^2
		75 x 10 cm	=	13 plants/m^2
		75 x 75 cm	=	1.7 plants/m^2
Design	:	RCBD		

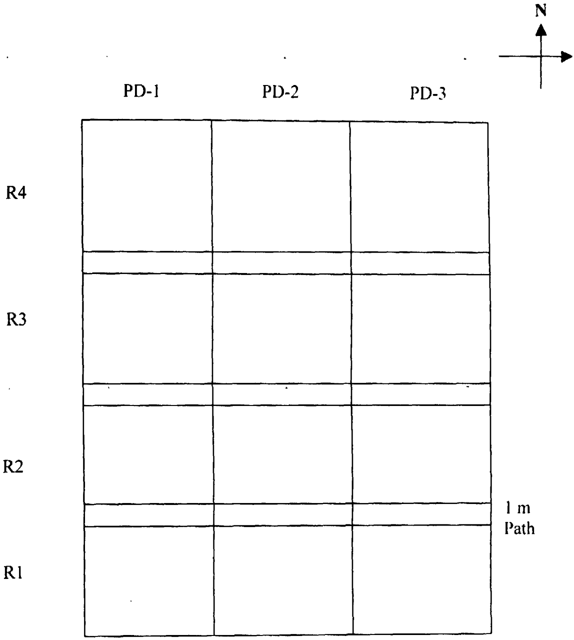


Fig 3.6 LAYOUT PLAN OF PLANTING DENSITY EXPERIMENT

PD-1 = 75 x 25 cm Spacing = 55,000 plants/ha
PD-2 = 75 x 10 cm Spacing = 1,30,000 plants/ha
PD-3 = 75 x 75 cm Spacing = 17,000 plants/ha

Variety : GCH-4

Replications : 4

Plot size : Gross plot : 9.0 x 10.0 m
Net plot : 4.5 x 8 m

Sowing date : 17-7-1997

3.2.2 SOIL

The soil was an alfisol (Clay loam) with good drainage. The composite samples of soil collected at random from the experimental field prior to the layout were analyzed for the physico-chemical properties. The chemical analysis indicated that the soil was slightly acidic in reaction, low in available N and medium in P and K. The soil physical properties of the experimental site are as follows

1. Bulk density : 1.673 g/cc

2. Field capacity : 0.18 g/g

3. Permanent wilting point : 0.14 g/g (Moisture content based on oven dry weight)

Table 3.1 Soil chemical properties of experimental site

Depth of the soil (cm)	P^H	Electrical conductivity (dSm^{-1})	Available Olsen 'P'kg ha^{-1})	Exchangeable K (kg ha^{-1})	NO_3 nitrogen (kg ha^{-1})	NH_4 nitrogen (kg ha^{-1})
K-97						
0-15	6.67	0.18	39.8	407.3	71.6	31.8
15-30	6.54	0.10	17.6	321.8	32.2	14.3
30-60	6.45	0.09	15.5	360.0	43.2	9.6
Average	6.55	0.12	24.3	362.9	49.0	18.5
K-98						
0-15	6.94	0.23	26.1	306.0	117.9	18.2
15-30	7.40	0.12	11.5	200.3	35.8	19.4
30-60	7.35	0.11	4.1	396.0	62.1	42.8
Average	7.23	0.15	13.2	300.8	71.9	26.8
Method of estimation	Glass electrode PH meter (Jackson, 1967)	Conductivity bridge (Jackson, 1973)	Olsen's method (Olsen et al.1954)	Flame photometry (Jackson, 1967)	Kjeldahl's Method (Kenney and Nelson, 1982)	Kjeldahl's Method (Kenney and Nelson, 1982)

3.4 CULTIVATION DETAILS

3.4.1 Previous crop history

Prior to the dates of sowing experiment, the field was fallow for two years. For the planting density experiment, the field had previously grown with a pigeon pea crop. Pigeon pea was grown before sowing *kharif* -97 and sorghum was grown before *kharif* -98 sowing.

3.4.2 Preparatory cultivation

The experimental field was prepared for sowing by working once with a tractor- drawn disc plough, followed by disc harrow twice. Then the tractor-drawn cultivator was run along and across the field. The land was leveled with a tractor-drawn leveler after removing the dried stubble and weeds. Finally ridges and furrows were made at a spacing of 75 cm. The plots were laid as per the layout plan.

3.4.3 Seeds and sowing

Seeds of selected castor cultivars Aruna, DCS-9, GAUCH-1, and GCH-4 were hand dibbled at a depth of 4-5 cm and 25 cm apart within the row and covered with soil, maintaining an inter-row spacing of 75 cm. The morphological characters of cultivars used in the field experiment are given in Table 3.2.

Table 3.2 Morphological characters of castor cultivars used in the field experiment

Character	Salient features of castor cultivars			
	Aruna	DCS-9	GAUCH-1	GCH-4
Stem colour	Red	Red	Green	Light Red
Duration (days)	120-150	90-150	180-240	210-240
Seed oil content (%)	51	49	50	48
Yield (kg ha^{-1})	960	1020	1700	2200

3.4.4. Fertilizer application

The experimental site was applied with the recommended dose of fertilizers (60 kg N ha^{-1} & 40 kg P_2O_5 ha^{-1}) Nitrogen was applied in three splits (50 % N as basal, 25 % N at 30 days after sowing (DAS) and 25 % at 60 DAS) by spot application. In N_1level (10 kg N ha^{-1}) during *kharif*-97 and *kharif*-98, the entire nitrogen was applied as basal.

3.4.5 Irrigation

All the experiments were uniformly irrigated immediately after sowing to assist in seed germination. Subsequent irrigations were given based on the requirement in case of dates of sowing and planting density experiments. In case of *kharif* -97 and *kharif*-98 experiments, irrigations were given only to irrigated blocks based on irrigation water depth / cumulative pan evaporation (IW / CPE) ratio of 0.75. The crop received a total of two irrigations during *kharif*-1997 and one irrigation during the entire crop growing season of *kharif*-1998.

3.4.6 Interculture operations

The weeds present between and within the plant rows were removed manually at 20, 55 and 80 DAS.

3.4.6 Plant protection

The crop was well protected when semi-loopers became a problem due to heavy rainfall during October by spraying Monocrotophos @ 0.05% and from Botrytis disease by spraying Carbendazim @ 0.05%.

3.4.7 Harvesting

The crop was harvested in 2-3 pickings based on the maturity of the main spikes and spikes that are formed on secondaries, tertiaries and quaternaries. The harvested spikes were sun-dried and threshed by manual beating with sticks. The threshed produce was winnowed and seeds cleaned. The seed and stalk yields for each plot were recorded separately after drying.

3.5 OBSERVATIONS RECOREDED

3.5.1 Meteorological Observations

Weather data (maximum & minimum temperatures, rainfall, solar radiation) were recorded at the meteorological observatory, ICRISAT center Patancheru which is 1.5 Km to the experimental site.

3.5.1.1 Heat units (Growing degree days)

Heat units expressed as growing degree-days (GDD) were calculated by the formula given below:

$$GDD = \sum ni \; \frac{(Tmax + Tmin)}{2} - Tb$$

Where $\sum ni$	=	Number of days taken for a phenophase
Tmax and Tmin	=	Daily maximum and minimum temperature
Tb	=	Minimum threshold temperature (10^0 c) for castor (Vijaya Kumar *et al*, 1997)
GDD	=	Growing degree days

Tb is also called as "Base temperature" and this is defined as the temperature below which, the physiological activity of the crop ceases.

3.5.1 Light observation

Radiation: The canopy light interception was measured by tube-solarimeter placed across the rows covering half canopy of one plant from one row and half canopy of another plant from another row. These solarimeters are used to record the radiation (0.35-2.5 μm) transmitted through the crop canopy at 2 minutes intervals, using the data collection system. Radiation readings are recorded and stored at hourly intervals by automatic millivoltmeter. Pyranometer was placed just above the crop level to measure the total incoming radiation (I_0) and tube solarimeters are placed 5 cm just above the ground to measure the radiation transmitted to ground (I). Dead leaves are removed at weekly intervals from plants around the tube-solarimeters, so that the radiation transmitted from green leaf area only was recorded. Daily totals and individual tube calibration factors were used to calculate the proportion of incident radiation intercepted in each plot.

The light interception (LI) was calcutated using following equation

$$LI (\%) = 100 - \% \text{ transmitted}$$

$$\%\text{Transmitted} = I / I_0$$

Where I = Total incoming radiation

I_0 = Radiation transmitted to ground

3.5.2 Soil moisture

Soil moisture at 0-15 cm depth was recorded gravimetrically and beyond 15 cm by neutron probe. For taking neutron-probe readings accession tubes were inserted at the centre of each plot. These tubes were inserted before sowing the crop. Probe readings were taken before and after irrigation and also after each rainy day.

3.5.3 Growth Parameters

Plant samples were collected at fifteen days interval until harvest for recording following growth parameters.

3.5.3.1 Plant height (cm)

Five plants were randomly selected within the net plot area and were tagged to record the plant height. This was recorded in the field (non-destructive sampling) and was measured on the main stem from the base of the plant (ground surface) to the tips of the apical bud.

3.5.3.2 Leaf area, leaf area index, leaf, stem and spike biomass

Three plants were sampled at random from every plot at 15 days interval starting from 15 DAS upto harvest. These plants were separated into components of leaf, stem and pod mass. The leaf area was measured with LI - 3100, area meter (Li - COR Inc. Nebraska,USA). The leaf mass, stem mass and pod mass were recorded separately after oven drying at 80^0C or 48 hours and computed for a square meter area. The leaf area index (LAI) was calculated by using the following formula:

$$LAI = \frac{\text{Leaf area}}{\text{Unit ground area}}$$

3.5.4 Days to 50 % flowering and maturity

50 % flowering	:	Day on which 50 percent of plants in one metre row length flowered.
Physiological maturity	:	Day on which capsules show characteristic browning.

3.5.5 Yield and yield components

3.5.5.1 Number of capsules per Spike

The total number of capsules from five tagged plants in each plot were counted and average number of capsules per plant was recorded.

3.5.5.2 Main spike length

The length of the spike was measured from the main spikes.

3.5.5.3 Number of spikes per Plant

Number of spikes present on the entire plant were counted before harvesting.

3.5.5.4 100 seed weight (g)

A random sample of 100 seeds from each net plot was taken and weighed in grams.

3.5.6 Seed yield (kg ha^{-1})

It was calculated from net plot area and computed on a per hectare basis and expressed as kg ha^{-1}.

3.5.7 Harvest index (HI)

This was calculated by using the following formula:

$$H.I. = \frac{\text{Seed yield ha}^{-1}}{\text{Total bio mass ha}^{-1}} \times 100$$

3.5.8 Chemical analysis

3.5.8.1 Plant analysis

Five randomly selected plants of destructive samples were collected, dried and ground and 1g of plant sample was used for N analysis using micro kjeldhal method after digesting the organic matter by H_2SO_4 and H_2O_2 (Piper, 1950) Phosphorus and potassium contents were determined in the extracts after digesting the plant material with the triacid mixture HNO_3; H_2SO_4; $HClO_4$ (9:2:1) (Piper, 1950)

P-content: The phosphorus content in the plant digest was determined by vanado-molybdo-phosphoric colorimetric method on Klettsummerson photoelectric colorimeter (Piper, 1950)

K-content: The potassium content was determined on Elico Flame photometer (Piper, 1950).

The N, P and K content were expressed in percentage. The uptake of N, P and K by Castor crop were computed as follows:

$$\text{Uptake of Nutrient (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content x Total dry matter (kg ha}^{-1}\text{)}}{100}$$

3.5.9 Quality characters of castor seed

3.5.9.1 Protein estimation

The quantitative determination of protein by Technicon Auto Analyser (TAA) involve the conversion of organic nitrogen into ammonia by digesting the sample with sulphuric acid using the block digestor (BD 40). Ammonical nitrogen reacts with sodium phenate in presence of sodium hypochlorite to form indo-phenol blue complex. This color complex is measured at 660 nm.

3.5.9.2 Oil estimation (Soxhlet method)

Oil content in the seed was estimated by Soxhlet apparatus, using a suitable solvent. The extracted oil was separated by evaporating the solvent.

3.5.10 Statistical analysis

The observations from the experiment were subjected to statistical analysis i.e. RBD (factorial concept) for dates of sowing experiment, Split–plot design for "Effect of water regimes and nitrogen levels on castor cultivars"(*kharif*-1997 & *kharif* 1998), and RCBD for planting density experiment using GENSTAT package (Gomez and Gomez, 1984).

RESULTS

CHAPTER-1V

RESULTS

The field experiments of the project "Crop growth and development of castor cultivars under optimal and sub-optimal water and nitrogen conditions in Telangana region" were carried out at ICRISAT center Patancheru, Hyderabad.

1. "Effect of dates of sowing on castor cultivars" from later part of *rabi* season 1996 to later part of *rabi* 1997

2. "Effect of water regimes and nitrogen levels on castor cultivars" during *kharif* season of 1997 and 1998 and

3. "Effect of planting density on castor yields" during *rabi* season of 1997.

EFFECT OF DATES OF SOWING ON CASTOR CULTIVARS

4.1 GROWTH PARAMETERS

4.1.1 Plant height at final harvest

The data on mean plant height at final harvest is presented in Table 4.1 Plant height increased progressively from sowing to harvest of castor. Interaction effect of sowing and cultivars was also significant at all crop growth stages. The plant height of castor cultivars ranged from 48.9 cm (DCS-9) to 63.1 cm (GCH-4). GCH-4 recorded 29 % taller plant height than DCS-9. Among different sowings the plant height ranged from 46.8 cm (November sowing) to 69.2 cm (June sowing).

Among the various interactions GCH-4 sown during the first week of June recorded the talleer plant height of 77.2 cm. Least plant height of 43.3 cm was recorded by DCS-9 sown during November.

Table 4.1 Interaction effect of sowing date on plant height (cm) of four Castor cultivars at final harvest

Cultivars	Sowing Date						
	Nov	Jan	April	June	July	Sep	Mean
Aruna	46.7	50.5	59.6	74.1	67.8	57.0	59.3
DCS-9	43.3	42.2	48.8	59.5	52.8	46.9	48.9
GAUCH-1	43.8	45.0	53.9	65.8	58.8	60.2	54.6
GCH-4	53.2	53.3	62.8	77.2	71.7	60.2	63.1
Mean	46.8	47.7	56.3	69.2	62.8	56.1	

	Cultivars	Sowing Dates	Cultivar x Sowing date
S.Ed. ±	0.71	0.86	1.73
CD (0.05)	1.40	1.72	3.45

Table 4.2 Interaction effect of sowing date on LAI at 45 DAS of four Castor cultivars

Cultivars	Sowing Date						
	Nov	Jan	April	June	July	Sep	Mean
Aruna	0.220	0.182	0.270	0.320	0.318	0.228	0.256
DCS-9	0.200	0.217	0.547	0.716	0.693	0.379	0.459
GAUCH-1	0.218	0.245	0.573	0.739	0.736	0.414	0.488
GCH-4	0.313	0.235	0.630	0.810	0.795	0.494	0.549
Mean	0.238	0.219	0.505	0.646	0.636	0.379	

	Cultivars	Sowing Dates	Cultivar x Sowing date
S.Ed. ±	0.01	0.01	0.03
CD (0.05)	0.02	0.03	0.05

Table 4.3 Interaction effect of sowing date on LAI at 105 DAS of four Castor cultivars

Cultivars	Sowing Date						
	Nov	Jan	April	Jun	July	Sep	Mean
Aruna	0.270	0.679	0.855	1.163	0.892	0.773	0.772
DCS-9	0.370	0.984	1.290	1.522	1.346	1.072	1.097
GAUCH-1	0.361	1.250	1.320	2.050	1.978	1.289	1.375
GCH-4	0.285	1.521	2.171	2.476	2.259	1.867	1.763
Mean	0.322	1.109	1.409	1.803	1.169	1.250	

	Cultivars	Sowing Dates	Cultivar x Sowing date
S.Ed. ±	0.01	0.02	0.30
CD (0.05)	0.03	0.03	0.48

Table 4.4 Interaction effect of sowing date on Total drymatter production (gm^{-2}) of four Castor cultivars at 45 DAS

Cultivars	Sowing Date						
	Nov	Jan	April	June	July	Sep	Mean
Aruna	19.8	30.5	39.1	45.4	44.2	35.4	35.7
DCS-9	18.5	29.1	40.0	49.0	46.3	35.8	36.5
GAUCH-1	19.1	35.4	49.7	53.4	49.5	38.6	41.0
GCH-4	27.8	44.4	66.8	71.6	68.3	55.1	55.7
Mean	21.3	34.0	48.9	54.9	52.1		41.2

	Cultivars	Sowing Dates	Cultivar x Sowing date
S.Ed. ±	1.03	1.26	2.52
CD (0.05)	2.05	2.52	5.04

Table 4.5 Interaction effect of sowing date on Total drymatter production (gm^{-2}) of four Castor cultivars at harvest

Cultivars	Sowing Date						
	Nov	Jan	April	June	July	Sep	Mean
Aruna	158.1	202.2	224.0	244.0	237.0	219.7	214.4
DCS-9	183.7	200.0	231.0	237.9	252.3	220.9	221.0
GAUCH-1	273.6	297.1	318.6	380.8	337.2	306.2	318.9
GCH-4	282.5	294.4	340.5	413.4	362.3	311.8	335.2
Mean	224.7	248.5	278.6	319.1	297.3	264.7	

	Cultivars	Sowing Dates	Cultivar x Sowing date
SED ±	2.36	3.12	6.24
CD (0.05)	5.08	6.24	12.45

4.1.2 Leaf area index at 45 and 105 DAS

LAI differed significantly due to cultivars, sowing dates and their interaction (Table 4.2). The LAI ranged from 0.256 (Aruna) to0.549 (GCH-4). Out of six sowing dates June sowings recorded the higher LAI of 0.646 and lower by the November sowings. June sown GCH-4 recorded the highest LAI of .810, which recorded 153 % more than that of Aruna.

LAI differed significantly at 105 DAS due to cultivars, sowing dates and their interaction (Table 4.3). LAI of castor cultivars ranged from 0.772 (Aruna) to 1.763 (GCH-4). Among the different sowings, June sowings recorded the higher LAI of 1.803 and the lowest LAI by November sowings. Interaction effect indicated that GCH-4 recording the highest LAI of 2.476, which was 112 % higher than Aruna in June sowings.

4.1.3. Total above ground drymatter production (gm^{-2}) at 45 DAS and harvest

The TDMP differed significantly due to cultivars, sowing dates and their interaction at 45 DAS (Table 4.4). The TDMP among cultivars ranged from 55.7 gm^{-2} (GCH-4) to 35.7 gm^{-2} (Aruna). Among different sowings June sowing recorded the highest TDMP of 54.9 gm^{-2}. Significant interaction effect indicated that June sown GCH-4 recorded 71.6g m^{-2} of TDMP, which was 57 % higher than the Aruna.

The TDMP at harvest (Table 4.5) also differed significantly due to cultivars, sowing dates and interaction. The TDMP of cultivars ranged from 214.4 g m^{-2} (Aruna) to 335.2 gm^{-2} (GCH-4). GCH-4 castor cultivar recorded 56 % more TDMP than Aruna. Regarding sowing dates, June sowings recorded the highest TDMP of 319.1gm^{-2}, which was 42 % higher than November sowings. Significant interaction between cultivars and sowings dates indicated that June sown GCH-4 recorded maximum TDMP of 413.4 g m^{-2} which was 69 % higher than Aruna. Lowest total drymatter was recorded by Aruna sown during the month of first week of November (158.1gm^{-2}).

4.2 YIELD ATTRIBUTES

4.2.1 Main spike length (cm)

The main spike length of castor differed significantly due to cultivars and sowing dates. The main spike length ranged from 22 cm (GCH-4) to 17.1 cm (Aruna). GCH-4 recorded 28 % taller main spike length than Aruna. June sowings recorded 72 % more spike length than November sowings. Among the various interactions GCH-4 sown during the first week of June recorded 26.8 cm of spike length, which was 23.5 % taller than Aruna. Aruna castor sown during the first week of November was recorded the spike length of 12.7 cm.

4.2.2 Spikes per plant

Out of the four cultivars, GCH-4 recorded the highest number of spikes per plant (4.7). GCH-4 recorded 11 % more number of spikes than Aruna. Among the sowing dates the spikes per plant ranged from 3.9 to 5.3.

Significant interaction between cultivars and sowing dates indicated that June sown GCH-4 recorded the highest number of spikes per plant (5.5), which was 5 % more than the Aruna.

Table 4.6 Interaction effect of sowing date on main spike length of four Castor cultivars

Cultivars	Sowing Date						
	Nov	Jan	April	June	July	Sep	Mean
Aruna	12.7	13.5	19.0	21.7	20.5	15.3	17.1
DCS-9	13.0	13.9	21.3	23.9	22.2	16.6	18.5
GAUCH-1	14.6	17.1	23.5	24.6	24.2	20.1	20.7
GCH-4	15.9	19.0	24.4	26.8	25.2	21.0	22.0
Mean	14.1	15.9	22.0	24.3	23.0	18.3	

	Cultivars	Sowing Dates	Cultivar x Sowing date
S.Ed. ±	0.25	0.20	0.49
CD (0.05)	0.49	0.40	0.98

Table 4.7 Interaction effect of sowing date on number of spikes per plant of four Castor cultivars

Cultivars	Sowing Date						
	Nov	Jan	April	June	July	Sep	Mean
Aruna	3.6	3.9	4.1	5.2	4.5	4.1	4.2
DCS-9	3.9	4.0	4.4	5.4	4.8	3.9	4.4
GAUCH-1	3.9	4.0	4.5	5.2	4.8	4.3	4.5
GCH-4	4.1	4.1	4.8	5.5	5.1	4.5	4.7
Mean	3.9	4.0	4.5	5.3	4.8	4.2	

	Cultivars	Sowing Dates	Cultivar x Sowing date
S.Ed. ±	0.08	0.06	0.16
CD (0.05)	0.16	0.13	0.32

4.2.3 Capsules per spike

The number of Capsules per spike differed significantly due to cultivars and sowing dates. The number of capsules per spike ranged from16.9 (Aruna) to 20.4 (GCH-4). GCH-4 recorded 20 % more capsules per spike. June sowings recorded the maximum number of capsules per spike (24.7)

Interaction effect between cultivars and sowing dates revealed that June sown GCH-4 recorded 27 % more number of capsules per spike than Aruna. November sown GCH-4 recorded the lowest number of capsules per spike (12.4).

4.2.4 100 seed-weight (g)

The 100 seed weight ranged from 23.63 g (Cv.GCH-4) to 16.44 g (Aruna). Among the various sowing dates June sown cultivars recorded 13 % higher 100 seed weight than November sowings. The significant interaction among cultivars and sowing date indicated that June sown GCH-4 recorded 25.45 g of 100 seed weight, which was 14 % higher than November sowings. GCH-4 sown during June recorded 31 % more 100 seed weight than Aruna.

4.3 Seed yield (kg ha^{-1})

The seed yield of Castor differed significantly due to cultivars and sowing dates. Among the different cultivars GCH-4 recorded seed yield of 2280 kg ha^{-1}, which was 66 % higher than the lowest yielder Aruna (1370 kg ha^{-1}). June sown cultivars recorded 46 % more seed yield than November sowings.

The cultivars and sowing dates interaction was also significantly. June sown GCH-4 recorded 2749 kg ha^{-1}of seed yield, which was 57 % higher than Aruna.

Table 4.8 Interaction effect of sowing date on number of Capsules per spike of four Castor cultivars

Cultivars	Sowing Date						
	Nov	Jan	April	June	July	Sep	Mean
Aruna	13.8	15.5	16.3	21.6	18.3	15.9	16.9
DCS-9	14.4	16.4	17.1	23.9	21.2	16.8	18.3
GAUCH-1	12.9	14.8	18.9	25.5	22.1	18.0	18.7
GCH-4	12.4	15.1	23.1	27.5	24.9	19.6	20.4
Mean	13.4	15.5	18.8	24.7	21.6	17.6	

	Cultivars	Sowing Dates	Cultivar x Sowing date
S.Ed. ±	0.47	0.38	0.93
CD (0.05)	0.93	0.76	1.85

Table 4.9 Interaction effect of sowing date on 100 Seed-Weight of four Castor cultivars

Cultivars	Sowing Date						
	Nov	Jan	April	June	July	Sep	Mean
Aruna	15.14	15.41	16.35	19.29	16.74	15.69	16.44
DCS-9	20.55	21.02	20.72	22.85	22.23	22.79	21.69
GAUCH-1	22.05	21.27	22.85	22.94	22.27	22.21	22.27
GCH-4	22.28	23.42	23.99	25.45	23.68	22.96	23.63
Mean	20.00	20.28	20.98	22.63	21.23	20.91	

	Cultivars	Sowing Dates	Cultivar x Sowing date
S.Ed. ±	0.19	0.16	0.39
CD (0.05)	0.39	0.32	0.77

Table 4.10 Interaction effect of sowing date on Seed Yield (kg ha^{-1}) of four Castor cultivars

Cultivars	Sowing Date						
	Nov	Jan	April	June	July	Sep	Mean
Aruna	1087	1182	1400	1750	1530	1310	1370
DCS-9	1220	1359	1581	1899	1817	1485	1560
GAUCH-1	1760	1861	2073	2464	2160	1957	2040
GCH-4	1954	2051	2313	2749	2445	2189	2280
Mean	1505	1613	1842	2204	1988	1735	

	Cultivars	Sowing Dates	Cultivar x Sowing date
S.Ed. ±	13.77	11.24	27.53
CD (0.05)	27.46	22.42	54.93

GCH-4 sown during first week of June recorded 40 % higher seed yield than the November sowing. Of all the interactions Aruna variety sown during in the first week of November recorded the lowest seed yield of 1087 kg ha^{-1}.

4.4 Harvest Index

The harvest index varied significantly due to cultivars, sowing dates and interaction. The harvest index ranged from 37.5 (GCH-4) to 33.6 (Aruna). There was 11 % increase in harvest index of GCH-4 than Aruna. June sowings recorded the highest index of 36.5, which was 4 % higher than November sowings. June sown GCH-4 recorded 38.2 per cent harvest index, which was 9 % higher than that of Aruna (35.0).

4.5 Heat units (GDD) accumulated at 50 % flowering and maturity

The data presented in table 4.12 indicated that the heat units accumulated by various castor cultivars under different sowings to reach 50 % flowering and maturity. Among the six dates, [November 1^{st} week (D1), January 1^{st} week (D2), April 1^{st} week (D3), June 1^{st} week (D4), July 1^{st} week (D5) and September 1^{st} week (D6)] almost all the castor cultivars required more heat units to attain 50 % flowering and maturity during June 1^{st} week of sowing. Both the cultivar GAUCH-1 and GCH-4 accumulated same number of heat units (2978) to attain maturity in June 1^{st} week sowings. Least number of heat units was accumulated by November 1^{st} week sowings.

Table 4.11 Interaction effect of sowing date on Harvest index of four Castor cultivars

Cultivars	Sowing Date						
	Nov	Jan	April	June	July	Sep	Mean
Aruna	32.28	32.88	34.05	35.03	34.10	33.55	33.64
DCS-9	35.65	34.65	36.10	36.15	35.98	36.03	35.76
GAUCH-1	35.20	35.25	36.00	36.40	36.03	35.95	35.81
GCH-4	36.85	37.03	37.40	38.23	37.95	37.33	37.47
Mean	35.00	35.20	35.89	36.45	36.02	35.72	

	Cultivars	Sowing Dates	Cultivar x Sowing date
S.Ed. ±	0.23	0.19	0.47
CD (0.05)	0.47	0.38	0.93

4.12 Accumulated Heat units (GDD) of four castor cultivars at 50 % flowering and at maturity

At 50 % Flowering

Treatments	Nov	Jan	April	June	July	Sep
C_1	698 (61)	914 (70)	1156 (58)	1200 (64)	1152 (67)	959 (61)
C_2	650 (55)	860 (67)	1018 (52)	1149 (55)	1102 (58)	914 (58)
C_3	760 (68)	1058 (78)	1364 (68)	1266 (68)	1262 (74)	1056 (68)
C_4	717 (63)	1006 (75)	1219 (61)	1216 (65)	1216 (71)	1024 (66)

At maturity

Treatments	Nov	Jan	April	June	July	Sep
C_1	1875 (149)	2393 (147)	2286 (118)	2273 (131)	2087 (129)	2095 (147)
C_2	1360 (118)	1749 (117)	1979 (101)	1824 (102)	1724 (104)	1737 (118)
C_3	2447 (182)	3019 (179)	3076 (166)	2978 (179)	2761 (180)	2522 (177)
C_4	2714 (195)	3288 (191)	3249 (177)	2978 (179)	2771 (181)	2796 (193)

Note: Figures in parenthesis indicate the number of days.

4.1 Growth parameters

4.1.1 Plant height at maturity

The plant height differences due to cultivars, nitrogen levels and water regimes were significant in the two years of study. Plant height ranged from 68 cm (DCS-9) to81.8 cm (GCH-4). GCH-4 was 20 % taller than DCS-9 cultivar. The plant height increased by about 4 % due to nitrogen fertilization, while irrigation had increased the plant height by about 7 %. The two-way and the three-way interactions were found to be significant in two years of study (Table No 4.13 - 4.15 & Fig 4.1 – 4.2). As compared to DCS-9, GCH-4 recorded a mean plant height of 85.3 cm under irrigated conditions and 78.4 cm in rainfed conditions.

Plants were 5 % taller when they received 60 kg N ha^{-1} than when they received 10 kg N ha^{-1}. At 60 kg N ha^{-1}, irrigated castor recorded a mean plant height of 78.3 cm, which was 6 % taller than the rainfed castor. Two years mean data indicated that the plant height of GCH-4 at 10 kg N ha^{-1} (84.1) was 19 % taller than DCS-9. GCH-4 at 60 kg N ha^{-1} was 22 % taller than DCS-9. GCH-4 at 60 kg N ha^{-1} was 6 % taller than 10 kg N ha^{-1}. From the three-way interaction, irrigated GCH-4 was 25 % taller with 60 kg N ha^{-1} than DCS-9, while it was 20 % taller at 10 kg N ha^{-1}. Under rainfed conditions the mean plant height of GCH-4 was 19 % greater than DCS-9 at 60 kg N ha^{-1}.

4.1.2 LAI

The table no 4.16 – 4.18 & Fig 4.3 – 4.4 will represent the mean values of LAI. There were significant differences in LAI at 45 DAS due to cultivars, nitrogen levels and

Table 4.13 Effect of water regimes, nitrogen levels and cultivars on Plant height at maturity (cm)

Year	Cultivars					
	C1	C2	C3	C4	S.Ed.±	CD (0.05)
1997-98	77.5	67.2	68.5	80.9	0.84	1.71
1998-99	79.2	68.8	69.1	82.7	0.82	1.66
Mean	78.4	68.0	68.8	81.8		

Year	Nitrogen Levels			
	N1	N2	S.Ed.±	CD (0.05)
1997-98	71.5	75.1	0.63	1.53
1998-99	73.2	76.7	0.80	1.96
Mean	72.4	75.9		

Year	Water regimes			
	W1	W2	S.Ed.±	CD (0.05)
1997-98	70.4	76.2	1.29	4.13
1998-99	72.3	77.5	0.13	0.40
Mean	71.4	76.9		

Table 4.14 Interaction effects of water regimes, nitrogen levels and cultivars on Plant Height at maturity (cm)

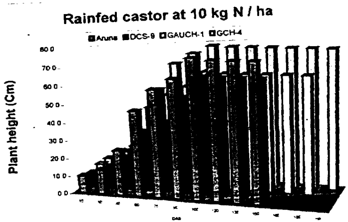
Year	N x W		C x W			
	N1	N2	C1	C2	C3	C4
1997-98						
W1	68.8	72.7	74.3	64.9	64.6	77.2
W2	74.3	77.4	78.7	69.5	72.5	84.7
	S.Ed.±	**CD (0.05)**		**S.Ed.±**	**CD (0.05)**	
	1.44	3.85		1.66	3.85	
1998-99						
W1	70.2	74.2	76.3	66.8	66.2	79.6
W2	76.2	79.1	82.0	70.5	71.3	85.9
	S.Ed.±	**CD (0.05)**		**S.Ed.±**	**CD (0.05)**	
	0.81	1.96		1.01	2.05	

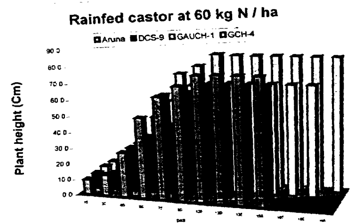
Year	Nitrogen levels x Cultivars (NxC)							
	1997-98				1998-99			
	C1	C2	C3	C4	C1	C2	C3	C4
N1	77.1	65.9	67.7	79.3	78.4	67.2	67.5	79.9
N2	79.9	67.4	69.4	82.6	79.9	69.6	71.1	85.6
	S.Ed.±	**CD (0.05)**			**S.Ed.±**	**CD (0.05)**		
N xC	1.21	2.44			1.28	2.63		

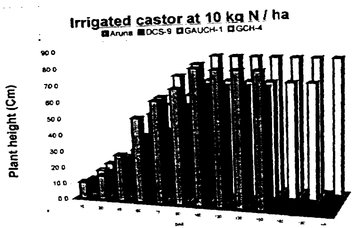
Table 4.15 Interaction effect of water regimes, nitrogen levels and cultivars on Plant Height at maturity (cm)

	W1		W2	
	N1	N2	N1	N2
1997-98				
C1	73.8	75.8	80.4	82.0
C2	63.1	66.6	68.8	68.2
C3	63.5	65.6	71.9	73.1
C4	74.7	79.7	83.9	85.4
S.Ed.±	2.05			
CD (0.05)	4.35			
1998-99				
C1	75.3	77.4	81.6	82.4
C2	64.4	69.2	69.9	70.1
C3	64.5	68.0	70.5	74.1
C4	76.8	82.4	82.9	88.7
S.Ed.±	1.63			
CD (0.05)	3.31			

Fig 4.1 Plant height as influenced by water regimes and nitrogen levels *Kharif*-1998







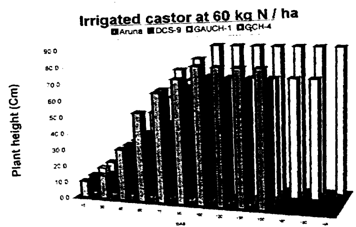


Fig 4.2 Plant height as influenced by water regimes and nitrogen levels *Kharif*-1997

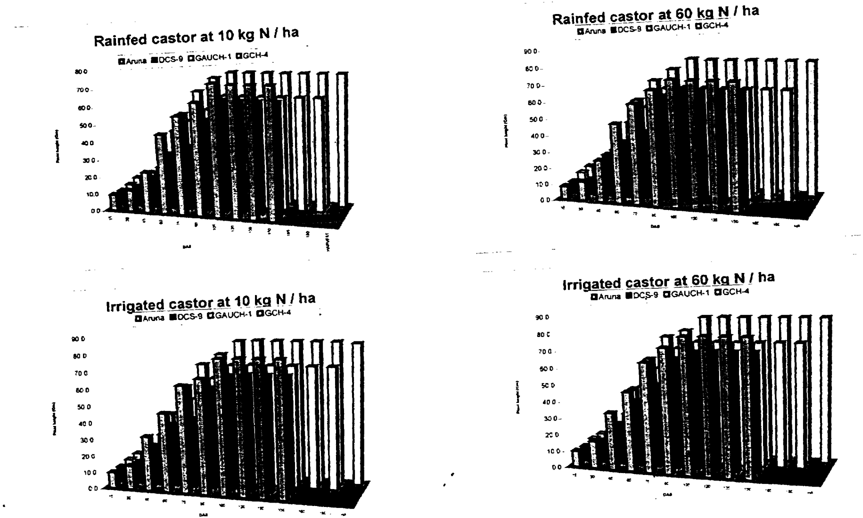


Table 4.16 Effect of water regimes, nitrogen levels and cultivars on LAI at 45 DAS

Year	Cultivars					
	C1	C2	C3	C4	S.Ed.±	CD (0.05)
1997-98	0.752	0.803	0.992	1.016	0.007	0.013
1998-99	0.749	0.802	0.992	1.017	0.007	0.013
Mean	0.751	0.803	0.992	1.017		

Year	Nitrogen Levels			
	N1	N2	S.Ed.±	CD (0.05)
1997-98	0.872	0.909	0.004	0.009
1998-99	0.873	0.906	0.004	0.009
Mean	0.873	0.908		

Year	Water regimes			
	W1	W2	S.Ed.±	CD (0.05)
1997-98	0.853	0.928	0.03	0.009
1998-99	0.877	0.903	0.02	0.006
Mean	0.873	0.908		

Table 4.17 Interaction effects of water regimes, nitrogen levels and cultivars on LAI at 45 DAS

Year	N x W		C x W			
	N1	N2	C1	C2	C3	C4
1997-98						
W1	0.840	0.866	0.714	0.765	0.954	0.978
W2	0.903	0.953	0.789	0.840	1.029	1.054
	S.Ed.±	CD (0.05)		S.Ed.±	CD (0.05)	
	0.005	0.013		0.009	0.019	
1998-99						
W1	0.863	0.890	0.735	0.789	0.979	1.004
W2	0.883	0.922	0.763	0.815	1.004	1.029
	S.Ed.±	CD (0.05)		S.Ed.±	CD (0.05)	
	0.004	0.009		0.008	0.016	

Year	Nitrogen levels x Cultivars (NxC)							
	1997-98				1998-99			
	C1	C2	C3	C4	C1	C2	C3	C4
N1	0.704	0.792	0.983	1.008	0.704	0.734	0.985	1.011
N2	0.799	0.814	1.001	1.025	0.794	0.810	0.998	1.023
	S.Ed.±	CD (0.05)			S.Ed.±	CD (0.05)		
N x C	0.008	0.017			0.009	0.018		

Table 4.18 Interaction effect of water regimes, nitrogen levels and cultivars on LAI at 45 DAS

	W1		W2	
	N1	N2	N1	N2
1997-98				
C1	0.673	0.756	0.736	0.843
C2	0.761	0.770	0.824	0.857
C3	0.951	0.958	1.014	1.045
C4	0.977	0.981	1.039	1.068
S.Ed.±	0.012			
CD (0.05)	0.025			
1998-99				
C1	0.693	0.777	0.715	0.811
C2	0.784	0.794	0.804	0.826
C3	0.975	0.983	0.995	1.014
C4	1.002	1.007	1.021	1.038
S.Ed.±	0.012			
CD (0.05)	0.024			

4.3 LAI as *influenced* by water regimes and nitrogen levels *Kharif*-1997

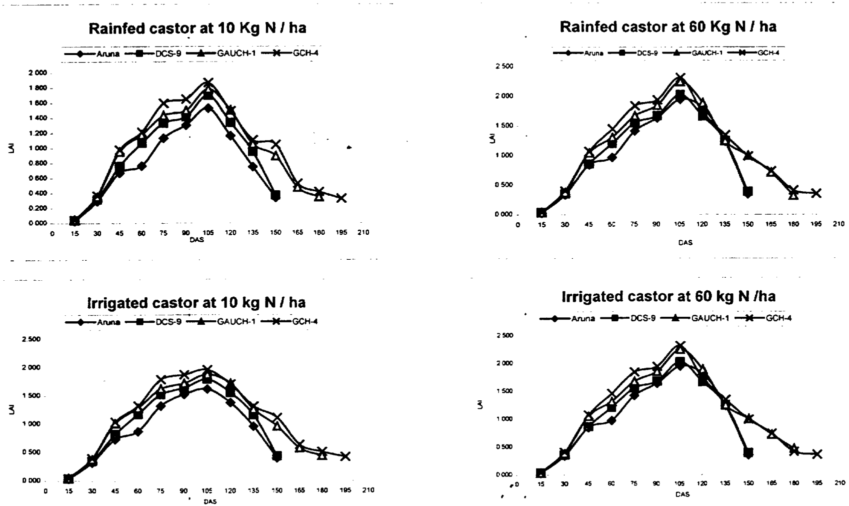
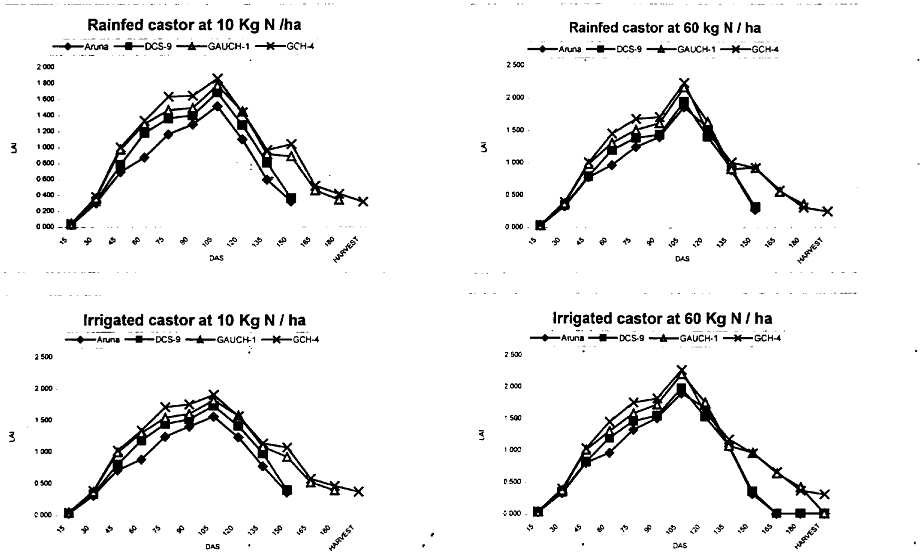


Fig 4.4 LAI as influenced by water regimes and nitrogen levels *Kharif*-1998



water regime in two years of study. The mean LAI at 45 DAS ranged from 1.017 (GCH-4) to 0.751 (Aruna). LAI increased by 4 % by nitrogen (60 Kg N ha^{-1}) application. Irrigation increased the LAI by 5 % over rainfed and recorded a mean LAI of 0.916 in two years of study.

The interaction effect between cultivars and water regime was found significant in both years of study. Rainfed GCH-4 recorded a mean LAI of 0.978, which was 36 % higher than Aruna. Under irrigated conditions GCH-4 registered a mean LAI of 1.054, which was 34 % higher than Aruna.

Significant nitrogen and water regime interaction revealed that 60 kg N ha^{-1} has increased the mean LAI of cultivars from 0.840 (10 kg N ha^{-1}) by 3 % under rainfed conditions and it is by 5 % under irrigated conditions. Nitrogen and cultivars interaction was also significant. GCH-4 registered 43 % increase in mean LAI than Aruna at 10 kg N ha^{-1} while it was 27 % increase at 60 kg N ha^{-1}. Interaction effect of water regime, nitrogen levels and cultivars were also found to be significant. Under irrigated conditions GCH-4 at 60 kg N ha^{-1} recorded mean LAI of 1.053, which was 27 % higher than Aruna, while it was 42 % higher under rainfed conditions.

The table 4.19 – 4.21 will represent the LAI at 105 DAS. There were significant differences in LAI at 105 DAS due to cultivars, nitrogen levels and water regimes in the two years. Mean for two years ranged from1.726 (Aruna) to 2.080 (GCH-4). There was 18 % increase in LAI by nitrogen application. Irrigation increased the LAI from 1.888 (rainfed) to 1.953. The significant interaction between cultivars and water regimes indicated that irrigated GCH-4 LAI was 20 % higher mean LAI than Aruna. Irrigated cultivars at 60 kg N ha^{-1} recorded 18.5 % more mean LAI than at 10 kg N ha^{-1}

The interaction effect between cultivars and nitrogen levels was also significant. At 60 kg N ha^{-1} GCH-4 recorded 19 % more mean LAI than at 10 kg N ha^{-1}. The three-way interaction was also significant. Irrigated GCH-4 at 60 kg N ha^{-1} recorded 2.292 mean LAI, which was 18 % higher than at 10 kg N ha^{-1}. Rainfed GCH-4 at 60 kg N ha^{-1} recorded 22 % higher mean LAI than at 10 kg N ha^{-1}.

4.1.3 Total above ground drymatter production

Table 4.22 – 4.24 indicates the data for to total dry matter production at 45 DAS. GCH-4 recorded mean drymatter of 78.4 gm^{-2}, which was 17 % higher than Aruna. Nitrogen application increased the drymatter from 70.0 g m^{-2} (10 kg N ha^{-1}) to 75.1 g m^{-2} (60 kg N ha^{-1}) Irrigation had increased the mean drymatter by 6 % over rainfed.

Significant cultivar and water regime interaction indicated that rainfed GCH-4 had 15.5 % higher dry matter than Aruna. With irrigation GCH-4 had 16 % more dry matter than Aruna. At 60 kg N ha^{-1} irrigated cultivars recorded 7 % more dry matter than rainfed. At 60 kg N ha^{-1} GCH-4 recorded mean dry matter of 84 gm^{-2}, which was 85 % higher than at 10 kg N ha^{-1}.

Cultivars, nitrogen levels and water regime interaction was also significant. Irrigated GCH-4 at 60 kg N ha^{-1} recorded highest drymatter of 82.50 g m^{-2}, which was 14 % higher than Aruna. Rainfed GCH-4 at 60 kg N ha^{-1} recorded 13 % higher dry matter than Aruna the lowest yielder.

Table 4.25 – 4.27 indicates the dry matter data at 105 DAS. The differences between cultivars, nitrogen levels and water regimes were significant. GCH-4 recorded the highest (2 years) dry matter of 324 g m^{-2}, which was 32 % higher than the lowest

Table 4.19 Effect of water regimes, nitrogen levels and cultivars on LAI at 105 DAS

Year	Cultivars					
	C1	C2	C3	C4	S.Ed.±	CD (0.05)
1997-98	1.740	1.872	2.020	2.091	0.019	0.039
1998-99	1.712	1.840	1.991	2.070	0.019	0.039
Mean	1.726	1.856	2.005	2.080		

Year	Nitrogen Levels			
	N1	N2	S.Ed.±	CD (0.05)
1997-98	1.764	2.094	0.008	0.019
1998-99	1.745	2.073	0.007	0.019
Mean	1.754	2.084		

Year	Water regimes			
	W1	W2	S.Ed.±	CD (0.05)
1997-98	1.892	1.972	0.013	0.041
1998-99	1.884	1.934	0.012	0.038
Mean	1.888	1.953		

Table 4.20 Interaction effects of water regimes, nitrogen levels and cultivars on LAI at 105 DAS

Year	N x W		C x W			
	N1	N2	C1	C2	C3	C4
1997-98						
W1	1.722	2.060	1.690	1.823	1.972	2.050
W2	1.800	2.131	1.781	1.910	2.062	2.142
	S.Ed.±	CD (0.05)	S.Ed.±	CD (0.05)		
	0.011	0.027	0.027	0.055		
1998-99						
W1	1.710	2.052	1.687	1.816	1.972	2.048
W2	1.759	2.093	1.736	1.862	2.017	2.092
	S.Ed.±	CD (0.05)	S.Ed.±	CD (0.05)		
	0.007	0.019	0.024	0.048		

Year	Nitrogen levels x Cultivars (NxC)							
	1997-98				1998-99			
	C1	C2	C3	C4	C1	C2	C3	C4
N1	1.571	1.742	1.832	1.911	1.541	1.714	1.801	1.885
N2	1.910	1.982	2.210	2.270	1.883	1.965	2.188	2.254
	S.Ed.±	CD (0.05)			S.Ed.±	CD (0.05)		
N x C	0.028	0.056			0.025	0.050		

Table 4.21 Interaction effect of water regimes, nitrogen levels and cultivars on LAI at 105 DAS

	W1		W2	
	N1	N2	N1	N2
1997-98				
C1	1.531	1.875	1.620	1.952
C2	1.690	1.952	1.792	2.070
C3	1.790	2.170	1.873	2.250
C4	1.872	2.241	1.962	2.310
S.Ed.±	0.035			
CD (0.05)	0.070			
1998-99				
C1	1.516	1.862	1.567	1.905
C2	1.689	1.944	1.739	1.986
C3	1.776	2.168	1.825	2.209
C4	1.862	2.337	1.909	2.274
S.Ed.±	0.034			
CD (0.05) 0.069				

Table 4.22 Effect of water regimes, nitrogen levels and cultivars on total above ground drymatter production at 45 DAS (gm^{-2})

Year	Cultivars					
	C1	C2	C3	C4	S.Ed.±	CD (0.05)
1997-98	67.6	71.2	76.2	79.2	1.37	2.78
1998-99	65.9	68.9	74.6	77.5	1.34	2.71

Year	Nitrogen Levels			
	N1	N2	S.Ed.±	CD (0.05)
1997-98	71.4	76.2	1.45	3.54
1998-99	68.6	73.9	1.37	3.34

Year	Water regimes			
	W1	W2	S.Ed.±	CD (0.05)
1997-98	70.6	77.0	0.11	0.34
1998-99	69.4	73.0	0.06	0.19

Table 4.23 Interaction effects of water regimes, nitrogen levels and cultivars on total above ground drymatter production at 45 DAS (gm^{-2})

Year	N x W		C x W			
	N1	N2	C1	C2	C3	C4
1997-98						
W1	70.1	71.1	65.3	65.8	75.5	75.6
W2	76.7	77.4	69.9	72.6	82.9	82.6
	S.Ed.±	CD (0.05)	S.Ed.±	CD (0.05)		
	1.45	3.54	1.68	3.41		
1998-99						
W1	68.6	69.9	64.1	64.8	74.4	74.5
W2	72.3	73.9	67.9	68.4	77.9	78.0
	S.Ed.±	CD (0.05)	S.Ed.±	CD (0.05)		
	1.37	3.34	1.69	3.32		

Year	Nitrogen levels x Cultivars (NxC)							
	1997-98				1998-99			
	C1	C2	C3	C4	C1	C2	C3	C4
N1	64.6	70.0	74.6	77.6	62.9	68.4	72.8	75.5
N2	70.7	72.4	77.8	80.5	68.0	69.3	76.0	79.4
	S.Ed.±	CD (0.05)	S.Ed.±	CD (0.05)				
N x C	2.22	4.57	2.12	4.35				

Table 2.24 Interaction effect of water regimes, nitrogen levels and cultivars on total above ground drymatter production at 45 DAS (gm^{-2})

	W1		W2	
	N1	N2	N1	N2
1997-98				
C1	62.5	68.2	66.7	73.2
C2	67.3	68.4	72.7	76.4
C3	71.0	74.1	78.3	81.5
C4	74.3	76.9	81.0	84.2
S.Ed.±	2.79			
CD (0.05)	5.64			
1998-99				
C1	61.2	66.9	64.7	71.1
C2	66.6	67.6	70.3	71.0
C3	71.4	74.3	75.1	77.7
C4	74.4	77.0	77.6	80.9
S.Ed.±	2.68			
CD (0.05)	5.44			

Table 4.25 Effect of water regimes, nitrogen levels and cultivars on total above ground drymatter production at 105 DAS (gm^{-2})

Year	Cultivars					
	C1	C2	C3	C4	S.Ed.±	CD (0.05)
1997-98	253	291	313	334	2.23	4.52
1998-99	235	272	293	314	2.17	4.39

Year	Nitrogen Levels			
	N1	N2	S.Ed.±	CD (0.05)
1997-98	278	318	1.11	2.71
1998-99	260	297	1.04	2.55

Year	Water regimes			
	W1	W2	S.Ed.±	CD (0.05)
1997-98	278	318	0.11	0.35
1998-99	266	290	0.07	0.22

Table 4.26 Interaction effects of water regimes, nitrogen levels and cultivars on total above ground drymatter production at 105 DAS (gm^{-2})

Year	N x W		C x W			
	N1	N2	C1	C2	C3	C4
1997-98						
W1	260.0	297.0	234.0	271.0	293.0	314.0
W2	297.0	339.0	272.0	311.0	333.0	354.0
	S.Ed.±	CD (0.05)		S.Ed.±	CD (0.05)	
	1.11	2.71		2.73	5.54	
1998-99						
W1	248.0	285.0	223.0	260.0	281.0	301.0
W2	272.0	309.0	247.0	283.0	305.0	326.0
	S.Ed.±	CD (0.05)		S.Ed.±	CD (0.05)	
	1.04	2.55		2.65	5.38	

Year	Nitrogen levels x Cultivars (NxC)							
	1997-98				1998-99			
	C1	C2	C3	C4	C1	C2	C3	C4
N1	233.0	274.0	291.0	315.0	216.0	257.0	272.0	295.0
N2	274.0	307.0	336.0	353.0	255.0	286.0	315.0	332.0
	S.Ed.±	CD (0.05)			S.Ed.±	CD (0.05)		
N x C	2.94	5.94			2.85	5.75		

Table 4.27 Interaction effect of water regimes, nitrogen levels and cultivars on total above ground drymatter production at 105 DAS (gm^{-2})

	W1		W2	
	N1	**N2**	**N1**	**N2**
1997-98				
C1	215	254	250	294
C2	257	286	291	329
C3	272	315	309	357
C4	296	332	334	373
S.Ed.±	4.02			
CD (0.05)	8.11			
1998-99				
C1	204.0	243.0	227.0	266.4
C2	245.0	274.6	269.0	298.0
C3	260.0	303.0	284.1	326.0
C4	283.0	320.0	308.0	344.0
S.Ed.±	3.89			
CD (0.05)	7.87			

yielder Aruna (244 gm^{-2}). Nitrogen increased the mean dry matter from 269.0 g m^{-2} (N_1) to 307 g m^{-2} (N_2). Irrigation significantly increased the dry matter by 11 % more than rainfed.

Cultivar and water regime interaction showed that, irrigated GCH-4 recorded 10 % higher than rainfed. Irrigated castor with 60 kg N ha^{-1} recorded 11 % more in dry matter than the rainfed castor. Significant interaction effect of nitrogen levels and cultivars indicated that GCH-4 with 60 Kg Nha^{-1} registered highest mean dry matter (343 gm^{-2}) which was 12 % higher than GCH-4 with 10 kg Nha^{-1}. The interaction effect of cultivars, nitrogen levels and water regime indicated that irrigated GCH-4 with 60 kg N ha^{-1} recorded mean dry matter of 359 g m^{-2}, which was 11 % higher than 10 kg N ha^{-1}. Under rainfed conditions GCH-4 with 60 kg N ha^{-1} recorded 12 % higher dry matter than at 10 kg N ha^{-1}.

4.2 YIELD COMPONENTS

4.2.1 Main spike length

The data on the mean main spike length is presented in table 4.28 – 4.30. The main spike length differed significantly due to cultivars, nitrogen and water levels. Two years mean spike length ranged from 29.7 cm (GCH-4) to 24.3 cm (Aruna). GCH-4 recorded 22 % increase in spike length than Aruna. 60 kg Nha^{-1} recorded 30.0 cm of main spike length, which was 26 % higher than 10 kg N ha^{-1}. Irrigation significantly increased spike length by about 7 % over the rainfed castor.

Cultivars and water regimes interaction was found to be significant. Two years mean main spike length of GCH-4 was 25 % higher than Aruna under rainfed conditions, but it was only 20 % higher under irrigated conditions. Irrigated GCH-4

Table 4.28 Effect of water regimes, nitrogen levels and cultivars on Main spike length (cm)

Year	Cultivars					
	C_1	C_2	C3	C4	S.Ed.±	CD (0.05)
1997-98	26.4	28.2	29.0	31.8	0.31	0.62
1998-99	22.5	24.3	25.2	27.6	0.20	0.41
Mean	24.3	26.3	27.1	29.7		

Year	Nitrogen Levels			
	N_1	N_2	S.Ed.±	CD (0.05)
1997-98	24.5	33.1	0.15	0.37
1998-99	22.9	27.0	0.06	0.16
Mean	23.7	30.1		

Year	Water regimes			
	W_1	W_2	S.Ed.±	CD (0.05)
1997-98	27.4	30.2	0.01	0.03
1998-99	24.3	25.6	0.02	0.06
Mean	25.9	27.9		

Table 4.29 Interaction effects of water regimes, nitrogen levels and cultivars on Main Spike Length (cm)

Year	N x W		C x W			
	N_1	N_2	C_1	C_2	C3	C4
1997-98						
W_1	23.6	31.2	24.4	26.6	27.7	30.8
W_2	25.4	35.0	27.6	29.8	30.3	32.9
	S.Ed.±	**CD (0.05)**		**S.Ed.±**	**CD (0.05)**	
	0.21	**0.52**		**0.43**	**0.88**	
1998-99						
W_1	22.0	26.6	21.8	23.7	24.6	27.2
W_2	23.7	27.5	23.3	25.1	25.8	28.1
	S.Ed.±	**CD (0.05)**		**S.Ed.±**	**CD (0.05)**	
	0.07	**0.16**		**0.25**	**0.51**	

Year	Nitrogen levels x Cultivars (NxC)							
	1997-98				1998-99			
	C_1	C_2	C3	C4	C_1	C_2	C3	C4
N_1	22.4	24.0	24.6	26.9	20.8	22.4	23.1	25.3
N_2	29.7	32.4	33.5	36.8	24.3	26.4	27.3	30.0
	S.Ed.±		**CD (0.05)**			**S.Ed.±**	**CD (0.05)**	
N x C	**0.40**		**0.82**			**0.26**	**0.52**	

Table 4.30 Interaction effect of water regimes, nitrogen levels and cultivars on Main Spike Length (cm)

	W_1		W_2	
	N_1	N_2	N_1	N_2
1997-98				
C_1	21.8	27.1	23.0	32.3
C_2	23.0	30.2	25.0	34.5
C_3	23.7	31.7	25.5	35.2
C_4	25.9	35.7	27.8	37.9
S.Ed.±	0.57			
CD (0.05)	1.15			
1998-99				
C_1	20.0	23.6	21.5	25.1
C_2	21.5	25.9	23.3	27.0
C_3	22.3	27.0	23.9	27.7
C_4	24.4	30.0	26.1	30.1*
S.Ed.±	0.36			
CD (0.05)	0.73			

recorded mean main spike length of 30.5 cm, which was 4.5 % higher than Aruna. Nitrogen levels and water regime interaction were also significant. At 60 kg N ha^{-1} irrigated castor recorded mean spike length of 31.2 cm, which was 7.5 % higher than rainfed castor.

Significant interaction was observed between nitrogen levels and cultivars. At 10 kg N ha^{-1}, there was 20 % increase in mean spike length of GCH-4 than Aruna, while at 60 g N ha^{-1} it was 23 %. GCH-4 recorded mean spike length of 31.7 cm at 60 kg N ha^{-1}, which was 27 % higher than 10 kg N ha^{-1}. Interaction effect of cultivars, nitrogen levels and water regime was also significant. Two years mean main spike length of irrigated GCH-4 at 60 kg N ha^{-1}, was 34 cm, which was 25 % higher than Aruna.

4.2.2 Spikes per plant

The data regarding the number of spikes per plant is presented in the table 4.31 – 4.33. The number of spikes per plant differed significantly due to cultivars, nitrogen levels and water levels. Two years mean number of spikes per plant ranged from 6.0 (Aruna) to 6.3 (GCH-4). With 60 kg N ha^{-1} there was mean spikes of 6.4, compared with only 5.9 at 10 kg N ha^{-1}. Nitrogen application increased the spikes by about 8 % compared 10 kg N ha^{-1}. Irrigation resulted in 6.6 spikes per plant compared with rainfed condition. Irrigated castor recorded 15 % more number of spikes per plant than rainfed conditions.

Irrigated GCH-4 resulted in 6.8 mean spikes per plant, but only 5.7 under rainfed conditions. GCH-4 had 6.4 mean spikes at 60 kg N ha^{-1} and 5.8 spikes at 10 kg N ha^{-1}.

Table 4.31 Effect of water regimes, nitrogen levels and cultivars on Spikes per plant

Year	Cultivars					
	C1	C2	C3	C4	S.Ed.±	CD (0.05)
1997-98	6.2	6.5	6.1	6.5	0.11	0.22
1998-99	5.8	5.8	6.1	6.1	0.11	0.22
Mean	6.0	6.2	6.1	6.3		

Year	Nitrogen Levels			
	N1	N2	S.Ed.±	CD (0.05)
1997-98	6.0	6.6	0.03	0.08
1998-99	5.7	6.2	0.02	0.04
Mean	5.9	6.4		

Year	Water regimes			
	W1	W2	S.Ed.±	CD (0.05)
1997-98	5.7	6.9	6.3	0.04
1998-99	5.6	6.3	0.02	0.06
Mean	5.7	6.6		

Table 4.32 Interaction effects of water regimes, nitrogen levels and cultivars on spikes per plant

Year	N x W		C x W			
	N1	N2	C1	C2	C3	C4
1997-98						
W1	5.6	5.9	5.5	6.0	5.6	5.8
W2	6.4	7.3	6.9	7.0	6.7	7.1
		S.Ed.±	CD (0.05)	S.Ed.±	CD (0.05)	
		0.04	0.08	0.13	NS	
1998-99						
W1	5.5	5.7	5.3	5.8	5.5	5.7
W2	6.0	6.6	6.2	6.4	6.1	6.5
		S.Ed.±	CD (0.05)	S.Ed.±	CD (0.05)	
		0.02	0.06	0.14	NS	

Year	Nitrogen levels x Cultivars (NxC)							
	1997-98				1998-99			
	C1	C2	C3	C4	C1	C2	C3	C4
N1	5.7	6.3	5.8	6.1	5.5	5.9	5.6	5.8
N2	6.5	6.7	6.4	6.8	6.0	6.3	6.1	6.4
		S.Ed.±	CD (0.05)		S.Ed.±	CD (0.05)		
N x C		0.14	NS		0.14	NS		

Table 4.33 Interaction effect of water regimes, nitrogen levels and cultivars on spikes per plant

	W1		W2	
	N1	N2	N1	N2
1997-98				
C1	5.3	5.7	6.4	7.3
C2	5.8	6.2	6.7	7.2
C3	5.5	5.7	6.2	7.1
C4	5.8	5.9	6.4	7.7
S.Ed.±	0.19			
CD (0.05)	NS			
1998-99				
C1	5.2	5.4	5.8	6.6
C2	5.7	6.0	6.2	6.7
C3	5.4	5.6	5.8	6.5
C4	5.6	5.9	6.0	6.9
S.Ed.±	0.19			
CD (0.05)	NS			

The interaction of water regimes and nitrogen levels was significant in two years of experimentation.

Irrigated cultivars at 60 kg N ha^{-1} had 7.0 spikes per plant which was 19 % higher than 10 kg N ha^{-1} There was 12 % increase in spikes per plant under irrigated conditions at 60 kg N ha^{-1} compared with 10 kg N ha^{-1}, while the increase was only 4 % under rainfed conditions.

Two years mean data indicated that under irrigated conditions the spikes per plant ranged from 6.1 (N_1C_1) to 7.3 (N_2C_4), while under rainfed conditions it ranged from 5.2 (N_1C_1) to 5.9 (N_2C_4). The number of spikes on a plant was similar in both years of study, regardless of whether it was rainfed or irrigated crop.

4.2.3 Capsules per Spike

The data on the mean capsules per spike are presented in table 4.34 – 4.36. The differences in the capsules per spike due to water, nitrogen and cultivars were significant. Significantly higher number of capsules per spike was produced by C_4 over the other cultivars. Maximum number of capsules per spike i.e. 24.4 (1997) and 22.6 (1998) was registered at 60 kg N ha^{-1}, and were found to be significantly higher than 10 kg N ha^{-1}.

Table 4.34 Effect of water regimes, nitrogen levels and cultivars on Capsules per Spike

Year	Cultivars					
	C_1	C_2	C3	C4	S.Ed.±	CD (0.05)
1997-98	19.0	21.5	24.0	25.5	0.31	0.63
1998-99	17.7	19.5	22.3	23.7	0.31	0.62
Mean	18.4	20.5	23.0	24.6		

Year	Nitrogen Levels			
	N_1	N_2	S.Ed.±	CD (0.05)
1997-98	21.8	24.4	0.02	0.05
1998-99	20.0	22.6	0.04	0.10
Mean	20.9	23.5		

Year	Water regimes			
	W_1	W_2	S.Ed.±	CD (0.05)
1997-98	20.6	24.4	0.04	0.12
1998-99	19.4	22.2	0.05	0.15
Mean	20.0	23.3		

Table 4.35 Interaction effects of water regimes, nitrogen levels and cultivars on Capsules per Spike

Year	N x W		C x W			
	N_1	N_2	C_1	C_2	C3	C4
1997-98						
W_1	19.8	21.4	16.7	19.5	22.2	23.9
W_2	23.8	25.1	21.3	23.6	25.7	27.2
	S.Ed.±	**CD (0.05)**		**S.Ed.±**	**CD (0.05)**	
N x W	**0.17**	**0.41**		**0.44**	**0.89**	
1998-99						
W_1	18.7	20.1	16.3	18.0	20.9	22.3
W_2	21.3	23.2	19.1	21.0	23.7	25.0
	S.Ed.±	**CD (0.05)**		**S.Ed.±**	**CD (0.05)**	
N x W	**0.06**	**016**		**0.77**	**0.43**	

Year	Nitrogen levels x Cultivars (NxC)							
	1997-98				1998-99			
	C_1	C_2	C3	C4	C_1	C_2	C3	C4
N_1	18.0	20.5	23.7	25.0	17.0	18.4	21.7	22.9
N_2	20.0	22.6	24.2	26.1	18.5	20.5	22.9	24.5
	S.Ed.±	**CD (0.05)**			**S.Ed.±**	**CD (0.05)**		
N x C	**0.40**	**0.81**			**0.38**	**0.77**		

Table 4.36 Interaction effect of water regimes, nitrogen levels and cultivars on Capsules per Spike

	W_1		W_2	
	N_1	N_2	N_1	N_2
1997-98				
C_1	15.5	18.1	20.6	22.0
C_2	18.1	20.9	22.8	24.3
C_3	22.1	22.3	25.3	26.0
C_4	23.6	24.2	26.5	27.9
S.Ed.±	0.56			
CD (0.05)	1.14			
1998-99				
C_1	15.8	16.9	18.2	20.1
C_2	17.0	19.0	19.9	22.1
C_3	20.5	21.4	22.9	24.5
C_4	21.7	23.0	24.1	26.0
S.Ed.±	0.53			
CD (0.05)	1.08			

The interaction effect between cultivars and water regimes was found significant in two years of study. Maximum number of capsules per spike i.e., 23.9 (1997) and 25.0 (1998) was recorded by treatment combination W_2C_4. Water regimes and nitrogen levels interaction was also found significant in both years. W_2N_2 treatment combination recorded the highest number of capsules per spike i.e., 25.1 (1997) and 23.2 (1998).

The interaction effect of cultivars and nitrogen levels was significant in both years. N_2C_4 recorded the maximum number of capsules per spike of 26.1 during 1997 and 24.5 during 1998 study.The interaction effect of water regimes, nitrogen levels and cultivars were significant in the both years of study, but the treatment GCH-4 at 60 kg N ha^{-1} under irrigated condition gave the highest number of capsules per spike.

4.2.4 100 Seed Weight (g)

Data on 100 seed-weight are presented in table 4.37 - 4.39. Differences in 100 seed weight due to cultivars, nitrogen levels were significant in both years of study except due to water regime. Among the different cultivars, GCH-4 recorded maximum 100 seed weight over the other cultivars. Maximum 100 seed weight of 23.9 g (1997) and 23.1 g (1998) was recorded at 60 kg N ha^{-1} and were found significantly higher than 10 g N ha^{-1}.

The interaction effect, between cultivars and water regimes was found significant in both years. Maximum 100 seed weight of 26.8 g (1997) and 25.4 g (1998) was recorded by W_2C_4. The interaction effect of nitrogen levels and water regimes was also significant in both years of study. Maximum 100 seed weight of 24.7 g (1997) and 23.7 g (1998) was recorded by W_2N_2.

Table 4.37 Effect of water regimes, nitrogen levels and cultivars on 100 Seed Weight (grams)

Year	Cultivars					
	C_1	C_2	C3	C4	S.Ed.±	CD (0.05)
1997-98	20.7	23.8	23.9	25.7	0.29	0.59
1998-99	19.9	23.0	23.1	24.5	0.29	0.60
Mean	20.3	23.4	23.5	25.1		

Year	Nitrogen Levels			
	N_1	N_2	S.Ed.±	CD (0.05)
1997-98	23.1	23.9	0.05	0.12
1998-99	22.2	23.1	0.02	0.06
Mean	22.7	23.5		

Year	Water regimes			
	W_1	W_2	S.Ed.±	CD (0.05)
1997-98	22.8	24.2	23.51	NS
1998-99	22.0	23.2	22.62	NS
Mean	22.4	23.7		

Table 4.38 Interaction effects of water regimes, nitrogen levels and cultivars on 100 Seed-weight (grams)

Year	N x W		C x W			
	N_1	N_2	C_1	C_2	C3	C4
1997-98						
W_1	22.5	23.2	20.1	23.2	23.3	24.6
W_2	23.8	24.7	21.3	24.3	24.5	26.8
	S.Ed.±	**CD (0.05)**		**S.Ed.±**	**CD (0.05)**	
	0.07	**0.17**		**0.41**	**0.84**	
1998-99						
W_1	21.7	22.4	19.5	22.5	22.5	23.6
W_2	22.7	23.7	20.4	23.5	23.6	25.4
	S.Ed.±	**CD (0.05)**		**S.Ed.±**	**CD (0.05)**	
	0.03	**0.06**		**0.37**	**0.74**	

Year	Nitrogen levels x Cultivars (NxC)							
	1997-98				1998-99			
	C_1	C_2	C3	C4	C_1	C_2	C3	C4
N_1	20.1	23.4	23.6	25.3	19.5	22.6	22.6	24.0
N_2	21.3	24.1	24.3	26.0	20.4	23.4	23.5	25.0
	S.Ed.±	**CD (0.05)**			**S.Ed.±**	**CD (0.05)**		
N x C	**0.36**	**0.73**			**0.37**	**0.55**		

Table 4.39 Interaction effect of water regimes, nitrogen levels and cultivars on 100 Seed-weight (grams)

	W_1		W_2	
	N_1	N_2	N_1	N_2
1997-98				
C_1	19.7	20.5	20.4	22.1
C_2	23.0	23.5	23.9	24.7
C_3	23.0	23.7	24.8	24.8
C_4	24.1	25.1	26.6	27.0
S.Ed.±	0.51			
CD (0.05)	NS			
1998-99				
C_1	19.1	19.8	19.8	20.6
C_2	22.2	22.8	23.1	23.9
C_3	22.1	22.9	23.2	24.0
C_4	24.1	23.1	24.9	25.9
S.Ed.±	0.52			
CD (0.05)	NS			

Table 4.40 Effect of water regimes, nitrogen levels and cultivars on Seed Yield (kg ha^{-1})

Year	Cultivars					
	C1	C2	C3	C4	S.Ed.±	CD (0.05)
1997-98	1200	1220	1620	1810	9.70	19.60
1998-99	910	1020	1360	1510	9.00	18.30
Mean	1050	1120	1490	1660		

Year	Nitrogen Levels			
	N1	N2	S.Ed.±	CD (0.05)
1997-98	1370	1510	7.00	17.10
1998-99	1100	1300	2.90	7.20
Mean	1230	1400		

Year	Water regimes			
	W1	W2	S.Ed.±	CD (0.05)
1997-98	1210	1670	7.20	22.90
1998-99	1060	1340	4.50	14.30
Mean	1130	1500		

Table 4.41 Interaction effects of water regimes, nitrogen levels and cultivars on Seed yield (kg ha^{-1})

Year	N x W		C x W			
	N1	N2	C1	C2	C3	C4
1997-98						
W1	1160	1260	960	1040	1370	1480
W2	1580	1760	1290	1370	1880	2140
	S.Ed.±	CD (0.05)	S.Ed.±	CD (0.05)		
	10.0	23.20	13.90	28.60		
1998-99						
W1	990	1120	810	920	1200	1310
W2	1210	1470	1010	1120	1520	1720
	S.Ed.±	CD (0.05)	S.Ed.±	CD (0.05)		
	5.40	13.10	11.90	24.20		

Year	Nitrogen levels x Cultivars (NxC)							
	1997-98				1998-99			
	C1	C2	C3	C4	C1	C2	C3	C4
N1	1020	1150	1560	1750	810	940	1260	1400
N2	1230	1260	1690	1870	1010	1100	1470	1620
	S.Ed.±	CD (0.05)	S.Ed.±	CD (0.05)				
N x C	13.80	27.90	11.40	23.20				

Table 4.42 Interaction effect of water regimes, nitrogen levels and cultivars on Seed Yield (kg ha^{-1})

	W1		W2	
	N1	N2	N1	N2
1997-98				
C1	870	1050	1170	1410
C2	990	1080	1300	1440
C3	1310	1420	1810	1950
C4	1450	1500	2060	2230
S.Ed.±	19.60			
CD (0.05)	39.50			
1998-99				
C1	730	880	880	1140
C2	870	970	1020	1220
C3	1130	1270	1380	1660
C4	1240	1370	1550	1880
S.Ed.±	16.50			
CD (0.05)	33.60			

The interaction effect of cultivars and nitrogen levels was also significant in both years of study (table). C_2 and C_3 were on par with each other at both levels of nitrogen. N_2C_4 recorded maximum 100 seed weight of 26.0 g during first year and 25.1 g during second year of study. $W_2N_2C_4$ recorded a mean 100 seed weight of 27.0 g (1997) and 25.9 g (1998).

4.3 Seed Yield

Data on seed yield was presented in table 4.40 – 4.42. Significant difference was observed due to cultivars, nitrogen levels and water regimes on seed yield. The mean seed yield ranged from 1055 kg ha^{-1} (Aruna) to1660 kg ha^{-1} (GCH-4). Nitrogen (60 kg N ha^{-1}) application increased the seed yield by 14 % compared to that with 10 kg N ha^{-1}. Irrigation increased castor seed yield by 32 % compared with rainfed crop.

Interaction effect of cultivars and water regimes was significant. Under rainfed conditions highest yielder GCH-4 recorded 58 % more mean seed yield than Aruna, while it was 68 % under irrigated conditions. Seed yield of irrigated GCH-4 was 1930 kg ha^{-1}, which was 38 % higher than rainfed GCH-4.

Significant interaction between nitrogen and water regimes indicated that, seed yield of irrigated castor cultivars was increased by 16 % with 60 kg N ha^{-1} than at 10 kg N ha^{-1}, while it was only 10 % under rainfed conditions. GCH-4 yielded 72 % higher than Aruna at 10 kg N ha^{-1}. At 60 kg N ha^{-1} GCH-4 had 56 % more yield than Aruna. The cultivar, nitrogen level and water regime interaction was also significant. Under irrigated

Table 4.43 Effect of water regimes, nitrogen levels and cultivars on Stalk yield (kg ha^{-1})

Year	Cultivars					
	C1	C2	C3	C4	S.Ed.±	CD (0.05)
1997-98	1690	1740	1980	2050	11.0	21.50
1998-99	1530	1650	1870	1980	10.0	20.30
Mean	1610	1700	1920	2020		

Year	Nitrogen Levels			
	N1	N2	S.Ed.±	CD (0.05)
1997-98	1790	1940	8.00	19.50
1998-99	1690	1820	3.60	8.70
Mean	1740	1880		

Year	Water regimes			
	W1	W2	S.Ed.±	CD (0.05)
1997-98	1650	2080	7.10	22.60
1998-99	1630	1880	4.30	13.70
Mean	1640	1980		

Table 4.44 Interaction effects of water regimes, nitrogen levels and cultivars on Stalk yield (kg ha^{-1})

Year	N x W		C x W			
	N1	N2	C1	C2	C3	C4
1997-98						
W1	1600	1690	1500	1530	1750	1800
W2	1990	2180	1880	1960	2200	2300
	S.Ed.±	CD (0.05)	S.Ed.±	CD (0.05)		
	10.70	24.40	14.90	30.30		
1998-99						
W1	1600	1660	1420	1540	1740	1830
W2	1770	1990	1640	1760	2000	2120
	S.Ed.±	CD (0.05)	S.Ed.±	CD (0.05)		
	5.60	13.70	13.00	26.40		

Year	Nitrogen levels x Cultivars (NxC)							
	1997-98				1998-99			
	C1	C2	C3	C4	C1	C2	C3	C4
N1	1590	1670	1850	2030	1440	1590	1800	1940
N2	1790	1820	2070	2080	1620	1710	1940	2020
	S.Ed.±	CD (0.05)	S.Ed.±	CD (0.05)				
N x C	15.20	30.90	12.80	25.90				

Table 4.45 Interaction effect of water regimes, nitrogen levels and cultivars on Stalk Yield (kg ha^{-1})

	W1		W2	
	N1	N2	N1	N2
1997-98				
C1	1400	1600	1770	1980
C2	1500	1570	1850	2070
C3	1670	1840	2100	2300
C4	1820	1780	2230	2380
S.Ed.±	21.20			
CD (0.05)	42.80			
1998-99				
C1	1350	1480	1530	1770
C2	1520	1550	1650	1870
C3	1710	1780	1890	2100
C4	1850	1810	2030	2220
S.Ed.±	18.20			
CD (0.05)	37.00			

conditions GCH-4 recorded a mean seed yield of 2050 kg ha^{-1}, which was 60 % higher than Aruna. Irrigated GCH-4 at 60 kg N ha^{-1} had 14 % higher seed yield than at 10 kg N ha^{-1}. The two years mean seed yield of rainfed GCH-4 at 60 kg N ha^{-1} was 6 % higher than 10 kg N ha^{-1}.

4.4 Stalk Yield

The data pertaining to stalk yield is presented in table 4.43 – 4.45. The differences due to cultivar, nitrogen levels and water regime were all significant. Stalk yield ranged from 1610 kg ha^{-1} (Aruna) to 2020 kg ha^{-1} (GCH-4). Nitrogen fertilizer increased the stalk yield by 8 % in the two years of the study. Irrigation increased stalk yield by about 20 % over rainfed condition and recorded mean stalk yield of 1985 kg ha^{-1}.

The interaction between cultivars and water regime was significant in both years of study. Under rainfed conditions, GCH-4 recorded a mean stalk yield of 1810 kg ha^{-1}, which was 24 % higher than Aruna. Irrigated GCH-4 recorded 26 % more mean stalk yield than Aruna. Irrigated GCH-4 recorded 24 % increase in stalk yield over the rainfed ones.

Nitrogen and water levels interaction revealed that 60 kg N ha^{-1} had greater stalk yield than with 10 kg N ha^{-1} under rainfed conditions, and the difference was 11 % under irrigated conditions.

The interaction between nitrogen levels and cultivars interaction was also significant. GCH-4 had 30 % greater mean stalk yield than Aruna when 10 kg N ha^{-1} was applied, while it was 20 % greater at 60 kg N ha^{-1}. The interaction effect of water regime, nitrogen levels and cultivars were also significant. Under irrigated conditions GCH-4 at

Table 4.46 Effect of water regimes, nitrogen levels and cultivars on Harvest Index (%)

Year	Cultivars					
	C_1	C_2	C3	C4	S.Ed.±	CD (0.05)
1997-98	39.7	40.7	44.9	46.6	0.20	0.41
1998-99	37.1	38.1	42.0	43.1	0.18	0.38
Mean	38.4	39.4	43.5	44.9		

Year	Nitrogen Levels			
	N_1	N_2	S.Ed.±	CD (0.05)
1997-98	42.7	43.3	0.11	0.27
1998-99	38.8	41.1	0.03	0.08
Mean	40.8	42.2		

Year	Water regimes			
	W_1	W_2	S.Ed.±	CD (0.05)
1997-98	42.0	44.0	0.08	0.27
1998-99	39.0	41.1	0.07	2.21
Mean	40.5	42.6		

Table 4.47 Interaction effects of water regimes, nitrogen levels and cultivars on Harvest Index (%)

Year	N x W		C x W			
	N_1	N_2	C_1	C_2	C3	C4
1997-98						
W_1	41.6	42.4	38.9	40.3	43.8	45.1
W_2	43.8	44.2	40.6	41.2	46.1	48.2
	S.Ed.±	**CD (0.05)**		**S.Ed.±**	**CD (0.05)**	
	0.14	**0.13**		**0.25**	**0.52**	
1998-99						
W_1	37.9	40.1	36.2	37.4	40.8	41.6
W_2	40.1	42.1	37. 9	38.8	43.2	44.6
	SED±	**CD (0.05)**		**S.Ed.±**	**CD (0.05)**	
	0.08	**0.19**		**0.24**	**0.48**	

Year	Nitrogen levels x Cultivars (NxC)							
	1997-98				1998-99			
	C_1	C_2	C3	C4	C_1	C_2	C3	C4
N_1	39.0	40.5	45.1	46.1	35.9	37.2	41.2	41.8
N_2	40.6	40.8	44.8	47.1	38.2	39.0	42.9	44.4
	S.Ed.±		**CD (0.05)**			**S.Ed.±**	**CD (0.05)**	
N x C	**0.27**		**0.54**	C x W		**0.23**	**0.46**	

Table 4.48 Interaction effect of water regimes, nitrogen levels and cultivars on Harvest Index (%)

	W_1		W_2	
	N_1	N_2	N_1	N_2
1997-98				
C_1	38.3	39.4	39.7	41.5
C_2	39.9	40.8	40.9	41.4
C_3	43.9	43.6	46.3	45.9
C_4	44.3	45.8	47.9	48.4
S.Ed.±	0.37			
CD (0.05)	0.75			
1998-99				
C_1	35.2	37.3	36.7	39.1
C_2	36.3	38.5	38.1	39.5
C_3	39.8	41.7	42.3	44.1
C_4	40.2	43.0	43.3	45.9
S.Ed.±	0.33			
CD (0.05)	0.67			

60 kg N ha^{-1} recorded the highest mean stalk yield of 2300 kg ha^{-1}, which was 22 % higher than Aruna, while it was 17 % higher than under rainfed conditions.

4.5 Harvest Index

Differences in harvest index occurred between cultivars, nitrogen levels and water regime. Within the cultivars, the maximum harvest index of 44.9 was in GCH-4. The harvest index increased significantly with increasing nitrogen. The maximum harvest index of 42.2 with 60 kg N ha^{-1} was significantly superior to harvest index with 10 kg N ha^{-1}. All the two way and three way interactions were significant in two years of experimentation.

The interaction effect of cultivars, nitrogen levels and water regimes were also significant (table 4.46 – 4.48). Maximum harvest index of 48.4 (1997) and 45.9 (1998) was recorded by irrigated GCH-4 at 60 kg N ha^{-1}.

4.6 Quality parameters

4.6.1 Oil content (%)

Data pertaining to oil content of castor seed was presented in table 4.49. There was no significant difference in oil content due to cultivars, nitrogen levels and water regimes. Mean oil content for cultivars ranged from 48.3 % (GCH-4) to 45.7 % (DCS-9) in the two years of the study. 60 kg N ha^{-1} recorded the mean oil content of 47.7 %, while it was only 47.0 % at 10 kg N ha^{-1}. Irrigated castor recorded the mean oil content of 47.8 per cent.

4.6.2 Protein content (%)

Table 4.49 Effect of water regimes, nitrogen levels and cultivars on Oil content (%)

Year	Cultivars					
	C1	C2	C3	C4	S.Ed.±	CD (0.05)
1997-98	48.7	45.6	49.2	49.8	0.47	NS
1998-99	46.5	45.8	46.8	47.0	0.81	NS
Mean	47.6	45.7	48.0	48.3		

Year	Nitrogen Levels			
	N1	N2	S.Ed.±	CD (0.05)
1997-98	47.9	48.7	0.29	NS
1998-99	46.2	46.8	0.24	NS
Mean	47.0	47.7		

Year	Water regimes			
	W1	W2	S.Ed.±	CD (0.05)
1997-98	47.6	49.0	0.41	NS
1998-99	46.3	46.7	0.18	NS
Mean	47.0	47.8		

Table 4.50 Effect of water regimes, nitrogen levels and cultivars on Protein content (%)

Year	Cultivars					
	C1	C2	C3	C4	S.Ed.±	CD (0.05)
1997-98	33.9	30.0	33.1	28.4	2.8	6.07
1998-99	29.8	30.0	30.9	30.9	1.8	3.89
Mean	31.9	30.0	32.0	29.7		

Year	Nitrogen Levels			
	N1	N2	S.Ed.±	CD (0.05)
1997-98	31.5	31.2	1.18	5.07
1998-99	30.1	30.7	1.80	7.76
Mean	30.8	31.0		

Year	Water regimes			
	W1	W2	S.Ed.±	CD (0.05)
1997-98	31.2	31.6	0.03	0.33
1998-99	28.7	32.1	0.55	7.05
Mean	30.0	31.8		

Data regarding the protein content of castor seeds was presented in table 4.50. In both years, differences due to cultivars, nitrogen levels and water regimes were non-significant. Mean (2 years) protein content of the cultivars ranged from 32.0 (GAUCH-1) to 30.0 (DCS-9). The mean protein content of cultivars ranged from 31.0 (60 kg N ha^{-1}) to 30.8 (10 kg N ha^{-1}) Irrigated castor recorded a mean protein content of 31.8, while it was only 29.9 under rainfed conditions.

4.7 Nutrient uptake

Uptake of nutrients by Leaf

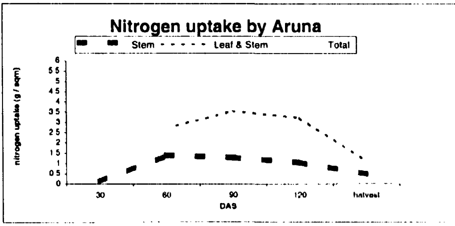
The differences in nutrient uptake by leaf due to water regimes, nitrogen levels and cultivars were non-significant. The nutrient uptake by leaf at 30, 60, 90, 120 DAS and at harvest are presented in the figure .As the crop grows the uptake of nutrients increased up to 90 DAS, thereafter the nutrient content of leaf decreased.

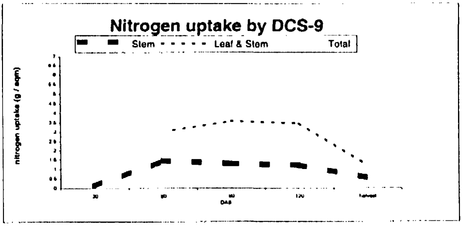
1997-98 *Kharif*

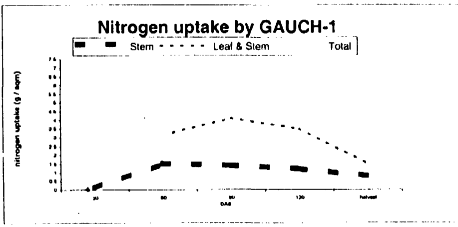
Under irrigated conditions, at harvest nutrient uptake by leaf was only 7.0 kg N ha^{-1}, 0.71 kg P ha^{-1} and 3.14 kg K ha^{-1}. At 60 kg N level the uptake was 6.78 kg N ha^{-1}, P was 0.63 kg ha^{-1} and 2.89 kg K $ha^{-1}$of potash. GCH-4 recorded only 6.97 kg N ha^{-1}, 0.66 kg P ha^{-1} and 3.48 kg K ha^{-1}.

1998-99 Kharif

Fig 4.5 Uptake of nitrogen by castor cultivars *Kharif*-1997







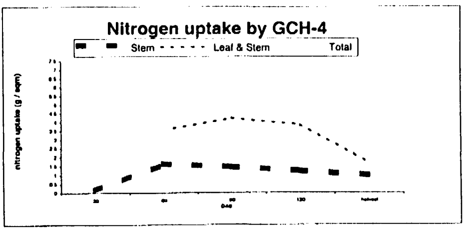
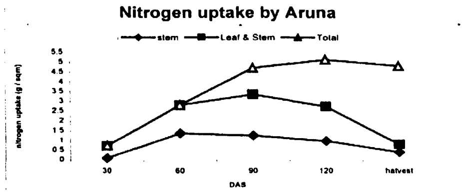
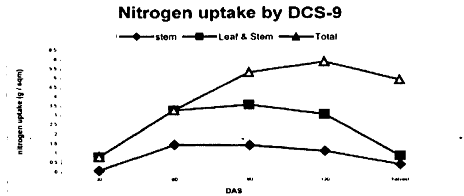
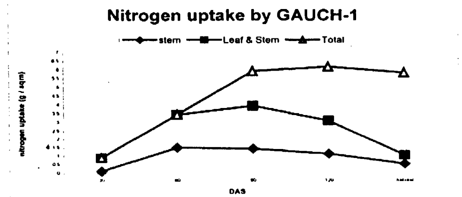


Fig 4.6 Uptake of nitrogen by castor cultivars *Kharif*-1998







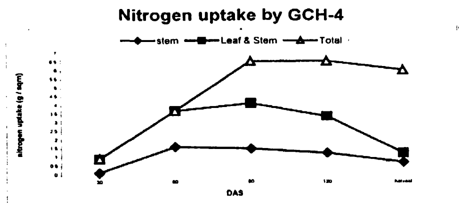
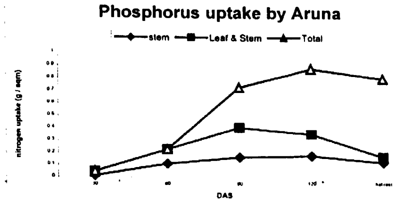
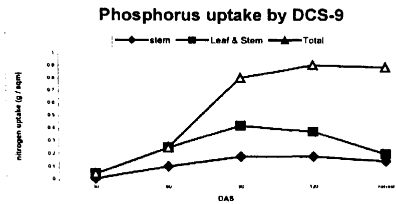
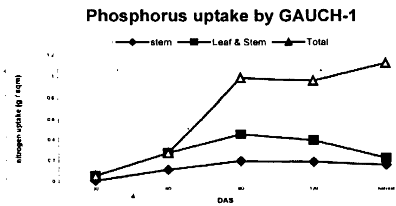


Fig 4.7 Uptake of phosphorus by castor cultivars *Kharif*-1997







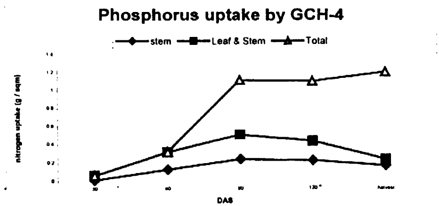


Fig 4.8 Uptake of phosphorus by castor cultivars *Kharif*-1998

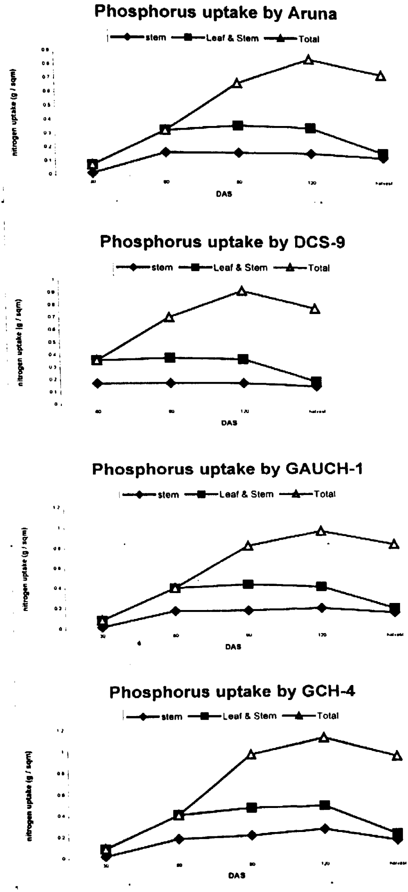
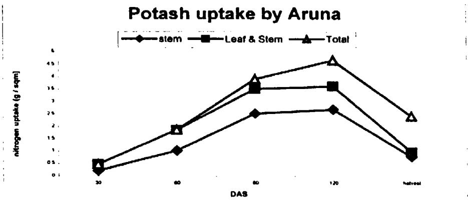
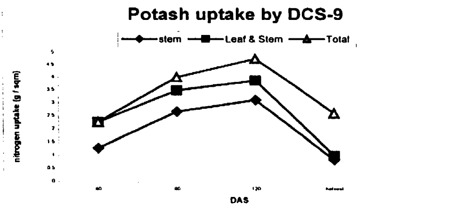
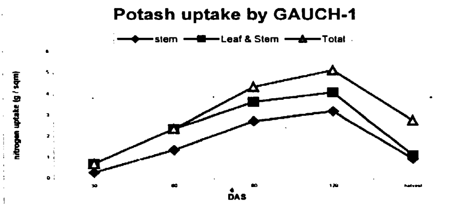
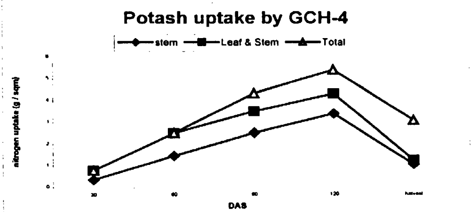


Fig 4.10 Uptake of potash by castor cultivars *Kharif*-1998









The irrigated castor recorded an uptake of 4.87 kg N ha^{-1}, 0.45 kg P ha^{-1} and 1.81 kg K ha^{-1}, while 60 kg N level recorded 5.0 kg N ha^{-1}, 0.45 kg P ha^{-1} and 1.81 kg K ha^{-1}. Out of all the cultivars, GCH-4 recorded the maximum amount of nutrient uptake i.e., 5.29 kg N ha^{-1}, 0.59 kg P ha^{-1} and 1.97 kg K ha^{-1}.

Uptake of nutrients by Stem

The nutrient uptake by stem is presented in the Fig 4.5 – 4.10 .The nutrient uptake by stem at various stages of crop growth was non-significant due to water regimes, nitrogen levels and cultivars. Similar to that of uptake of nutrients by leaf, the nutrient uptake by stem also increased with growth up to 90 DAS. Later, as the crop reaches maturity the uptake decreased.

1997 *Kharif*

At harvest the irrigated castor recorded uptake of 8.35 kg N ha^{-1}, 1.90 kg P ha^{-1} and 12.96 kg K ha^{-1}. As compared to 10 kg N ha^{-1} level, 60 kg N ha^{-1} level recorded maximum uptake i.e., 7.98 kg N ha^{-1}, 1.61 kg P $ha^{-1}$and 11.94 kg K ha^{-1}. Out of four cultivars tested GCH-4 recorded the highest amount of uptake of 9.65 kg N ha^{-1}, 1.67 kg P $ha^{-1}$and 15.87 kg K ha^{-1} at harvest.

1998 *Kharif*

In *Kharif* 1998 experimentation, an uptake of about 5.15 kg N ha^{-1}, 1.57 kg P ha^{-1} and 8.9 kg K ha^{-1} was recorded by irrigated castor. The 60 kg N ha^{-1} level recorded the highest amount of nutrient uptake than 10 kg N ha^{-1} level. Highest yielder GCH-4 recorded 7.05 kg N ha^{-1}, 1.59 kg P ha^{-1} and 10.42 kg K ha^{-1}.

Uptake of nutrients by the Spike

The N, P and K uptake by the spike at 90, 120 DAS and at harvest were presented in the Fig 4.5 – 4.10 . As the crop approached maturity the uptake of nutrients increased in the spike. With regard to the uptake of nutrients by spike, only the cultivars differed significantly.

1997 kharif

Irrigated castor recorded 45.6 kg of nitrogen uptake per hectare, 9.33 kg of 'P' per hectare and 15.7 kg K per hectare at harvest. With increase in nitrogen application there was improvement in the uptake of nutrients. At harvest N60 level recorded 46.4 kg of nitrogen uptake, 9.4 kg of P and 15.7 kg of K uptake. GCH-4 recorded the highest nitrogen uptake of 47.5 kg ha^{-1} than the other cultivars and 9.74 kg of P and 19.2 kg of K.

1998-99 *Kharif*

At harvest irrigated castor recorded 48 kg of nitrogen uptake, 8.16 kg of phosphorus uptake and 16.8 kg potash uptake per hectare. N60 recorded the nitrogen uptake of 29.45 kg, 6.63 kg P and 17.41 kg of potash. At harvest GCH-4 recorded highest nitrogen uptake of 48.1kg ha^{-1}, which was 20 % higher than Aruna, the lowest yielder.7.31 kg of P uptake was registered by GCH-4 at harvest and was 28 % higher than Aruna. The highest yielder GCH-4 recorded 18.29 kg ha^{-1} uptake of potash at harvest, while Aruna recorded 15.47 kg of uptake only.

4.7 Heat units (GDD) accumulated by various treatments at 50 % flowering and maturity of *kharif* experiment

The data presented in table 4.51 – 4.52 reveals the growing degree days required for 50 % flowering and maturity by various treatments. Overall data indicated that

Table 4.51 Heat units (GDD) accumulated by various treatments at 50 % flowering and maturity of *kharif* experiment-1997

50 % Flowering

Treatments	W_1N_1	W_1N_2	W_2N_1	W_2N_2
C_1	**1147 (65)**	**1211 (69)**	**1162 (66)**	**1228 (70)**
C_2	**1101 (62)**	**1147 (65)**	**1101 (62)**	**1178 (67)**
C_3	**1246 (71)**	**1312 (75)**	**1228 (70)**	**1326 (76)**
C_4	**1211 (69)**	**1262 (72)**	**1211 (69)**	**1262 (72)**

Maturity

Treatments	W_1N_1	W_1N_2	W_2N_1	W_2N_2
C_1	**2358 (144)**	**2385 (146)**	**2401 (147)**	**2416 (148)**
C_2	**2345 (143)**	**2372 (145)**	**2372 (145)**	**2385 (146)**
C_3	**2791 (176)**	**2805 (177)**	**2791 (176)**	**2831 (179)**
C_4	**3002 (192)**	**3013 (193)**	**3013 (194)**	**3023 (194)**

Table 4.52 Heat units (GDD) accumulated by various treatments at 50 % flowering and maturity of *kharif* experiment-1998

50 % Flowering

Treatments	W_1N_1	W_1N_2	W_2N_1	W_2N_2
C_1	1121 (69)	1179 (63)	1149 (64)	1074 (66)
C_2	1029 (63)	1058 (64)	1043 (64)	1149 (70)
C_3	1208 (75)	1255 (78)	1194 (74)	1254 (78)
C_4	1179 (73)	1223 (76)	1179 (73)	1223 (76)

Maturity

Treatments	W_1N_1	W_1N_2	W_2N_1	W_2N_2
C_1	2231 (148)	2252 (150)	2273 (151)	2263 (150)
C_2	2218 (146)	2231 (148)	2242 (149)	2252 (150)
C_3	2521 (180)	2521 (180)	2530 (181)	2530 (181)
C_4	2636 (194)	2646 (195)	2664 (197)	2664 (197)

Note: Figures in parenthesis indicate the number of days.

irrigated treatments accumulated more number of heat units than rainfed one. Out of the two levels of nitrogen 60 kg N ha^{-1} accumulated higher GDD to attain 50 % flowering or maturity. Best yielder GCH-4, under irrigated conditions with 60 kg N ha^{-1} accumulated 1262 GDD to attain 50 % flowering and 3023 GDD to reach maturity in 1997 *kharif* and 1223 (50 % flowering) and 2664 (maturity) in 1998 *kharif* experiments.

4.9 Peak Radiation use efficiency of castor cultivars recorded by different treatments during its crop growth

The data in table 4.53 reveals that the maximum RUE recorded by 1997 *kharif* was more than that of 1998 *kharif* trial. Maximum dose of nitrogen (60 Kg N ha^{-1}) recorded higher values of RUE in almost all cultivars both in rainfed and irrigated treatments in two years of experimentation. When compared to rainfed ones, irrigated castor recorded the highest RUE in both years of study. In 1997 the GAUCH-1 cultivar recorded the highest RUE of 1.130, while it was 0.499 in 1998 indicating the most favorable conditions in *kharif* 1997 season.

The slope of the relationship between biomass accumulation and intercepted radiation gives the RUE, which was represented graphically from Fig4.11 – 4.18.

Table 4.53 Peak radiation use efficiency of castor cultivars recorded by different treatments during its crop growth

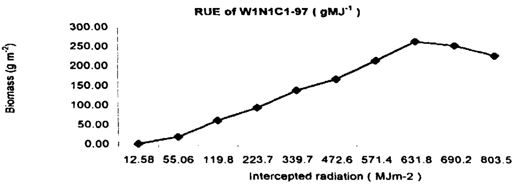
Kharif-1997

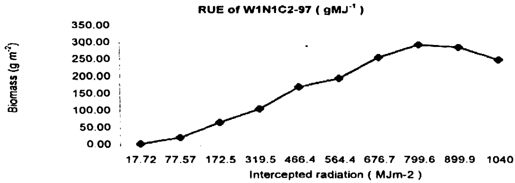
	N_1				N_2			
	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4
W_1	0.522	0.385	0.418	0.414	0.349	0.403	0.717	0.464
W_2	0.615	0.416	0.518	0.526	0.487	0.661	1.130	0.635

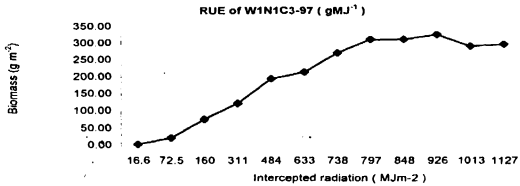
Kharif-1998

	N_1				N_2			
	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4
W_1	0.311	0.322	0.421	0.360	0.402	0.421	0.493	0.457
W_2	0.414	0.403	0.459	0.501	0.422	0.430	0.494	0.459

FIG 4.11 RADIATION USE EFFICIENCY OF DIFFERENT CULTIVARS







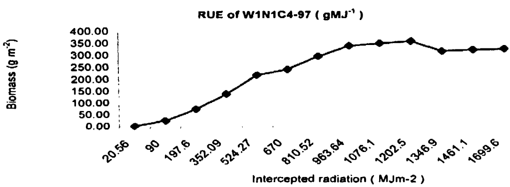


FIG 4.12 RADIATION USE EFFICIENCY OF DIFFERENT CULTIVARS

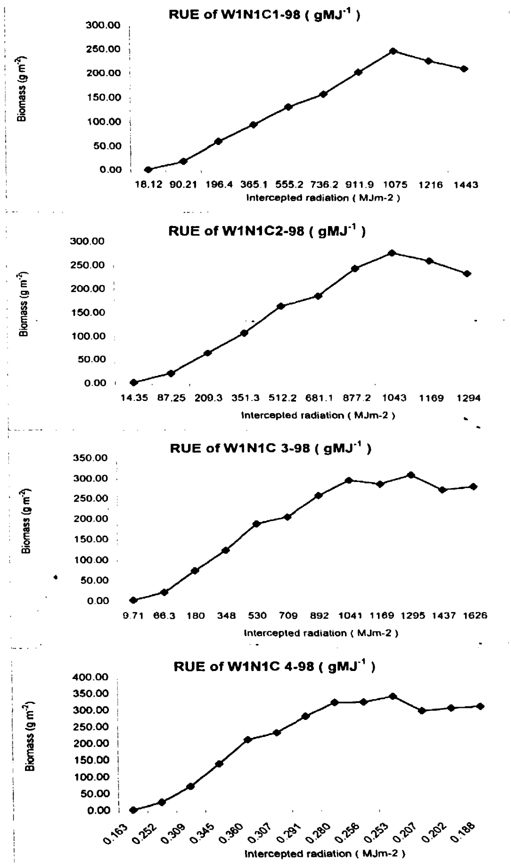
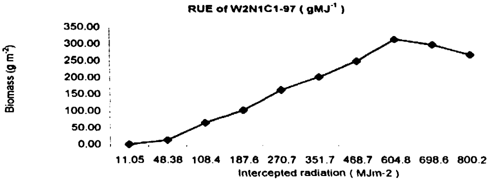
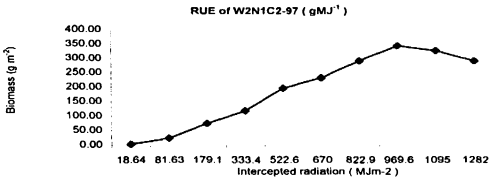
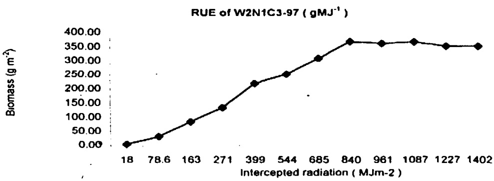


FIG 4.13 RADIATION USE EFFICIENCY OF DIFFERENT CULTIVARS







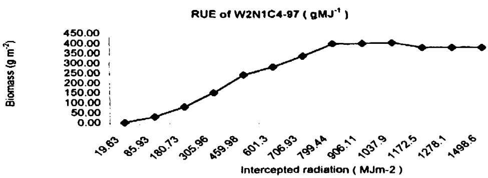
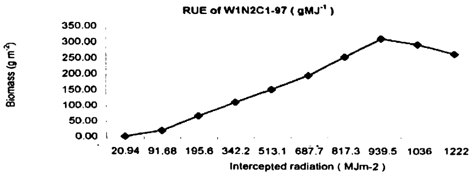
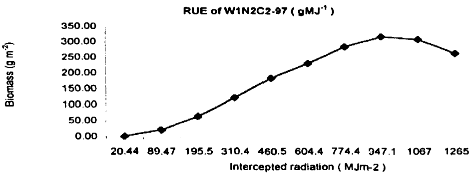
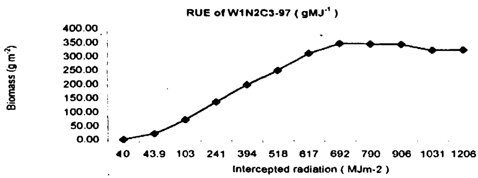


FIG 4.14 RADIATION USE EFFICIENCY OF DIFFERENT CULTIVARS







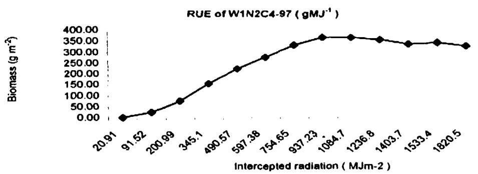


FIG 4.15 RADIATION USE EFFICIENCY OF DIFFERENT CULTIVARS

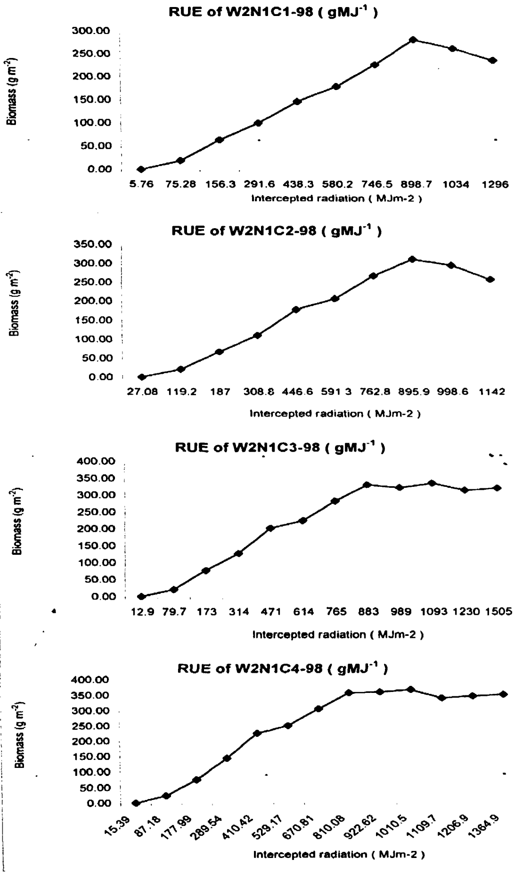


FIG 4.16 RADIATION USE EFFICIENCY OF DIFFERENT CULTIVARS

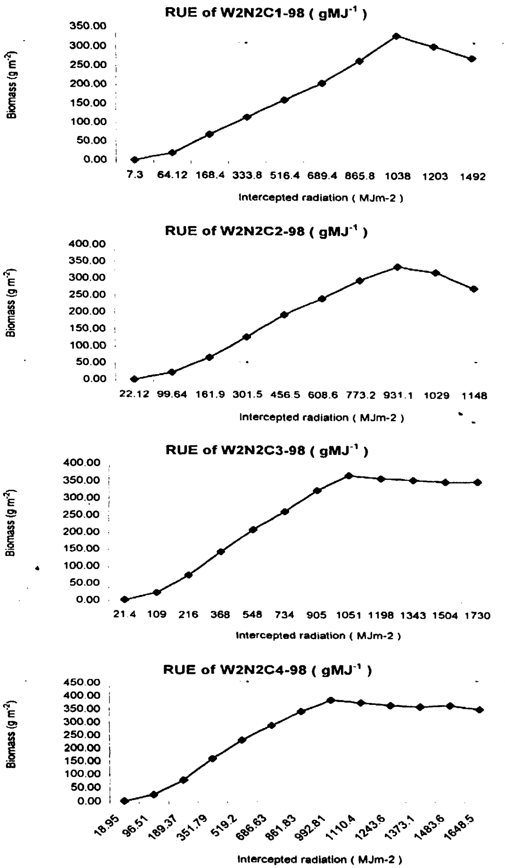


FIG 4.17 RADIATION USE EFFICIENCY OF DIFFERENT CULTIVARS

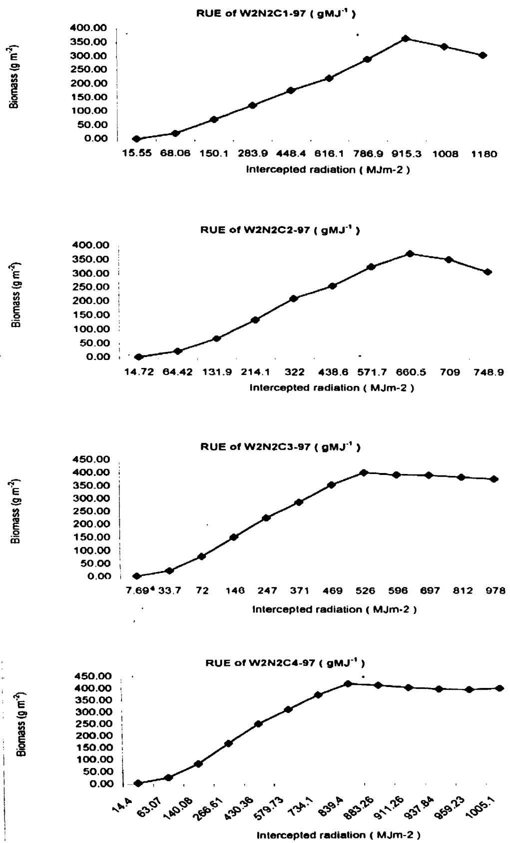


FIG4.18 RADIATION USE EFFICIENCY OF DIFFERENT CULTIVARS

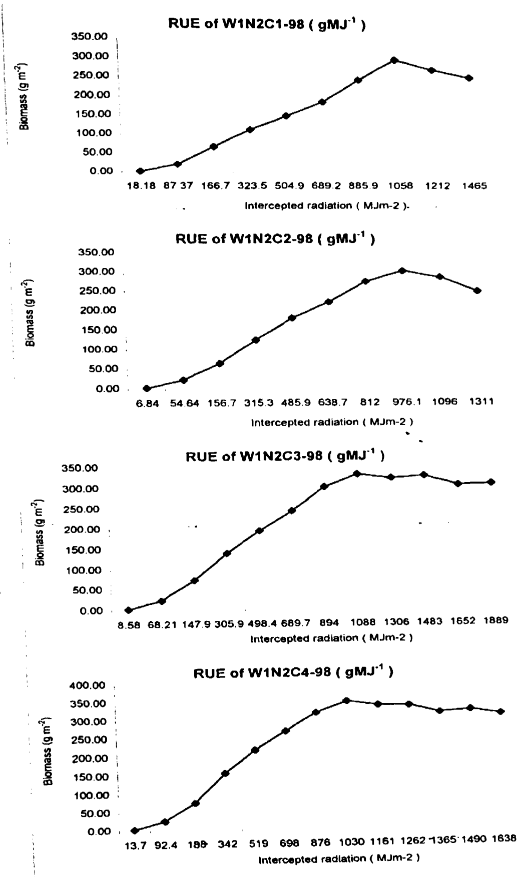
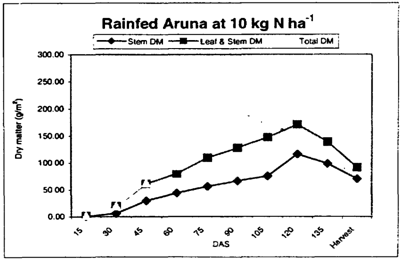
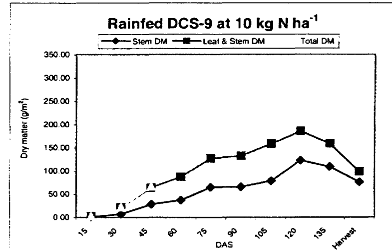
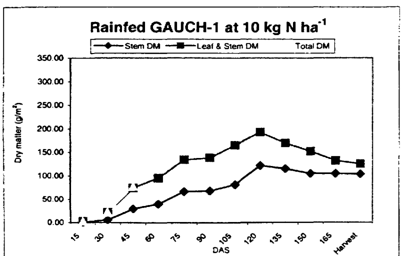


Fig 4.19 Partitioning of above ground drymatter Kharif-1997







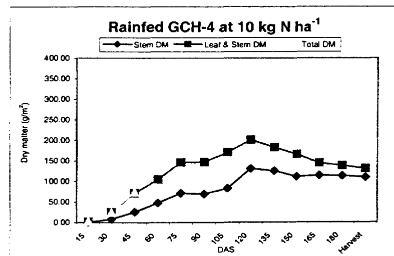


Fig 4.20 Partitioning of above ground drymatter Kharif-1998

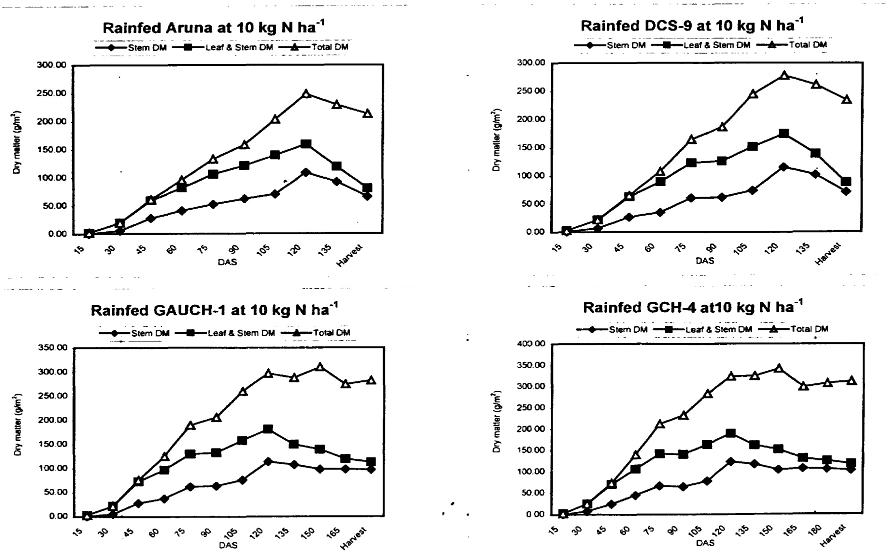


Fig 4.20 Partitioning of above ground drymatter Kharif-1998

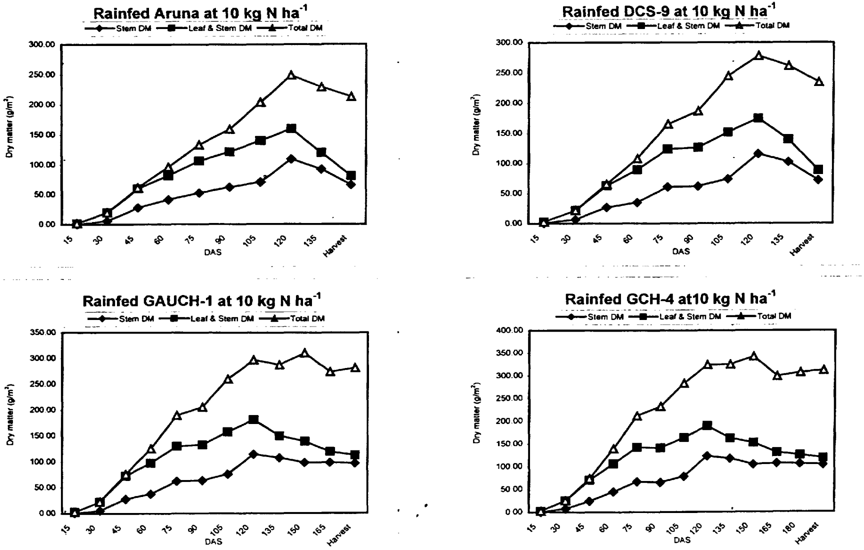


Fig 4.21 Partitioning of above ground drymatter Kharif-1997

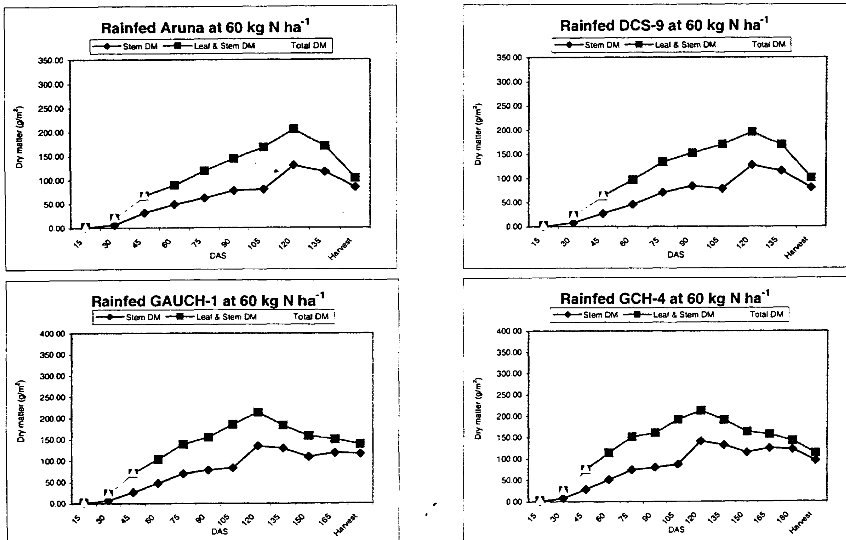


Fig 4.22 Partitioning of above ground drymatter Kharif-1998

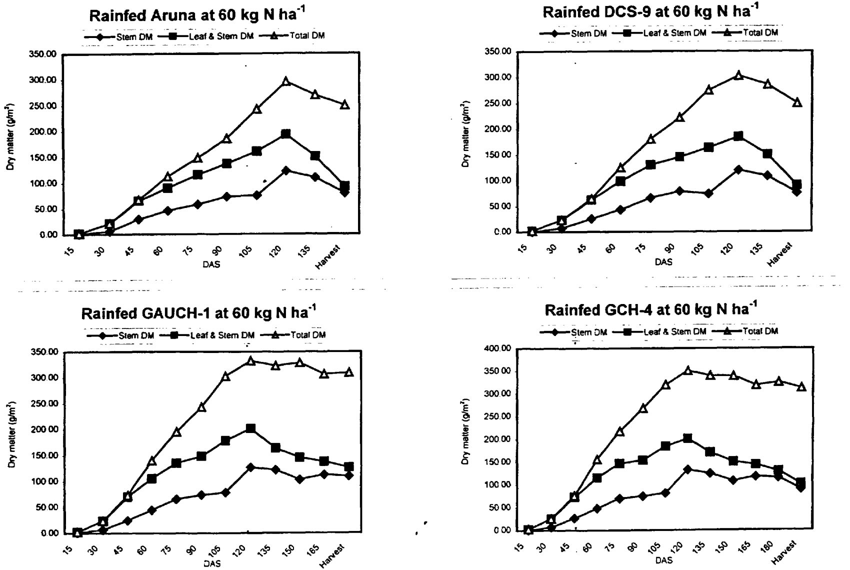


Fig 4.23 Partitioning of above ground drymatter Kharif-1997

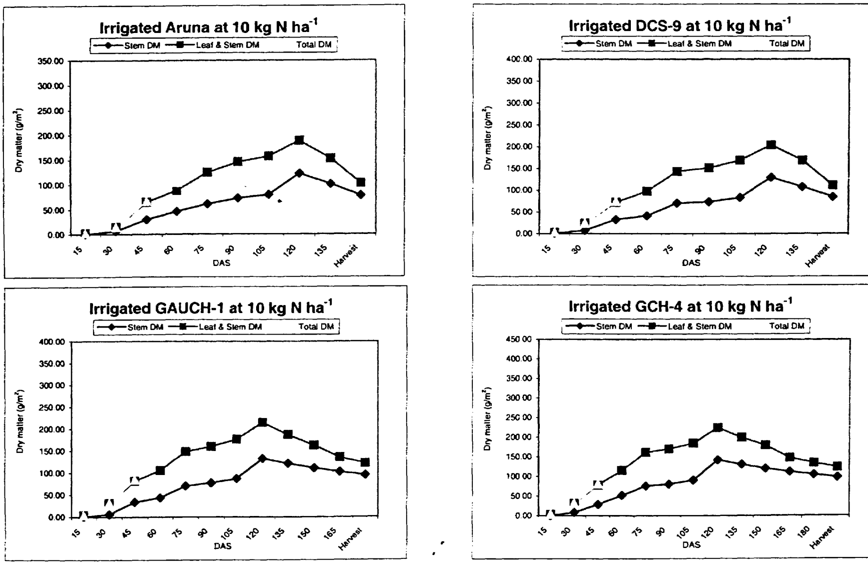


Fig 4.24 Partitioning of above ground drymatter Kharif-1998

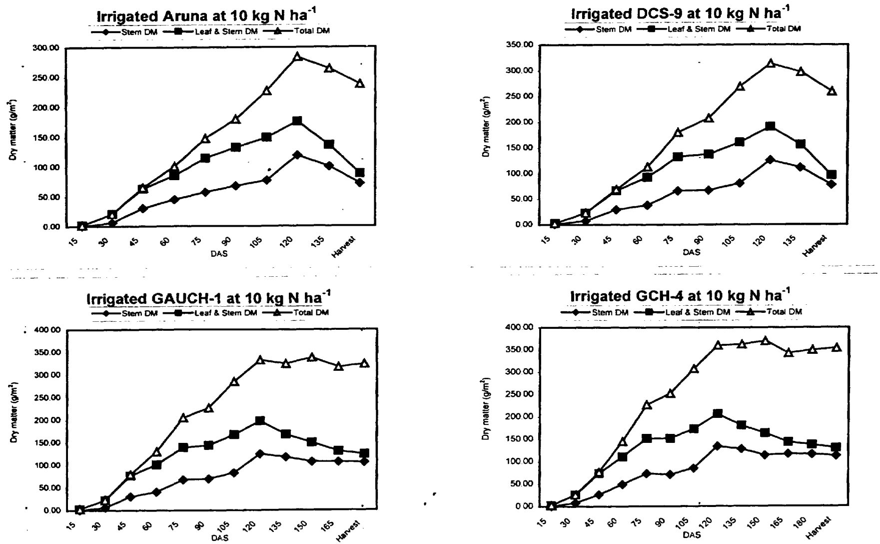


Fig 4.25 Partitioning of above ground drymatter Kharif-1997

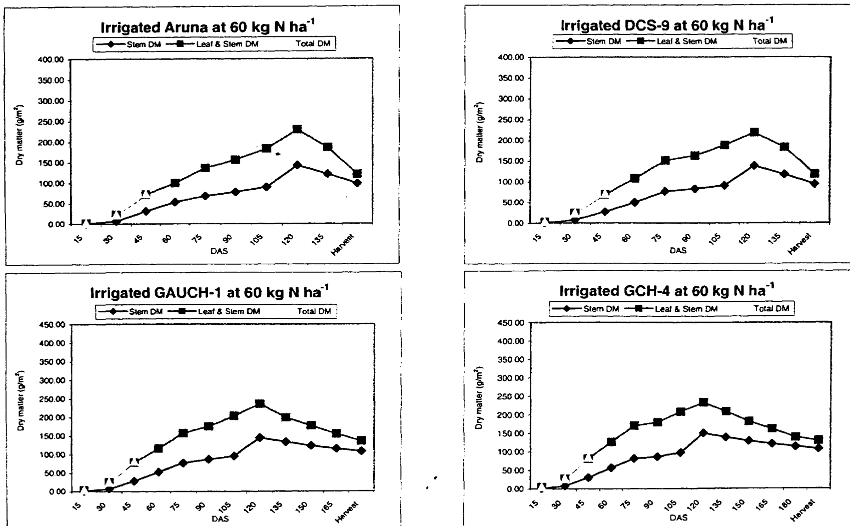
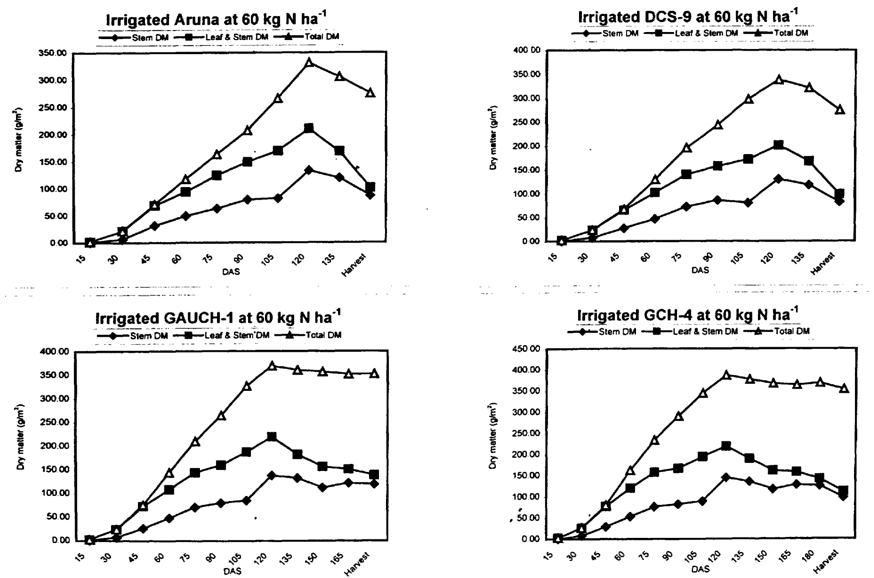


Fig 4.26 Partitioning of above ground drymatter Kharif-1998



4.10 Partitioning

Partitioning of the above ground drymatter was depicted from figures in which the amount of drymatter partitioned to stem, together stem and leaf and total above ground drymatter (stem, leaf and spike) is presented in Fig 4.19 – 4.26.

Irrespective of the effect of different treatments, the amount of drymatter partitioned to the stem portion was comparatively higher than the amount partitioned to other parts of the plant. As the growth advanced, the partitioning of assimilates was more towards leaf area development. With the initiation of reproductive phase assimilates were transported to sink as well as vegetative parts. After attaining the peak reproductive phase (after the initiation of primary and secondary spikes) the transportation of assimilates to stem and leaf started declining.

As compared to rainfed treatments irrigated castor recorded maximum amount of total above ground drymatter production, as such more is the amount partitioned to sink portion for the production of economically useful portion i.e. bean yield. Irrigated castor cultivars with 60 kg N ha^{-1} recorded comparatively higher drymatter production than the castor cultivars cultivated with 10 kg N ha^{-1}. Out of the four cultivars tested, GCH-4 recorded the maximum amount of photosynthates partitioned in the production of seed yield followed by GAUCH-1.

4.11 Correlation

Table 4.54 Correlation between cumulative Light interception, LAI and Seed yield (*kharif*-1997)

Treatments	Seed Yield ($kgha^{-1}$)	CIR at 60DAS	LAI at 60 DAS	CIR at 90 DAS	LAI at 90 DAS	CIR at Harvest	LAI at Harvest
W1N1C1	872	223.7	0.766	472.6	1.305	803.7	.333
W1N1C2	994	319.5	1.066	564.4	1.416	1039.7	.368
W1N1C3	1309	311.0	1.177	632.9	1.498	1127.2	.347
W1N1C4	1455	352.1	1.214	670.0	1.651	1699.6	.327
W1N2C1	1042	342.2	0.815	687.6	1.418	1221.6	.284
W1N2C2	1079	310.4	1.087	604.4	1.454	1265.2	.322
W1N2C3	1423	240.9	1.192	518.3	1.630	1205.6	.370
W1N2C4	1503	345.1	1.334	597.4	1.723	1820.5	.260
W2N1C1	1166	187.6	0.873	351.99	1.522	800.2	.400
W2N1C2	1305	333.4	1.175	670.0	1.633	1281.8	.435
W2N1C3	1809	270.7	1.284	543.6	1.715	1402.4	.441
W2N1C4	2055	305.9	1.321	601.3	1.868	1498.6	.421
W2N2C1	1412	283.9	0.968	616.1	1.635	1180.1	.351
W2N2C2	1437	214.1	1.204	438.6	1.671	748.9	.389
W2N2C3	1946	145.6	1.309	370.9	1.847	977.7	.464
W2N2C4	2230	266.6	1.451	579.7	1.940	1005.1	
Seed yield x CIR	-0.18675			-0.07226		0.22785	
Seed yield x LAI		0.835291			0.9669		0.4344
CIR x LAI			0.078592		-0.0733		-0.3326

Table 4.55 Correlation between cumulative Light interception, LAI and Seed yield (*kharif*-1998)

Treatments	Seed Yield (kgha^{-1})	CIR at 60DAS	LAI at 60 DAS	CIR at 90 DAS	LAI at 90 DAS	CIR at Harvest	LAI at Harvest
W1N1C1	732	365.0	0.877	736.2	1.289	1443.4	0.324
W1N1C2	867	351.3	1.181	681.1	1.402	1293.6	0.361
W1N1C3	1131	348.4	1.294	708.6	1.495	61625.6	0.342
W1N1C4	1243	404.6	1.333	757.2	1.947	1655.6	0.318
W1N2C1	881	323.5	0.965	689.2	1.401	1465.1	0.279
W1N2C2	970	315.3	1.201	638.7	1.439	1311.4	0.318
W1N2C3	1273	305.9	1.310	689.7	1.616	1888.9	0.363
W1N2C4	1371	341.6	1.453	697.9	1.711	1638.9	0.249
W2N1C1	883	291.6	0.879	580.2	1.406	1295.5	0.362
W2N1C2	1017	308.8	1.184	591.2	1.518	1141.9	0.398
W2N1C3	1385	314.3	1.299	614.4	1.605	1504.8	0.391
W2N1C4	1555	289.5	1.339	529.2	1.756	1364.9	0.370
W2N2C1	1136	333.8	0.967	689.4	1.518	1492.1	0.315
W2N2C2	1221	301.5	1.203	608.6	1.555	1147.7	0.354
W2N2C3	1658	367.9	1.311	734.4	1.732	1730.1	0.414
W2N2C4	1880	351.8	1.455	686.6	1.826	1648.5	0.301
Seed yield x CIR	0.0948			-0.0179		0.4810	
Seed yield x LAI		0.7821			0.9656		0.1042
CIR x LAI			0.1785				-0.1868

Castor seed yield and cumulative intercepted radiation are negatively correlated at different stages of the crop growth except during harvest. There was 14.6 % average variation in seed yield by the change in the cumulative intercepted radiation at harvest.

LAI and seed yields were positively correlated during the entire crop growth. Maximum amount of about 90 per cent variation was observed at 90 DAS and 12 % variation was noticed at harvest between seed yield and LAI.

LAI and cumulative intercepted radiation was positively correlated at initial stages of the crop growth and at later stages both are negatively correlated.

4.6 EFFECT OF PLANTING DENSITY ON CASTOR YIELDS

4.6.1 Plant height

When the plant height was measured from the base of the stem to the tip of the main spike there was gradual increase in plant height from emergence to 105-120 DAS. Later on the plant height remained steady. Out of the three planting densities PD-2 (1,30,000 plants ha^{-1}) recorded the tallest plant height followed by PD-1 (55,000 plants ha^{-1}) and PD-3 (17,000 plants ha^{-1}).

4.6.2 LAI

As the growth advances the LAI increased at an increasing order. Up to 45 DAS, the LAI of all plant densities were almost equal. Later on there was drastic improvement in LAI especially in PD-1 (55,000 plants ha^{-1}) and PD-2 (1,30,000 plants ha^{-1}). Peak LAI of 4.0 was recorded by PD-2 followed by PD-1.

4.6.3 Yield and yield components

The data regarding yield and yield components of planting density experiment was presented in table 4.56. The yield and yield components differed significantly due to densities. PD-3 (17,000 plants ha^{-1}) recorded significantly highest seed yield of 2220 kg ha^{-1} followed by PD-1 (55,000 plants ha^{-1}). The seed yield of PD-1 (1890 kg ha^{-1}) was on par with PD-2 (1670 kg ha^{-1}). PD-1 recorded significantly highest harvest index of 47.7 and the lowest by PD-2 (40.8). PD-3 recorded significantly highest main spike length of 40.1 cm. PD-3 recorded significantly highest spikes per plant (15.2) and capsules per

Table 4.56 Effect of planting density on yield and yield components of castor cultivar GCH-4

Treatment	Seed Yield (kg/ha)	Harvest Index (%)	Main Spike Length (cm)	Spikes per Plant	Capsule per Spike	100 seed Weight (g)
PD-1 (55,000 pl/ha)	1890	47.7	27.9	9.6	18.2	21.3
PD-2 (1,30,000 pl/ha)	1670	40.8	20.0	5.1	5.8	19.1
PD-3 (17,000 pl/ha)	2220	45.8	40.1	15.1	38.9	23.7
S.Ed.±	90.3	2.0	1.8	1.3	2.6	0.61
CD(0.05)	221.0	4.9	4.5	3.1	6.6	1.48

FIG 4.27 EFFECT OF PLANTING DENSITY ON PLANT HEIGHT OF GCH-4 CASTOR

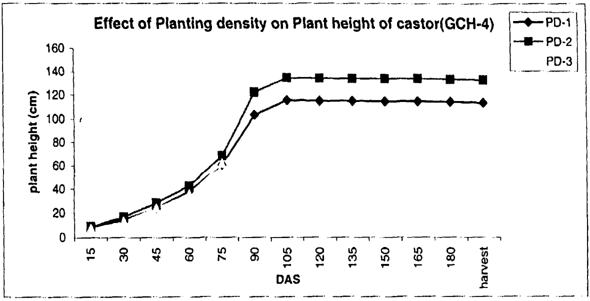


FIG 4.28 EFFECT OF PLANTING DENSITY ON PLANT HEIGHT OF GCH-4 CASTOR

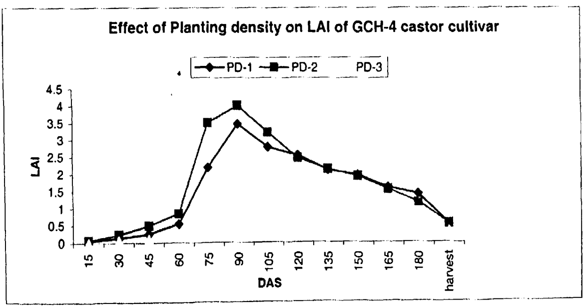
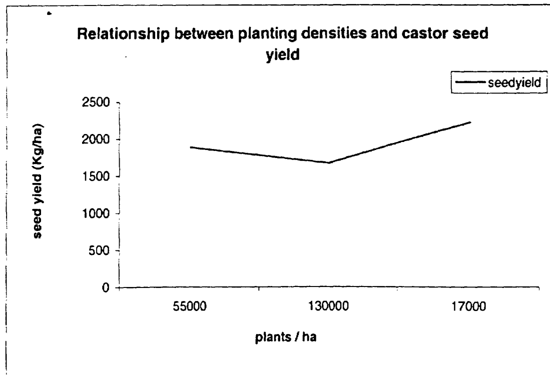


FIG 4.29 EFFECT OF PLANTING DENSITIES ON CASTOR YIELDS



spike (38.9) followed by PD-1. PD-2 recorded lowest number of spikes per plant and capsules per spike. PD-3 recorded 23.7 g of 100 seed weight, which was significantly higher than other densities. 21.3 g was recorded by PD-1 followed by PD-2 (19.1 g) regarding 100 seed-weight.

DISCUSSION

CHAPTER V

DISCUSSION

Crop growth and subsequent yields are the results of interaction between genetic structure of the plant and external environment, which in turn are varied in nature. These external factors influence the agronomic practices, hence constitute a major problem in crop production. As castor is grown as rainfed crop, studies on effect of irrigation on castor yields were meager. In addition to irrigation, dates of sowing, planting density, growth and yield of castor are influenced to a greater extent by nitrogen. The response of cultivars to applied fertilizers depends on the genetic potential of different genotypes. Keeping the above points in view, the present investigation was conducted to study the "crop growth and development of castor cultivars under optimal and sub-optimal water and nitrogen conditions in Telangana region".

The results of two years investigations presented in the preceeding chapter were discussed under growth parameters, yield components and nutrient uptake. The life history of castor plant can be divided into two periods 1. Vegetative period and 2. Reproductive period. The vegetative growth period is the period during which the castor plant grows itself after germination. Increase in the number of nodes and leaf size is the most salient features of this period. The reproductive growth period is divided into four monthly periods broadly coinciding with the physiological stages of the crop.

Days	Stage of the crop
1-30	vegetative
31-60	flowering of primaries
61-90	flowering of secondaries and maturity of primaries

91-120	flowering of tertiaries and maturity of secondaries
121-150	maturity of tertiaries and higher order spikes

The reproductive phase was characterized by the spike formation and its growth. The two growth periods are demarcated by the initiation of the primaries. In the present investigation, plant height at harvest was significant.

5.1 EFFECT OF SOWING DATE ON GROWTH OF FOUR CASTOR CULTIVARS

Lowest plant height was recorded by castor cultivars in November and January sowings, which was mainly due to low temperatures prevailed during germination and the subsequent growth was also poor, finally affecting the plant height. Maximum plant height of GCH-4 sown during the first week of June was due to the expression of the genetic potential under the most favorable conditions.

LAI mainly depends on initial growth of the plant i.e. the leaf number and leaf size in terms of area. The differences in LAI at 45 DAS among the cultivars were least due slow initial growth. As the growth advanced, at 105 DAS all most all the cultivars recorded the peak LAI. Increase in LAI by 112 % of GCH-4 in June sowings over Aruna was due to maximum growth expression by a cultivar under favorable environmental conditions.

The differences between cultivars in total drymatter production at early stages of growth (45 DAS) were minimum, because the crop has less difference in leaf area. The leaf area had a positive effect on the drymatter production, as is the case with photosynthetic activity. In June sowing, GCH-4 recorded 57 % higher TDMP than Aruna at 45 DAS, while it was 69 % at harvest. As the growth advances, the differences in total drymatter production also increased.

Optimum temperature and solar radiation were the most important factors for increased drymatter production in June sowings of all the castor cultivars. Lowest total drymatter production in November sowings was due to low temperatures prevailed during germination and the initial vegetative growth, which might have affected the plant height, leaf area index and finally the total drymatter production.

5.1.1 Yield attributes

Main spike length may not be a true representative for higher seed yield because sometimes even though the spike length is more the capsule per spike will be less. The number of capsules on main spike length depends on the initial growth and development of crop. Main spike length of GCH-4 is 28 % taller than Aruna over sowing which is a varietal characteristic. 23.5 % increase in main spike length of GCH-4 than Aruna in June sowings was due to more LAI, total drymatter production and partitioning of more assimilates to the spike.

Spikes per plant depend on the growth and development of the crop during the crop period. The more the branches and leaf area development, the more will be the number of spikes. Increase in number of spikes by 5 % in GCH-4 than Aruna in June sowings was again a varietal characteristic, which is expressed to its maximum under more favorable conditions.

The number of capsules per spike depends on the drymatter produced by the plant and partitioning of photosynthates to the reproductive part spike. When compared to Aruna, GCH-4 recorded 27 % more number of capsules per spike in June sowings. This was due to more TDMP and partitioning to spike for the production of capsules. 100 seed- weight is a genetic characteristic, which depends on the overall growth, development of the plant. There was 14 % increase in 100 seed-weight of GCH-4 in June sowings than November, which was due to more favourable temperature and moisture available for the dry matter production, partitioning and seed development. Low temperatures and high relative humidity prevailed during crop period had affected the growth, DMP and partitioning of photosynthates, which had finally affected the 100 seed-weight. June sown GCH-4 recorded 31 % increase in test weight that of Aruna due to the presence of high temperatures at flowering and maturity.

5.1.2 Seed and stalk yield

Al most all the cultivars recorded highest seed yield in June sowing followed by July sowing. Crops sown later than July recorded the lowest seed yield due to the coincidence of flowering or capsule development with relatively low temperatures of November and December, which adversely affected fertilization. This is in agreement with Thomas (1960) and Juang (1975). Also heavy rains coupled with high relative humidity during this period cause severe damage of Botrytis mould.

Seed yield of GCH-4 when sown in the first week of June were 40 % higher than with the November sowings. This can be attributed to longer primary spikes and the favorable female to male flower ratio in the primary spike. Main spike length, number of capsules per spike and test weight of GCH-4 all contributed to perceptible increased seed yield. Increased yield of the June sown crop was mainly due to more favourable rainfall during the entire crop growth period.This was also observed by Baby Akula and Bapi Reddy (1998).

5.1.3 Harvest Index

Harvest index indicates the amount of dry matter partitioned to the spike (sink) in the production of economic yield (seed yield). GCH-4 recorded 11 % higher increase in harvest index than Aruna, indicating the highest partitioning efficiency of GCH-4. The more the partitioning, the more will be the harvest index and seed yield. June sown GCH-4 recorded the highest harvest index of 38.2, which was due to higher LAI, TDMP and partitioning of dry matter to reproductive parts i.e. spike.

5.1.4 Growing degree days

Highest seed yields were recorded by GCH-4 sown in early June when there was maximum accumulation of heat units. This indicates the importance of sowing time, which has a direct bearing on yield indicating the importance of temperature (both maximum and minimum temperature) on plant growth.

Lowest seed yields were with November sowing castor cultivars due to very low temperatures during this crop period, which had a direct affect on growth, development and finally on seed yield.

5.2 EFFECT OF WATER AND NITROGEN

In the present study plant height at maturity was increased by irrigation and nitrogen in all the cultivars in both years. The cultivar GCH-4 was the tallest particularly under irrigated conditions with added nitrogen. The combined effects of nitrogen and adequate soil moisture influence many components of crop growth and yield including cell multiplication, growth enhancement, and in the manufacture of food materials, and better development of roots which help in better uptake of nutrients.

LAI was significantly increased by water and nitrogen, particularly in higher yielding cultivars. Early in growth that is at 45 DAS the increase was small. Only 4 % increase in LAI due to nitrogen application, and 5 % increase due to irrigation. At 45 DAS irrigated GCH-4 with 60 kg N ha^{-1} recorded 27 % higher LAI than rainfed Aruna with 60 kg N ha^{-1} while it was 42 % under irrigated Aruna with 60 kg N ha^{-1}. At 105 days after sowing irrigated GCH-4 with addition of 60 kg N ha^{-1} recorded 2.29 LAI, which was 18 % higher than with only 10 kg N ha^{-1} added.

Thus in the presence of adequate moisture and nitrogen, the differences in LAI between the cultivars were small. Differences between the cultivars were higher when they were grown under moisture deficit conditions. Adequate moisture and nutrients might have met the uptake needs of the crop. This helped for proper growth and development of canopy which had a positive effect on the photosynthetic activity and finally on LAI. The optimum leaf area helps in better absorption of radiation thus higher dry matter production and yield.

Total dry matter production increased with application of nitrogen and water with higher yielding cultivars. The highest yielder GCH-4 recorded 32 % high total dry matter than the lowest yielder Aruna. There was 14 % increase in total dry matter due to nitrogen application and 11 % increase in total dry matter due to irrigation. The irrigated GCH-4 with 60 kg N ha^{-1} recorded 11 % higher total dry matter than GCH-4 with 10 kg N ha^{-1}. Thus the response of cultivars to applied fertilizer depends on the genetic makeup of different genotypes. Vigorous shoot growth helps in the manufacture of photosynthates in large quantities. Increase in growth parameters such as plant height, and LAI might have helped the plant to synthesize more photosynthates. Rainfed GCH-4 with 60 kg N ha^{-1} recorded 12 % higher total dry matter than rainfed GCH-4 with 10 kg N ha^{-1}. Moisture deficit caused lower photosynthesis due to low photosynthetic rate, and also adversely affected the translocation of photosynthates to growing parts.

5.2.1 Yield attributes

Main spike length differed between cultivars and nitrogen and water regimes. There was 26 % increase in spike length by nitrogen application, and 7 % increase due to irrigation. Among the various interactions irrigated GCH-4 with 60 kg N ha^{-1} recorded 18 % longer spikes than irrigated Aruna with 60 kg N ha^{-1}. Thus if there is no limitation for moisture and nitrogen growth and development was at its peak, and spike length was maximized thus having a direct bearing on seed yield.

Spikes per plant were also influenced by water, nitrogen and higher yielding cultivars. Flowering (primaries, secondary spike stage) was the most sensitive stage for moisture and nutrients. Lack of moisture in these stages adversely affected the spike production and the yield. Similar findings were reported by Subba Reddy *et al.* 1996.Increasing the nitrogen input from 10 kg N ha^{-1} to 60 kg N ha^{-1} gave 12 % increase in spikes per plant under irrigated conditions whereas it was only 4 % under rainfed conditions. Two years mean data indicated that irrigated GCH-4 with 60 kg N ha^{-1} recorded the highest number of spikes per plant.

Cultivars, nitrogen levels and water regimes significantly influenced the number of capsules per spike. GCH-4 recorded the highest number of capsules per spike under irrigated conditions. GCH-4 under irrigated conditions with 60 kg N ha^{-1} had registered the maximum number of capsules per spike. This might be due to the availability of nitrogen under irrigated conditions for uptake that helped in the production of more number of male flowers, without affecting the production of female flowers and further there was a great improvement in seed yield. Vijaya Kumar and Shiva Shankar (1992) also reported the same findings.

Nitrogen and cultivars significantly influenced the 100 seed weight. Irrigated GCH-4 with 60 kg N ha^{-1} had a mean 100 seed weight of 26.5g. The 100 seed-weight is a stable varietal character because the bean size is rigidly controlled by the size of the capsule coat. Hence seed cannot grow to a size greater than that permitted by the capsule coat, no matter how favorable weather conditions and nutrient supply are.

5.2.2 Seed and stalk yield

Seed yield differed significantly due to cultivars, nitrogen levels and water regimes in both years. GCH-4 had the highest yield of 1930 kg N ha^{-1} under irrigated condition, which was 38 % higher than rainfed ones. Irrigation improved the growth and development of the crop. There was significant increase in LAI, which in turn increased the dry matter accumulation and yield.

GCH-4 was the highest yielding cultivar and the highest seed yield at was at 60 kg N ha^{-1} under irrigated conditions. This is confirms the findings of Bind and Patil (1991). Lack of response of Aruna to fertilizer application may be attributed to its yield potential being well below the productivity level of GCH-4.

Nitrogen application with irrigation enhanced the production of male and female flowers without affecting the sex ratio. Thus there was increased number of capsules per plant, which increased seed yield.

The higher levels of nitrogen might have provided nitrogen in adequate quantities under favourable soil moisture conditions influencing the yield attributes namely the number of spikes per plant, capsules per spike and 100 seed weight. This facilitated overall increase in the seed production at higher nitrogen levels compared to the low level of nitrogen application.

Stalk yield of castor cultivars was significantly influenced by nitrogen and irrigation in both years of study. At 60 kg N ha^{-1} significant interaction effect indicated that there was 4 % increase in stalk yield of cultivar under rainfed condition, while it was 11 % under irrigated conditions. This is because of the availability of nutrients for uptake by the plants under irrigated conditions. This facilitated for the significant growth, development and accumulation of dry matter by the plant.

Irrigated GCH-4 with 60 kg N ha^{-1} had stalk yield of 2,300 kg ha^{-1} which, was 22 % higher than irrigated Aruna with 60 kg N ha^{-1} and 17 % higher than rainfed Aruna with 60 kg N ha^{-1}. This clearly states that a cultivar will accumulate the dry matter to a maximum extent expressing its genetic potentiality under adequate moisture and nutrient conditions, due to the improvement in the plant height, high LAI and dry matter production.

5.2.3 Harvest index

The harvest index of castor differed significantly between cultivars, nitrogen levels and water regimes. GCH-4 recorded highest maximum harvest index of 44.9. This was due the efficiency of that cultivar to accumulate dry matter and to partition accumulated dry matter to the useful sink. Maximum harvest index was recorded by irrigated GCH-4 with 60 kg N ha^{-1} in both years. This indicates that this plant can synthesize, accumulate and partition more dry matter when there is no limitation for moisture and nutrients.

5.2.4 Oil and protein content

Even though the oil content was not significantly influenced by water, nitrogen and cultivars irrigated castors recorded the highest oil percent. Excess application of nitrogen beyond the optimum (60 kg N ha^{-1}) increase the formation of protein precursors, so that protein formation competes more strongly for photosynthesis. As such the fat synthesis was very much affected finally affecting the oil yield. Effect of water, nitrogen and cultivars on protein content of castor bean were non-significant. Minute differences in protein (%) content either among nitrogen treatments or among the water regimes indicates that nitrogen and irrigation are having less effect on seed protein.

5.2.5 Nutrient uptake

The growth pattern of castor as well as the nutrient uptake differs greatly under different agro-climatic conditions. This is due to variation in the climatic factors, soil factors and management, which include variety and amount of nutrient applied. Nutrient uptake by plant parts was mainly influenced by the yield of respective plant parts.

Higher uptake of all the nutrients measured was observed with increasing levels of nitrogen. This may be due to the favorable effect of nitrogen on all the growth and yield attributes, particularly root and shoot growth, which might have facilitated for the absorption of nutrients.

Leaf: As the growth advances after germination, the nitrogen, phosphorus and potash uptake by the leaf increased until peak flowering and thereafter it declined in both years of study. It was due to higher demand of nutrients by seeds and translocation of nutrients into reproductive parts from vegetative parts. Uma Devi *et al.*, 1991 also reported the same findings.

With 60 kg N ha^{-1} and irrigated treatments recorded comparatively higher amounts of nutrient uptake than the lower levels of nitrogen (10 kg N ha^{-1}) and rainfed treatment. This was due to the availability of more nutrients in the root zone at 60 kg N $ha^{-1}$and soil moisture present in the soil. Under adequate moisture conditions, the availability of nutrients was increased, and this was responsible for increased uptake by the plants.

Shoot: Concentration of nitrogen, phosphorus and potash in plant shoots decreased steadily from the commencement of the reproductive phase. Due to the high mobility of nitrogen, nutrients were translocated to the capsules and the concentration in the castor beans increased. This shows that much of the castor beans nitrogen is derived from other plant parts. However, the amount of nitrogen removed to the capsules is proportionately lower than the quantity of nitrogen available in the foliage. Possibly some quantity of nitrogen is being utilized in the increase in dry weight of vegetative parts. Williams (1979) also observed a decline in the amount of nitrogen in leaves and stems shortly after the reproductive growth. Phosphorus and potash in the shoot of castor increased up to peak flowering and thereafter decreased due to the partitioning to the reproductive parts as well as increase in dry matter production. Nitrogen application had increased the nutrient uptake by the vegetative plant parts. Irrigation increased the stalk yields, which ultimately increased the removal of nutrients from the soil.

Spike: Accumulation of nitrogen, phosphorus and potash in floral parts started from flowering. As the spike grew and reached to full maturity, the nutrient uptake also increased. The nutrients are translocated from the vegetative parts (both leaf and shoot) to the reproductive parts. Application of 60 kg N ha^{-1} had increased the uptake by leaf and shoot, and moreover it was partitioned to spike more than at lower nitrogen level (10 kg N ha^{-1}). Similar findings also reported by Venkateswarulu (1988). Irrigation had increased the availability of nutrients at the root zone level, as such increased the uptake by vegetative parts. There was overall increase in dry matter production. Seed yields and nutrient uptake by seed was increased due to irrigation. GCH-4, which recorded the highest seed yield had recorded the maximum nutrient uptake.

5.2.6 Radiation use efficiency

Differences between the two years of experimentation was mainly due to the weather conditions prevailing during those seasons. Temperatures prevailed during the vegetative growth had a direct bearing on the crop growth, infrastructure development and also on overall growth of the crop. With increase in application of nitrogen there was increase in RUE also. This was mainly because of the availability of nitrogen for the plant needs in adequate amounts for crop growth and development. 60 kg N ha^{-1} under irrigated conditions had recorded greater RUE values because the nutrient nitrogen will be available for the uptake by plant roots only when moisture is sufficient. Insufficient moisture in soil will reduce the amount of plant nutrient made.

Even though GAUCH-3 recorded the greater RUE values, the seed yields are lower than the GCH-4 cultivar both under rainfed and irrigated condition. This was mainly due to the differences in partitioning of assimilates from source (leaf) to sink (spike) portion.

Differences in RUE of *kharif* 1998 experiment between rainfed and irrigated treatments were low. This is because of the rainfall pattern of the season. The 1997 irrigated treatments received one irrigation, 1997 *kharif* received two irrigations due to dry weather and less number of rainy days. The resulting plants were tall and lanky with fewer branches in 1998 due to low temperatures and high humidity prevailed during crop growth. The plants were stronger enough with more branches due to higher temperatures and low humidity occurred during the crop period of 1997 *kharif*. The slope of the relationship between net biomass accumulation and cumulative intercepted radiation was linear throughout most of the growth except during the capsule development phase. The decrease in RUE just prior to maturity was associated with loss of biomass due to leaf shedding.

5.2.7 Partitioning

The amount of photosynthates partitioned to the stem ranged from 60 to 80 % out of the total dry matter produced at initial stages of the crop growth. It is mainly for the growth and development of the plant infrastructure. As the crop growth advances, the amount of assimilates partitioned to stem attained a steady state (75-110 DAS). Once the crop entered the reproductive phase, the amount of dry matter partitioned to stem strarted declining reaching to a minimum of 8-10 % of the total above ground dry matter produced.

Out of the total above ground dry matter produced, the amount of dry matter transported to leaf ranged from 25-40 % at the initial stages of crop growth. As the crop growth increases, the amount of dry matter partitioned also increased which depends mainly on the activity of the crop in the production of new leaves, leaf expansion and light interception. Maximum dry matter partitioning to leaf portion was recorded during 90-120 DAS (peak LAI). Later the percentage of assimilates partitioned to leaf portion started declining due to mobilization of assimilates from leaf to sink.

Mobilization of photosynthates to sink starts with the initiation of reproductive phase. Spike initiation itself indicates the partitioning of assimilates to sink portion. The percentage of dry matter partitioned to spike increased with the advancement of reproductive phase to maturity.

5.2.8 Correlation

Negative correlation between seed yield and cumulative intercepted radiation up to 60 DAS was due to the utilization of intercepted radiation for the growth and development of the plant infrastructure rather than for the production of seed. As the crop growth advances, the amount of radiation intercepted increases and most of the accumulated radiation is used in the production and development of the seed.

As the growth advances amount of radiation intercepted increases and it has a positive effect on LAI because of maximum light interception between 90 to 105 DAS. After that assimilates produced by the plant were utilized for the production of seed. The correlation between LAI and seed yield decreased and reached to minimum when once the partitioning of assimilates to seed started. Senescence of leaves at harvest was also one of the reason for the decrease in the correlation between seed yield and LAI.

Unless and until there is no shading of leaves by another one the LAI and cumulative intercepted radiation are positively correlated. Once shading starts with increase in LAI, there was decrease in cumulative intercepted radiation.

5.3 EFFECT OF PLANTING DENSITY ON CASTOR YIELDS

Maximum plant height of PD-2 (130000 plants ha^{-1}) was due to high competition between plants within a row and among rows. As such the inter-nodal length increased very much than the plants in other densities.

Highest LAI was recorded at 105 DAS (active growth period). Highest LAI recorded by PD-2 was mainly due to the presence of more number of plants per square metre. Lack of competition had helped to put-forth more number of secondaries, tertiary branches with large leaf area, which might have contributed for higher LAI of PD-1.

5.2.9 Yield and yield components

PD-3 recorded more spikes per plant, capsules per spike, higher 100 seed weight and seed yield than PD-1. This is because of higher harvest index i.e. partitioning of more dry matter to the reproductive sink from the source.

The more number of plants per unit area in PD-1 compensated the lower per plant yield and yield components to some extent. As such the yields of PD-1 are comparatively higher than PD-2. Optimum plant spacing had reduced the competition between plants for moisture, nutrients, light and space. The same findings have been reported by Singh and Singh (1988) & Vijay kumar Bhosekar (1992). The reduction in seed and stalk yield under high density planting in PD-2 (1,30,000 plants ha^{-1}) was mainly due to lower values of growth and yield attributing characters. Thadoda *et al.* (1996) had also reported the same research findings.

Initially the experiment was planned for the development of castor model. Extra data was recorded which will be used in the castor model development in near future.

SUMMARY

CHAPTER VI

SUMMARY

Castor is an important non-edible oilseed crop grown in India. Today castor oil finds its application in the manufacture of an ever expanding range of industrial products such as nylon fibres, jet engine lubricants, hydraulic surfactants, coatings, greases, fungistats, pharmaceuticals, cosmetics, polyesters and polymers. Suitable agronomic practices need to be developed to improve the productivity of new promising castor varieties for increasing castor production to meet the increasing future demands. An experiment on "Crop growth and development of castor cultivars under optimal and sub-optimal water and nitrogen conditions in Telangana region" was conducted with three objectives namely

1. To determine the relationship between light interception, leaf area development and seed yield.
2. To understand the effects of water and nitrogen on growth and productivity of castor cultivars.
3. To quantify the partitioning of assimilates to castor seeds in different cultivars.

Initially the project was planned with a view to develop a castor model and extra experiments on sowing dates and planting density were carried out. So the dates of sowing and planting density experiments were carried out for one year for data generation and to develop model. Extra data will be used for model development

in near future. Due lack of special programme on castor the title of the project was changed and model development part was deleted from the project work.

4. To study the effect of sowing dates on growth and development of castor cultivars.
5. To study the effect of planting densities on castor yields.

The dates of sowing experiment was laid in CRBD with six dates and four cultivars replicated four times. The experiment was laid out in a split plot design with water regimes as main plots, nitrogen levels as sub-plots and castor cultivars as sub-sub-plots with four replications. The planting density experiment was laid in RBD design with four replications.

Biometrics on growth and physiological parameters, yield and yield attributes were recorded and chemical analysis was done to determine nutrient uptake, oil and protein content. The salient findings of the investigation are summarised here below.

Favourable day length and temperatures prevailed during June first week sowings were responsible for the expression of taller plant height by GCH-4 to the fullest extent. GCH-4 recorded 112 % increase in LAI at 105 DAS and 69 % higher total above ground dry matter production than Aruna at harvest due to the prevalence of favourable day length, temperature and solar radiation during June sowings. Higher yield components like main spike length, number of spikes, capsules per plant and 100 seed -weight of GCH-4 in June sowings contributed to significant increase in seed yield. The crop sown beyond July recorded the lowest seed yield, which was due to the coincidence of flowering and capsule development with relatively low temperatures finally affecting the fertilization and sometimes due to Botrytis mould disease. The same treatment recorded 11 % increase in harvest index than Aruna indicating the highest partitioning efficiency of GCH-4. The more the partitioning the more will be the seed yield and harvest index. Highest seed yields recorded by GCH-4 in June sowings than the remaining dates were due to the accumulation of maximum heat units. This indicates the importance of sowing time, which has a direct bearing on yield indicating the importance of daylength and temperature.

In the experiment where water regimes and nitrogen tested against each other, irrigated GCH-4 castor cultivar at 60 kg N ha^{-1} recorded the tallest plant height. This was due to the increased availability of nutrients under irrigated conditions than the rainfed, which has a positive effect on cell multiplication growth and development. Irrigated GCH-4 with 60 kg N ha^{-1} recorded 2.29 mean LAI and 11 % higher total above ground drymatter than at 10 kg N ha^{-1}.

There was 26 % increase in main spike length by nitrogen application and 7 % increase due to irrigation. Nitrogen application under irrigated conditions had enhanced the production of male and female flowers without affecting the sex ratio. As such there was improvement in the production of capsules per plant, which had a positive effect on seed yield. Out of the four cultivars tested, GCH-4 recorded the higher seed yield of 1920 kg ha^{-1} under irrigated conditions, which was 38 % higher than the rainfed ones. The higher levels of nitrogen might have provided nitrogen in adequate quantities under favourable soil moisture conditions influenced the yield and yield attributes namely main spike length, spikes per plant, capsules per spike and 100 seed weight. This might have facilitated the overall increase in seed production at higher levels of nitrogen. At 60 kg N ha^{-1} stalk yield increased by 11 % under irrigated condition, while it was only 4 % under rainfed situation. This is because of the availability of nutrients for the uptake by the plant under irrigated conditions. This facilitated the significant growth, development and accumulation of drymatter by the plant.

Irrigated GCH-4 with 60 kg N ha^{-1} recorded the higher mean harvest index of 44.9, which indicates that a plant can synthesize, accumulate and partition more drymatter when there is no limitation for the moisture and nutrients. The plants have a temperature requirement for their growth, development and maturity. Temperature influences the plant through root growth, nutrient uptake, water absorption, photosynthesis, respiration and translocation of photosynthates. The highest seed yield recorded by GCH-4 at 60 kg N ha^{-1} under irrigated conditions was mainly due to the accumulation of higher growing degreedays. Peak RUE recorded by irrigated GCH-4 at higher level of nitrogen was due to the availability of nutrients in adequate amounts for the plant growth and development. Slight changes in RUE was due to the disease incidence, leaf shedding. Same treatment combination also recorded maximum drymatter partitioning to leaf portion during 90-120 DAS (peak LAI). Later the percentage of assimilates partitioned to leaf portion started declining due to the mobilization of assimilates from leaf to sink portion. The percentage of drymatter partitioned to spike portion increased with the advancement of reproductive phase to maturity.

Unless and until there is no shading of leaves by the above leaves the LAI and cumulative intercepted radiation are positively correlated. Once shading starts with increase in LAI, there was decrease in the amount of radiation intercepted. The uptake of the major nutrients by the leaf increased from germination until peak flowering and there after it starts declining due to higher demand for the nutrients by seed and translocation of nutrients into the reproductive parts from vegetative portion. The amount of nitrogen in leaves and stem started declining after the reproductive growth. Phosphorus and potash in the shoot of the castor cultivars increased up to the peak flowering and thereafter decreased due to the partitioning to the reproductive parts as well as with the advancement in the growth. Out of the four cultivars, GCH-4 recorded the highest seed yield, nutrient uptake, oil and protein content.

Out of the three planting densities, PD-2 (75x 10 cm) recorded the maximum plant height and LAI. Less competition in PD-1 (75x 25 cm) helped it to put forth more branches that contributed for higher LAI than PD-3 (75 x 75 cm). PD-3 recorded more number of spikes per plant, capsules per spike, and higher100 seed-weight and seed yield than PD-1. This is due to less competition between plants within a row and between rows and also due to the partitioning of more drymatter to the reproductive parts. Optimum plant spacing had reduced the competition between plants for moisture, nutrients, light and space.

The following conclusions can be drawn from the results of the present study

1. Sowing of castor during first week of June was found to be the best. Sowing beyond June-July was found to reduce the castor yield drastically due to the coincidence of flowering with high relative humidity, low temperatures, incidence of Botrytis mould and semi-looper attack.

2. Wherever there is irrigation facility, castor can be grown under irrigated conditions by scheduling the irrigation at IW / CPE ratio of 0.75.

3. When compared to 10 kg N ha^{-1} application of 60 kg N ha^{-1} was found to be better. Application of 60 kg N ha^{-1} under irrigated conditions will help to boost the castor seed yield. Under irrigated conditions top dressing with nitrogen at vegetative phase and spike initiation will help in achieving higher yields.

4. Among the cultivars investigated, GCH-4 was found to perform better under irrigated conditions with recommended dose of nitrogen (60 kg ha^{-1}), owing to its efficiency in partitioning of the assimilates from source to sink.

5. Out of three planting densities 17,000 plants ha^{-1} was found to yield better than 1,30,000 plants $ha^{-1}$and 55,000 plants ha^{-1}.

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APPENDICES

Appendix I

Weekly Meteorological data during the Crop period. (*kharif*, 1998)

Std. Week	Date	Month	T max	Tmin	Mean RH	Solar Radiation	Evaporation	Rainfall (mm)	Rainy days
26	26-2	June	33.3	22.5	47.5	16.4	49.3	0.4	0.0
27	3-9	July	30.7	22.0	49.1	12.0	37.9	18.4	2
28	10-16	July	33.4	21.7	46.2	18.7	55.8	0.8	0
29	17-23	July	33.1	21.1	47.95	19.5	42.6	69.7	2
30	24-30	July	31.6	21.0	51.3	16.2	32.8	194.0	4
31	31-6	Aug	28.3	20.4	54.25	14.5	25.4	75.6	5
32	7—13	Aug	29.1	20.3	55.45	18.2	25.2	88.9	3
33	14-20	Aug	29.6	20.8	54.85	14.5	22.4	75.8	5
34	21-27	Aug	30.9	21.2	53.3	18.2	27.2	44.0	4
35	28-3	Sep	29.6	20.6	51.95	17.6	31.4	1.4	0
36	4-10	Sep	28.5	20.5	55.95	12.6	21.4	74.5	5
37	11-17	Sep	29.5	20.4	53.5	15.5	24.6	3.8	0
38	18-24	Sep	29.4	20.2	53.15	15.2	25.6	83.6	5
39	25-1	Oct	29.4	20.7	53.8	15.1	23.9	30.3	5
40	2-8	Oct	30.2	19.9	54.1	17.0	26.8	41.8	4
41	9-15	Oct	29.7	20.5	53.2	15.0	25.8	94.9	5
42	16-22	Oct	28.6	17.6	50.75	15.7	27.9	22.7	1
43	23-29	Oct	30.4	17.6	47.2	20.6	28.9	0.0	0
44	30-5	Nov	28.2	17.4	49.6	12.6	21.5	7.2	1
45	6-12	Nov	29.6	17.9	49.65	14.3	26.2	0.6	0
46	13-19	Nov	29	15.4	44.65	18.0	32.9	0.0	0
47	20-26	Nov	28.7	13.7	47.25	16.3	26.4	13.0	1
48	27-2	Dec	28.2	10.6	41.35	17.6	30.0	0.0	0
49	3-9	Dec	28.8	8.9	39.35	18.0	34.6	0.0	0
50	10-16	Dec	26.8	10.0	40.85	15.5	30.8	0.0	0
51	17-23	Dec	27.1	8.0	40	17.0	26.1	0.0	0
52	24-31	Dec	26.8	9.0	40.15	16.9	31.8	0.0	0
1	1-7	Jan	26.6	10.6	35.75	15.7	24.3	0.0	0
2	8-14	Jan	26.9	11.6	40.5	15.8	26.4	0.0	0
3	15-21	Jan	27.4	10.3	41.9	14.9	34.0	0.0	0

Weekly Meteorological data during the Crop period

Std. Week	Date	Month	T max	Tmin	Mean RH	Solar Radiation	Evaporation	Rainfall (mm)	Rainy days
44	30-5	Nov 1996	29.6	15.6	64.5	18.0	32.9	0	0
45	6-12	Nov	29.4	17.7	66.3	17.2	33.1	22.4	1
46	13-19	Nov	29.8	16.3	64.0	18.4	35.6	0	0
47	20-26	Nov	28.4	14.3	66.7	14.0	27.8	0	0
48	27-2	Dec	28.2	12.2	64.7	16.6	30.7	0	0
49	3-9	Dec	27.5	14.6	65.6	14.1	27.2	0	0
50	10-16	Dec	28.1	14.1	60.4	13.9	28.6	0	0
51	17-23	Dec	28.4	13.6	61.0	14.8	30.0	0	0
52	24-31	Dec	27.3	11.7	62.9	16.2	33.2	0 .	0
1	1-7	Jan 1997	26.5	12.0	96.4	16.0	30.0	0	0
2	8-14	Jan	25.9	15.7	70.5	13.7	29.6	1	0
3	15-21	Jan	26.8	15.8	72.3	14.2	26.3	10.4	1
4	22-28	Jan	28.4	12.4	58.7	18.9	34.4	0	0
5	29-4	Feb	30.0	13.6	58.1	19.4	34.0	0	0
6	5-11	Feb	31.1	14.3	58.2	19.4	39.3	0	0
7	12-18	Feb	31.1	11.0	51.2	21.4	46.6	0	0
8	19-25	Feb	32.4	15.7	54.5	20.4	27.9	0	0
9	26-4	Mar	34.0	15.1	48.8	21.5	53.8	0	0
10	5-11	Mar	34.6	17.0	47.8	19.5	54.6	0	0
11	12-18	Mar	37.1	19.3	46.0	20.8	59.5	0	0
12	19-25	Mar	36.0	19.9	49.0	22.5	58.1	3	1
13	26-1	April	34.1	19.8	58.9	22.7	52.6	53.8	2
14	2-8	April	32.6	20.3	63.2	20.9	45.2	9.6	1
15	9-15	April	36.1	20.6	42.8	24.7	63.4	0	0
16	16-22	April	34.6	20.6	55.6	23.5	61.6	20	2
17	23-29	April	36.5	21.8	51.8	23.0	66.0	8.8	1
18	30-6	May	34.4	21.1	58.2	22.8	60.3	1.5 .	3
19	7-13	May	36.8	24.4	49.2	24.6	60.1	0	0
20	14-20	May	39.7	24.9	41.6	23.7	78.9	0	0
21	21-27	May	40.2	24.8	34.9	24.8	84.9	0	0
22	28-3	June	40.0	24.4	34.3	25.5	96.7	0	0
23	4-10	June	37.2	24.3	50.2	21.4	67.5	3	1
24	11-17	June	35.5	23.8	60.4	21.2	66.4	3.2	1
25	18-24	June	34.6	23.7	60.4	20.9	69.2	9	1
26	26-2	June	35.7	24.1	58.3	19.1	65	14.6	3
27	3-9	July	30.3	22.2	75.15	13.8	32.4	51.7	4
28	10-16	July	32.8	23.5	66.1	17.0	54.6	16.2	1
29	17-23	July	33.8	24.4	60.5	19.0	61.0	0	0
30	24-30	July	31.1	23.1	72.5	15.4	43.0	77.4	5
31	31-6	Aug	30.2	22.9	73.6	13.2	40.6	4.3	1
32	7-13	Aug	30.3	22.7	71.9	15.8	35.2	10.2	1
33	14-20	Aug	31.3	22.6	71.2	18.1	41.0	21.6	4
34	21-27	Aug	30.6	22.5	74.6	15.0	36.2	4.4	1
35	28-3	Sep	29.8	21.6	73.8	17.5	44.3	98.4	2
36	4-10	Sep	30.6	22.5	79.0	16.1	31.4	55.8	3
37	11-17	Sep	30.	22.3	80.8	16.5	26.0	6.6	1
38	18-24	Sep	29.7	21.5	83.25	17.1	29.5	52.9	5

Std. Week	Date	Month	T max	Tmin	Mean RH	Solar Radiation	Evaporation	Rainfall (mm)	Rainy days
39	25-1	Oct 1997	30.8	21.3	76.8	18.1	30.4	36	2
40	2-8	Oct	30.6	19.3	72.0	20.1	30.5	1.8	0
41	9-15	Oct	31.2	18.9	66.4	21.8	34.1	0	0
42	16-22	Oct	31.3	20.0	67.6	18.2	34.3	0	0
43	23-29	Oct	30.0	19.8	72.7	14.8	30.9	34	2
44	30-5	Nov	29.5	19.8	83.1	15.3	27.1	22.4	1
45	6-12	Nov	29.7	17.9	70.2	16.7	28.6	0.9	0
46	13-19	Nov	29.0	19.8	79.4	13.0	23.5	46.6	3
47	20-26	Nov	29.0	19.8	74.7	15.0	27.1	0	0
48	27-2	Dec	29.2	20.4	74.3	15.2	30.9	3.5	1
49	3-9	Dec	28.1	18.1	73.0	14.5	28.5	2.5	1
50	10-16	Dec	26.9	17.1	78.3	13.5	18.1	0.7	0
51	17-23	Dec	27.5	18.7	77.8	11.9	18.4	2.5	1
52	24-31	Dec	29.4	17.6	69.2	16.3	32.4	0	0
1	1-7	Jan1998	27.8	14.0	68.5	15.9	29.7	0	0
2	8-14	Jan	28.4	12.5	68.7	17.3	26.5	0	0
3	15-21	Jan	31.3	15.8	67.8	16.5	32.4	0	0

SOIL MOISTURE CONTENT RECORDED AT DIFFERENT PROFILES (mm of moisture /mm depth of soil)

1997 Treatment	Sampling	**0-15**	**15-22.5**	**22.5-37.5**	**37.5-52.5**	**52.5-67.5**	**67.5-82.5**	**82.5-97.5**	**97.5-112.5**
W1N2C1	18-7-97	0.059	0.022	0.016	0.126	0.128	0.104	0.118	0.209
W1N2C1	7/8/97	0.081	0.005	0.071	0.093	0.12	0.133	0.084	0.183
W1N2C1	13-8-97	0.066	0.009	0.083	0.088	0.108	0.113	0.072	0.064
W1N2C1	16-8-97	0.159	0.042	0.075	0.079	0.101	0.109	0.08	0.181
W1N2C1	29-8-97	0.207	0.137	0.066	0.122	0.139	0.115	0.08	0.175
W1N2C1	9/9/97	0.201	0.092	0.017	0.127	0.113	0.071	0.108	0.18
W1N2C1	15-9-97	0.16	0.068	0.024	0.096	0.107	0.109	0.076	0.175
W1N2C1	19-9-97	0.172	0.064	0.044	0.129	0.107	0.063	0.114	0.186
W1N2C1	23-9-97	0.184	0.073	0.038	0.119	0.113	0.069	0.108	0.184
W1N2C1	30-9-97	0.127	0.045	0.038	0.086	0.099	0.097	0.065	0.168
W1N2C1	27-10-97	0.05	0.022	0.093	0.105	0.082	0.047	0.075	0.181
W1N2C1	28-10-97	0.191	0.050	0.091	0.102	0.084	0.04	0.067	0.195
W1N2C1	29-10-97	0.191	0.065	0.062	0.109	0.074	0.061	0.067	0.175
W2N2C1	18-7-97	0.073	0.083	0.093	0.165	0.087	0.064	0.116	0.09
W2N2C1	7/8/97	0.108	0.084	0.059	0.158	0.109	0.058	0.102	0.121
W2N2C1	13-8-97	0.1	0.078	0.055	0.134	0.081	0.167	0.158	0.153
W2N2C1	16-8-97	0.223	0.157	0.09	0.158	0.106	0.06	0.105	0.132
W2N2C1	29-8-97	0.259	0.217	0.175	0.188	0.124	0.084	0.133	0.159
W2N2C1	9/9/97	0.22	0.154	0.087	0.137	0.068	0.127	0.167	0.148
W2N2C1	15-9-97	0.154	0.120	0.086	0.164	0.09	0.045	0.083	0.112
W2N2C1	19-9-97	0.158	0.117	0.075	0.15	0.049	0.043	0.103	0.102
W2N2C1	23-9-97	0.135	0.104	0.072	0.146	0.042	0.04	0.099	0.089
W2N2C1	30-9-97	0.175	0.115	0.054	0.139	0.066	0.02	0.056	0.083
W2N2C1	27-10-97	0.079	0.056	0.032	0.115	0.005	0.009	0.064	0.05
W2N2C1	28-10-97	0.08	0.052	0.023	0.118	0.002	0.047	0.05	0.041
W2N2C1	29-10-97	0.239	0.189	0.138	0.15	0.039	0.037	0.074	0.059

SOIL MOISTURE CONTENT RECORDED AT DIFFERENT PROFILES (mm of moisture /mm depth of soil)

1997		**0-15**	**15-22.5**	**22.5-37.5**	**37.5-52.5**	**52.5-67.5**	**67.5-82.5**	**82.5-97.5**	**97.5-112.5**
Treatment	Sampling date								
W1N1C1	18-7-97	0.058	0.049	0.039	0.119	0.090	0.200	0.203	0.146
W1N1C1	7/8/97	0.073	0.017	0.039	0.108	0.043	0.151	0.249	0.189
W1N1C1	13-8-97	0.062	0.002	0.058	0.093	0.045	0.150	0.246	0.184
W1N1C1	16-8-97	0.168	0.062	0.044	0.089	0.032	0.145	0.240	0.181
W1N1C1	29-8-97	0.212	0.166	0.119	0.153	0.092	0.172	0.241	0.172
W1N1C1	9/9/97	0.208	0.143	0.078	0.102	0.085	0.220	0.200	0.128
W1N1C1	15-9-97	0.138	0.091	0.044	0.118	0.054	0.160	0.237	0.157
W1N1C1	19-9-97	0.149	0.098	0.046	0.104	0.088	0.220	0.183	0.127
W1N1C1	23-9-97	0.158	0.108	0.057	0.102	0.083	0.219	0.186	0.125
W1N1C1	30-9-97	0.128	0.082	0.035	0.109	0.045	0.146	0.234	0.157
W1N1C1	27-10-97	0.054	0.015	0.024	0.080	0.052	0.208	0.175	0.107
W1N1C1	28-10-97	0.185	0.080	0.025	0.076	0.059	0.196	0.175	0.108
W1N1C1	29-10-97	0.185	0.107	0.028	0.081	0.052	0.193	0.174	0.112
W2N1C2	18-7-97	0.077	0.102	0.127	0.175	0.075	0.124	0.182	0.133
W2N1C2	7/8/97	0.092	0.071	0.05	0.166	0.105	0.162	0.133	0.097
W2N1C2	13-8-97	0.092	0.067	0.041	0.163	0.107	0.098	0.134	0.142
W2N1C2	16-8-97	0.163	0.121	0.079	0.154	0.056	0.102	0.183	0.177
W2N1C2	29-8-97	0.253	0.216	0.178	0.21	0.131	0.152	0.206	0.177
W2N1C2	9/9/97	0.207	0.186	0.164	0.146	0.079	0.145	0.2	0.156
W2N1C2	15-9-97	0.171	0.153	0.134	0.179	0.054	0.101	0.168	0.164
W2N1C2	19-9-97	0.178	0.174	0.169	0.124	0.065	0.118	0.179	0.139
W2N1C2	23-9-97	0.184	0.162	0.139	0.131	0.053	0.118	0.172	0.124
W2N1C2	30-9-97	0.133	0.117	0.101	0.167	0.041	0.069	0.136	0.139
W2N1C2	27-10-97	0.074	0.077	0.08	0.1	0.033	0.071	0.136	0.091
W2N1C2	28-10-97	0.061	0.063	0.065	0.097	0.02	0.073	0.126	0.088
W2N1C2	29-10-97	0.22	0.190	0.159	0.121	0.037	0.075	0.138	0.089

SOIL MOISTURE CONTENT RECORDED AT DIFFERENT PROFILES (mm of moisture /mm depth of soil)

1997

Treatment	Sampling	0-15	15-22.5	22.5-37.5	37.5-52.5	52.5-67.5	67.5-82.5	82.5-97.5	97.5-112.5
W1N1C3	18-7-97	0.058	0.062	0.066	0.141	0.176	0.202	0.189	0.125
W1N1C4	7/8/97	0.074	0.036	0.003	0.112	0.153	0.215	0.222	0.168
W1N1C5	13-8-97	0.067	0.019	0.029	0.098	0.148	0.211	0.232	0.188
W1N1C6	16-8-97	0.17	0.060	0.051	0.094	0.03	0.185	0.22	0.217
W1N1C7	29-8-97	0.224	0.176	0.127	0.155	0.175	0.205	0.213	0.162
W1N1C8	9/9/97	0.188	0.116	0.043	0.131	0.187	0.2	0.182	0.12
W1N1C9	15-9-97	0.139	0.089	0.039	0.114	0.149	0.204	0.209	0.146
W1N1C10	19-9-97	0.162	0.095	0.028	0.14	0.185	0.199	0.174	0.12
W1N1C11	23-9-97	0.183	0.105	0.026	0.127	0.177	0.194	0.174	0.123
W1N1C12	30-9-97	0.142	0.085	0.028	0.106	0.142	0.2	0.204	0.15
W1N1C13	27-10-97	0.061	0.019	0.023	0.139	0.188	0.2	0.17	0.101
W1N1C14	28-10-97	0.187	0.078	0.032	0.113	0.176	0.185	0.165	0.11
W1N1C15	29-10-97	0.187	0.083	0.022	0.115	0.175	0.185	0.165	0.099
W2N1C3	18-7-97	0.087	0.135	0.183	0.188	0.127	0.117	0.184	0.15
W2N1C3	7/8/97	0.101	0.097	0.093	0.193	0.157	0.125	0.199	0.215
W2N1C3	13-8-97	0.107	0.100	0.093	0.187	0.145	0.113	0.202	0.176
W2N1C3	16-8-97	0.226	0.177	0.128	0.181	0.134	0.106	0.192	0.214
W2N1C3	29-8-97	0.247	0.233	0.219	0.227	0.183	0.15	0.222	0.228
W2N1C3	9/9/97	0.225	0.236	0.246	0.187	0.119	0.144	0.22	0.211
W2N1C3	15-9-97	0.173	0.186	0.198	0.21	0.16	0.114	0.202	0.201
W2N1C3	19-9-97	0.188	0.213	0.238	0.179	0.105	0.142	0.207	0.168
W2N1C3	23-9-97	0.18	0.203	0.226	0.172	0.097	0.136	0.202	0.195
W2N1C3	30-9-97	0.14	0.159	0.178	0.198	0.143	0.089	0.186	0.194
W2N1C3	27-10-97	0.082	0.115	0.147	0.141	0.059	0.112	0.165	0.151
W2N1C3	28-10-97	0.079	0.111	0.143	0.143	0.059	0.091	0.159	0.144
W2N1C3	29-10-97	0.261	0.240	0.219	0.157	0.07	0.113	0.169	0.154

SOIL MOISTURE CONTENT RECORDED AT DIFFERENT PROFILES (mm of moisture /mm depth of soil)

1997 Treatment	Sampling	0-15	15-22.5	22.5-37.5	37.5-52.5	52.5-67.5	67.5-82.5	82.5-97.5	97.5-112.5
W1N1C4	18-7-97	0.045	0.038	0.031	0.137	0.168	0.12	0.181	0.196
W1N1C4	7/8/97	0.061	0.009	0.044	0.111	0.122	0.124	0.147	0.197
W1N1C4	13-8-97	0.075	0.013	0.049	0.094	0.109	0.098	0.102	0.094
W1N1C4	16-8-97	0.168	0.067	0.034	0.095	0.093	0.095	0.134	0.203
W1N1C4	29-8-97	0.203	0.162	0.12	0.157	0.154	0.103	0.118	0.208
W1N1C4	9/9/97	0.187	0.129	0.07	0.13	0.107	0.072	0.165	0.189
W1N1C4	15-9-97	0.157	0.097	0.036	0.118	0.101	0.08	0.118	0.19
W1N1C4	19-9-97	0.172	0.104	0.035	0.118	0.096	0.065	0.165	0.192
W1N1C4	23-9-97	0.178	0.104	0.029	0.115	0.138	0.064	0.168	0.186
W1N1C4	30-9-97	0.149	0.084	0.018	0.109	0.095	0.065	0.107	0.18
W1N1C4	27-10-97	0.06	0.012	0.037	0.104	0.092	0.062	0.158	0.168
W1N1C4	28-10-97	0.182	0.040	0.103	0.079	0.042	0.104	0.074	0.16
W1N1C4	29-10-97	0.182	0.088	0.006	0.109	0.088	0.049	0.139	0.169
W2N1C4	18-7-97	0.065	0.072	0.079	0.146	0.079	0.146	0.171	0.159
W2N1C4	7/8/97	0.096	0.078	0.059	0.153	0.106	0.119	0.181	0.178
W2N1C4	13-8-97	0.093	0.069	0.045	0.154	0.098	0.113	0.186	0.161
W2N1C4	16-8-97	0.213	0.156	0.098	0.153	0.1	0.116	0.183	0.188
W2N1C4	29-8-97	0.278	0.218	0.158	0.184	0.151	0.154	0.195	0.199
W2N1C4	9/9/97	0.205	0.163	0.121	0.167	0.083	0.097	0.139	0.139
W2N1C4	15-9-97	0.171	0.136	0.1	0.156	0.094	0.113	0.177	0.181
W2N1C4	19-9-97	0.175	0.142	0.109	0.139	0.08	0.146	0.184	0.19
W2N1C4	23-9-97	0.17	0.138	0.105	0.143	0.074	0.141	0.171	0.178
W2N1C4	30-9-97	0.134	0.110	0.086	0.145	0.072	0.094	0.154	0.174
W2N1C4	27-10-97	0.072	0.057	0.041	0.111	0.038	0.105	0.15	0.144
W2N1C4	28-10-97	0.068	0.059	0.05	0.106	0.026	0.093	0.143	0.139
W2N1C4	29-10-97	0.256	0.184	0.111	0.123	0.036	0.105	0.149	0.145

SOIL MOISTURE CONTENT RECORDED AT DIFFERENT PROFILES (mm of moisture /mm depth of soil)

1997 Treatment	Sampling	**0-15**	**15-22.5**	**22.5-37.5**	**37.5-52.5**	**52.5-67.5**	**67.5-82.5**	**82.5-97.5**	**97.5-112.5**
W1N2C2	18-7-97	0.053	0.061	0.068	0.126	0.076	0.106	0.156	0.152
W1N2C2	7/8/97	0.065	0.032	0.002	0.115	0.074	0.093	0.172	0.159
W1N2C2	13-8-97	0.063	0.026	0.012	0.107	0.057	0.085	0.177	0.196
W1N2C2	16-8-97	0.164	0.086	0.007	0.106	0.048	0.075	0.178	0.178
W1N2C2	29-8-97	0.221	0.169	0.117	0.145	0.051	0.059	0.16	0.166
W1N2C2	9/9/97	0.198	0.118	0.038	0.098	0.019	0.091	0.143	0.157
W1N2C2	15-9-97	0.14	0.096	0.051	0.109	0.028	0.047	0.169	0.151
W1N2C2	19-9-97	0.172	0.104	0.036	0.096	0.022	0.098	0.143	0.157
W1N2C2	23-9-97	0.181	0.110	0.038	0.095	0.017	0.088	0.135	0.164
W1N2C2	30-9-97	0.127	0.079	0.03	0.104	0.021	0.034	0.136	0.142
W1N2C2	27-10-97	0.064	0.011	0.043	0.077	0.009	0.081	0.116	0.144
W1N2C2	28-10-97	0.187	0.077	0.033	0.077	0.016	0.067	0.119	0.131
W1N2C2	29-10-97	0.187	0.085	0.017	0.077	0.014	0.063	0.117	0.142
W2N2C2	18-7-97	0.088	0.079	0.07	0.149	0.125	0.18	0.182	0.161
W2N2C2	7/8/97	0.108	0.080	0.052	0.149	0.121	0.165	0.202	0.211
W2N2C2	13-8-97	0.122	0.085	0.047	0.146	0.121	0.155	0.208	0.211
W2N2C2	16-8-97	0.207	0.141	0.075	0.141	0.116	0.165	0.21	0.215
W2N2C2	29-8-97	0.259	0.214	0.168	0.179	0.155	0.203	0.22	0.226
W2N2C2	9/9/97	0.203	0.150	0.096	0.146	0.138	0.183	0.217	0.187
W2N2C2	15-9-97	0.18	0.135	0.089	0.145	0.114	0.168	0.203	0.213
W2N2C2	19-9-97	0.154	0.121	0.087	0.142	0.12	0.188	0.212	0.183
W2N2C2	23-9-97	0.151	0.112	0.073	0.138	0.129	0.185	0.209	0.184
W2N2C2	30-9-97	0.204	0.139	0.073	0.135	0.099	0.17	0.204	0.203
W2N2C2	27-10-97	0.079	0.054	0.028	0.121	0.112	0.159	0.169	0.138
W2N2C2	28-10-97	0.08	0.048	0.016	0.117	0.088	0.151	0.164	0.129
W2N2C2	29-10-97	0.262	0.182	0.102	0.126	0.107	0.155	0.175	0.135

SOIL MOISTURE CONTENT RECORDED AT DIFFERENT PROFILES (mm of moisture /mm depth of soil)

1997									
Treatment	Sampling	**0-15**	**15-22.5**	**22.5-37.5**	**37.5-52.5**	**52.5-67.5**	**67.5-82.5**	**82.5-97.5**	**97.5-112.5**
W1N2C3	18-7-97	0.057	0.028	0.02	0.108	0.092	0.153	0.187	0.231
W1N2C3	7/8/97	0.079	0.006	0.068	0.075	0.027	0.123	0.172	0.254
W1N2C3	13-8-97	0.073	0.004	0.081	0.068	0.017	0.098	0.125	0.122
W1N2C3	16-8-97	0.179	0.047	0.086	0.06	0.004	0.004	0.061	0.193
W1N2C3	29-8-97	0.194	0.142	0.09	0.142	0.116	0.136	0.169	0.238
W1N2C3	9/9/97	0.196	0.116	0.035	0.105	0.105	0.145	0.191	0.253
W1N2C3	15-9-97	0.151	0.091	0.031	0.098	0.059	0.129	0.166	0.251
W1N2C3	19-9-97	0.172	0.089	0.005	0.097	0.104	0.147	0.227	0.254
W1N2C3	23-9-97	0.177	0.095	0.013	0.095	0.099	0.142	0.205	0.254
W1N2C3	30-9-97	0.122	0.068	0.014	0.094	0.049	0.109	0.15	0.248
W1N2C3	27-10-97	0.057	0.100	0.076	0.066	0.064	0.12	0.194	0.242
W1N2C3	28-10-97	0.194	0.055	0.085	0.066	0.061	0.112	0.184	0.221
W1N2C3	29-10-97	0.194	0.077	0.04	0.068	0.06	0.119	0.181	0.22
W2N2C3	18-7-97	0.1	0.141	0.181	0.2	0.134	0.129	0.161	0.202
W2N2C3	7/8/97	0.139	0.141	0.143	0.214	0.178	0.138	0.162	0.215
W2N2C3	13-8-97	0.124	0.136	0.147	0.202	0.173	0.166	0.154	0.179
W2N2C3	16-8-97	0.25	0.219	0.187	0.212	0.159	0.132	0.165	0.232
W2N2C3	29-8-97	0.265	0.250	0.234	0.229	0.2	0.162	0.173	0.233
W2N2C3	9/9/97	0.248	0.226	0.204	0.185	0.114	0.128	0.183	0.232
W2N2C3	15-9-97	0.184	0.177	0.169	0.195	0.138	0.104	0.141	0.221
W2N2C3	19-9-97	0.189	0.182	0.175	0.176	0.099	0.123	0.179	0.225
W2N2C3	23-9-97	0.288	0.230	0.172	0.171	0.09	0.107	0.167	0.234
W2N2C3	30-9-97	0.181	0.165	0.149	0.179	0.107	0.087	0.124	0.196
W2N2C3	27-10-97	0.091	0.119	0.147	0.149	0.061	0.084	0.135	0.186
W2N2C3	28-10-97	0.091	0.114	0.136	0.147	0.061	0.078	0.135	0.197
W2N2C3	29-10-97	0.235	0.223	0.21	0.165	0.086	0.105	0.147	0.191

SOIL MOISTURE CONTENT RECORDED AT DIFFERENT PROFILES (mm of moisture /mm depth of soil)

1997 Treatment	Sampling	**0-15**	**15-22.5**	**22.5-37.5**	**37.5-52.5**	**52.5-67.5**	**67.5-82.5**	**82.5-97.5**	**97.5-112.5**
W1N2C4	18-7-97	0.047	0.043	0.038	0.135	0.151	0.165	0.17	0.187
W1N2C4	7/8/97	0.076	0.035	0.06	0.124	0.122	0.181	0.181	0.19
W1N2C4	13-8-97	0.064	0.027	0.01	0.112	0.095	0.191	0.189	0.188
W1N2C4	16-8-97	0.162	0.083	0.003	0.104	0.082	0.17	0.179	0.206
W1N2C4	29-8-97	0.196	0.163	0.13	0.165	0.127	0.174	0.191	0.206
W1N2C4	9/9/97	0.189	0.125	0.06	0.122	0.132	0.157	0.163	0.184
W1N2C4	15-9-97	0.144	0.103	0.062	0.119	0.088	0.154	0.161	0.175
W1N2C4	19-9-97	0.174	0.093	0.012	0.119	0.131	0.154	0.162	0.186
W1N2C4	23-9-97	0.192	0.103	0.014	0.114	0.131	0.154	0.151	0.178
W1N2C4	30-9-97	0.146	0.084	0.021	0.11	0.075	0.145	0.152	0.158
W1N2C4	27-10-97	0.053	0.004	0.046	0.086	0.089	0.115	0.127	0.142
W1N2C4	28-10-97	0.173	0.064	0.04	0.089	0.081	0.114	0.118	0.145
W1N2C4	29-10-97	0.173	0.098	0.022	0.098	0.095	0.119	0.122	0.143
W2N2C4	18-7-97	0.084	0.066	0.047	0.16	0.121	0.147	0.201	0.195
W2N2C4	7/8/97	0.117	0.074	0.03	0.166	0.12	0.165	0.211	0.237
W2N2C4	13-8-97	0.155	0.084	0.013	0.158	0.129	0.168	0.222	0.186
W2N2C4	16-8-97	0.236	0.152	0.067	0.164	0.127	0.165	0.226	0.247
W2N2C4	29-8-97	0.198	0.179	0.159	0.202	0.168	0.197	0.237	0.256
W2N2C4	9/9/97	0.251	0.180	0.108	0.153	0.143	0.183	0.231	0.241
W2N2C4	15-9-97	0.175	0.109	0.042	0.165	0.12	0.152	0.213	0.242
W2N2C4	19-9-97	0.202	0.150	0.097	0.153	0.13	0.179	0.233	0.262
W2N2C4	23-9-97	0.169	0.125	0.08	0.149	0.123	0.166	0.222	0.235
W2N2C4	30-9-97	0.143	0.089	0.034	0.15	0.106	0.137	0.191	0.223
W2N2C4	27-10-97	0.089	0.064	0.038	0.128	0.1	0.129	0.175	0.18
W2N2C4	28-10-97	0.092	0.063	0.033	0.124	0.095	0.126	0.167	0.185
W2N2C4	29-10-97	0.225	0.193	0.161	0.167	0.148	0.165	0.214	0.224

SOIL MOISTURE CONTENT RECORDED AT DIFFERENT PROFILES (mm of moisture /mm depth of soil)

1998

Treatment	Sampling	**0-15**	**15-22.5**	**22.5-37.5**	**37.5-52.5**	**52.5-67.5**	**67.5-82.5**	**82.5-97.5**	**97.5-112.5**
W1N1C1	7/7/98	19.2	24.15	29.1	39.1	45.5	49	43.2	35
W1N1C2	7/7/98	21.07	22.29	23.5	35.35	40.5	40.8	37.05	40.5
W1N1C3	7/7/98	22.4	21.90	21.3	37.75	42.4	39.2	38.7	38.4
W1N1C4	7/7/98	18.5	22.32	26.05	31.85	41.5	35.4	34.2	31.3
W1N2C1	7/7/98	16.9	18.40	20.05	34.5	40.62	41	35.65	40.7
W1N2C2	7/7/98	19.5	16.78	17.4	34.56	31.1	32.1	33.45	31.7
W1N2C3	7/7/98	19.12	18.36	16.45	30.8	30.81	36.2	34.6	40.1
W1N2C4	7/7/98	14.75	15.36	32.1	29,87	42	40.88	39.3	35.3
W2N1C1	7/7/98	22.8	27.44	25.75	38.1	43.75	43.9	42.3	37.8
W2N1C2	7/7/98	22.5	24.16	24.6	38.2	42.55	41.15	43.69	38.7
W2N1C3	7/7/98	20.9	22.70	24.5	30.8	40.88	42.35	40.55	35.4
W2N1C4	7/7/98	24.3	24.45	22.5	33.45	39.65	38.65	35.1	31.8
W2N2C1	7/7/98	18.05	20.30	21.8	35.9	35.15	35.4	28.3	34.3
W2N2C2	7/7/98	18.9	20.30	29.7	38.15	29.35	33.4	36.45	38
W2N2C3	7/7/98	20.7	25.20	27.3	38.15	42.58	40.45	39.33	29.1
W2N2C4	7/7/98	21.15	19.85	25.3	40.8	36.89	31.58	30.6	30.4
W2N1C1	9/7/98	31.1	43.60	55.7	40.8	41.95	40.35	35.65	30.4
W2N1C2	9/7/98	40	39.140	47.3	38.9	42.65	39.1	39.3	37.5
W2N1C3	9/7/98	28.65	37.680	47.3	39.65	41.4	37.6	41.65	37.2
W2N1C4	9/7/98	29.4	38.590	47.8	33.45	41.9	39.3	35.5	33.9
W2N2C1	9/7/98	28.2	36.750	45.6	37.2	35.2	30.3	36.75	35.6
W2N2C2	9/7/98	28.42	33.890	39.6	41.1	32.8	44.3	34.7	39.2
W2N2C3	9/7/98	28.8	39.940	51.36	36.6	31.8	32.5	38.75	35.9
W2N2C4	9/7/98	28.65	30.400	34.6	38.32	35.6	44.1	35.45	33.3
W1N1C1	1/8/98	25.3	26.740	26.35	37.25	43.3	39.4	40.1	33.5
W1N1C2	1/8/98	27.4	23.690	25.3	34.5	38.7	37.6	35.6	39.2
W1N1C3	1/8/98	25.5	24.22	23.6	35.9	38.9	33.6	37.06	36.8
W1N1C4	1/8/98	27.9	26.4	25.36	33.25	36.7	37.65	29.75	30.1

SOIL MOISTURE CONTENT RECORDED AT DIFFERENT PROFILES (mm of moisture /mm depth of soil)

1998

Treatment	Sampling	0-15	15-22.5	22.5-37.5	37.5-52.5	52.5-67.5	67.5-82.5	82.5-97.5	97.5-112.5
W1N2C1	1/8/98	24.5	22.04	24.36	34.4	38.2	31.55	33.35	39
W1N2C2	1/8/98	27.6	25	26.7	34.3	30.2	35.03	33.15	35.31
W1N2C3	1/8/98	24.6	22.7	26.34	29.8	30.7	37.1	33.8	33.1
W1N2C4	1/8/98	25.4	18.2	21.3	28.337.4	40.1	40.9	38.05	29.41
W2N1C1	1/8/98	27	30.2	35.63	34.2	43.7	41.1	37.05	37.2
W2N1C2	1/8/98	28.5	27.7	32,12	37.15	40.9	38.6	40.47	32.5
W2N1C3	1/8/98	25.5	25.4	27.2	33.9	41.75	34	29.87	31.8
W2N1C4	1/8/98	29.5	28.99	25.36	35.5	40.2	31.8	34.5	35.2
W2N2C1	1/8/98	26.85	26.13	25.39	37.9	33.4	30	27.03	36.3
W2N2C2	1/8/98	25.3	24.88	26.35	37.36	29.3	28.16	30.05	33.6
W2N2C3	1/8/98	26	29.3	38.3	35.2	42.1	27.29	37.05	27.2
W2N2C4	1/8/98	25.97	22.8	25.64	29.34	33.75	30.21	30.1	23.1