WATER-NUTRIENT INTERACTION ON PRODUCTIVITY OF GROUNDNUT

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Water–nutrient interaction on productivity of groundnut"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"Water- nutrient interaction on productivity of groundnut"** is a record of research work done independently by **Mr T. Boopathi**, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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Dedicated to

My beloved friend Vezhavendan

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

@	- at the rate of
DAS	- Days after sowing
DBS	-Days before planting
DMP	- Dry matter production
Fig.	- Figure
g	- gram
ha	- hectare
HI	- Harvest index,
IW/CPE	-Irrigation water/Cumulative pan evaporation
N	-Nitrogen
NS	-Not significant
P	-Phosphorus
K	- Potassium
kg	- kilogram
kg ha^{-1}	- kilogram per hectare
LAI	- Leaf area index
m	- meter
mm	- millimeter
%	- per cent
ppm	- parts per million
Sig.	-Significant
t	- tonnes

Introduction

1. INTRODUCTION

Groundnut is the king of oilseeds in India. In India it is cultivated in an area of 8.7 million ha with a production of 6.4 million tonnes (Hegde, 2002). India stands first in world area and second in world production .The productivity of groundnut is 913 kg ha^{-1} and India ranks eighth in productivity (Thakare et al., 1998 and Hedge, 2002).

Kerala has only 11,292 ha under groundnut cultivation with a production of 9471 tonnes (GOK, 2001). The productivity is nearly 74 kg lesser than the national average. Even though it had played a major role in yellow revolution of oilseeds in India, it is generally grown in summer rice fallows in Kerala. Summer rice fallows are generally starved of water and nutrients.

In order to cater to the growing needs of the state as well as nation it is necessary to double the productivity through management manipulations Among the many factors that contribute to successful growth of groundnut, water and nutrition play a vital role. An efficient use of water and fertilizer is highly critical to sustained agricultural production. Water and nutrients being a costly inputs, their use must be made effective and a scientific water-nutrient management study to the agro-ecological situation is necessary.

Groundnut shows specific response to water (Champan et al., 1993). The pod yield was doubled by increasing IW/CPE ratio from 0.2 to 1.2 (Gulati and Lenka, 1999). There are reports of increased N, P and K uptake in different parts of groundnut due to irrigation.

Uptake of native cationic elements is regulated by rhizosphere acidity induced by fertilizers as well as the reduced environment brought about by water management. Among the fertilizers, P fertilizers induce maximum acidity. The P recommendation is more than that is removed by a crop and this excess addition only serves to increase the rhizosphere acidity. Application of 20 kg P_2O_5 ha^{-1} resulted in highest pod yield and when the level was increased further, there was decrease in pod yield (Metha and Rao, 1996).

Groundnut is a heavy feeder of K and adequate supply of this nutrient is indispensable to obtain better yield (Lakshminarayana and Subbiah, 1996). Levels of application of K on the other hand is far less than that is removed leading to progressive cationic imbalance in the rhizophere environment. The average P and K uptake of groundnut was 36.0 and 151.0 kg ha^{-1} respectively in laterite soil and the nutrient removal by 1000 kg pod was to the tune of 3.19 to 3.86 kg P and 5.49 to 6.46 kg K respectively (Senthil, 2000).

Native elements interfere with functional elements and reduce the productivity. Water is the medium for release, uptake and utilization of nutrients. Depending on quantity and dilution, the nutrient absorption spectrum is changed. It is neither the levels of application nor the uptake that decide the yield, but the specific combination of nutrients and water decides the yield. A fertigaion trial with banana at Banana Research Station, Kannara revealed that when dilution was increased, there was increase in pH of fertilizer solution from 2.9 to 3.4 and thereby the yield was doubled (Deepa, 2001).

Soil moisture plays an important role in the availability and absorption nutrients. All minerals in soil exist comparatively in inert forms. When minerals are in soil solution, they are in active ionic form and the availability and absorption of nutrients are increased. Fertilizer response is greatly influenced by soil moisture and the availability of fertilizer nutrients is severely limited when soil moisture is reduced to a lower level (Saren and Jana,1999). Soil moisture also regulates the oxidation reduction of the environment and hence the release of nutrients into the soil solution.

Hence there must be need based application of fertilizer and water to minimise the non-nutritional harmful effects of inputs and thereby increase the soil health and nutrient use efficiency and productivity of crops.

Under these circumstances the present study was undertaken with the following objectives

- To study the interacting influences of various levels of moisture on the availability, absorption and their functional efficiency of applied and native elements.
- To study the effect of reduced level of P application as well as increased level of K application on groundnut
- To develop a comprehensive management technology for high nutrient use efficiency and productivity of groundnut.

Review of Literature

2. REVIEW OF LITERATURE

Groundnut is an important oilseed crop, which responds well to irrigation and fertilizer. Some of the major works conducted in India and abroad on the influence of these factors on growth, yield, quality and nutrient uptake of this crop are reviewed here under.

2.1 EFFECT OF IRRIGATION ON GROWTH CHARACTERS OF GROUNDNUT

2.1.1 Plant height

There are several reports on the influence of irrigation on plant height. A decrease in plant height with increase in moisture stress was noted by Reddy (1974) and Babu et al. (1977). Mathew (1981) observed that plant height at all stages was significantly increased by irrigation at shorter intervals and the height was maximum when irrigation was scheduled at an IW/CPE ratio of 0.9. Ravikumar et al. (1987) observed that the irrigation scheduling at 0.95 IW/CPE throughout the crop period increased the plant height. Muktha (1995) reported that irrigating at a closer interval increased plant height remarkably. Gulati et al. (1999) reported an increase in plant height with increasing IW/CPE ratio from 0.2 to 1.2.

2.1.2 Number of branches

Moisture stress due to irrigation in groundnut at IW/CPE ratio of 0.4 at the seedling stage, flowering, peg formation or maturity stage reduced the number of branches (Shinde and Pawar, 1982). Plants irrigated at IW/CPE of 1.0 produced significantly more number of primary branches compared to those irrigated at IW/CPE ratio of 0.6 (Patel et al., 1988). Muktha (1995) reported favourable influence of adequate moisture supply on the normal physiological activities of the plant and had led to the production of more number of branches. The number of branches increased progressively with increasing IW/CPE ratio from 0.2 to 1.2. (Gulati et al., 1999).

2.1.3 Shoot: root ratio

A moisture level of 50 per cent was found to be optimum for maximum shoot : root ratio (Varma and Rao, 1975). Khan and Morey (1980) reported that shoot and root weight was significantly influenced by soil moisture regimes and the maximum shoot: root ratio was observed under no stress situations. The crop receiving only one irrigation recorded about eight per cent reduction in shoot dry weight (Patra et al., 1999).

2.1.4 Dry matter production

The total dry matter production was significantly influenced by soil moisture regimes and the maximum dry matter production was obtained under no stress situation (Khan and Morey, 1980). Significant difference in dry matter production and haulm yield due to the effect of various moisture levels in groundnut was also reported by Mathew et al. (1982) and Desai et al. (1984). Ravikumar et al. (1987) observed that irrigation scheduling at 0.95 IW/CPE ratio throughout the crop period increased the dry matter production. Muktha (1995) revealed that the highest dry matter production at 30 and 60 DAS was obtained when the crop was irrigated at an IW/CPE ratio of 0.75 in a sandy loam soil. In clayey soil, irrigation at IW/CPE ratio of 0.6 significantly influenced the dry matter production over 0.4 CPE ratios but it was on par with 0.8 IW/CPE ratio (Pawar et al., 1995).

2.1.5 Nodulation

Reddy and Tanner (1981) observed that irrigation did not alter nodulation but enhanced nitrogen fixation significantly. Muktha (1995) observed increase in number of nodules with a decrease in moisture stress and adverse effect of moisture stress on nodulation was highest at flowering stage. Irrigation at higher value of 0.75 IW/CPE ratio resulted in higher nodule number (Ramachandrappa and Nanjappa, 1995). But Patra et al. (1999) found that irrigation had no significant effect on nodulation.

2.1.6 Leaf area index

Mathew et al. (1982) observed a significant enhancement of LAI with frequent irrigation at early stages of groundnut. Sridhara et al. (1995) observed that irrigation at 0.8 CPE gave higher leaf area and leaf area index. A lysimeter experiment conducted by Patel and Golakkiya (1991) to study the effect of water stress imposed at different phenophases on the growth and yield of T-11 and GG-2 groundnut varieties revealed that leaf expansion of T-11 was more sensitive to drought condition, leading to reduced leaf area index. Golakkiya and Patel (1992) reported decrease in LAI due to water stress. Leaf Area Index (LAI) of groundnut in summer rice fallow increased with increase in frequency of irrigation and the highest LAI was obtained at an IW/CPE ratio of 1.0 and it was followed by IW/CPE ratio of 0.75.

2.2 EFFECT OF IRRIGATION ON YIELD ATTRIBUTES AND YIELD

2.2.1 Yield attributes

Moisture stress during early stages of the crop growth delayed flowering (Reddy et al., 1980). Flower initiation was delayed by 45 days leading to an increase in days to 50 percent flowering, if moisture stress was given at flowering stage (Patel and Golakkiya, 1991). Muktha (1995) reported that the crop needed least time period to attain 50 per cent flowering when irrigation was scheduled at an IW/CPE ratio of 0.75 and it was followed by IW/CPE ratio of 1.0.

Gowda (1977) observed that in groundnut, moisture stress did not reduce the total number of flowers, but reduce the number of gynophores formed from the first flush of flowering was reduced. Number of pegs per plant was found to decrease with decrease in irrigation frequency (Reddy, 1980). Shelling percentage of groundnut was influenced significantly with increasing irrigation levels (Mathew, 1981).

Patel et al. (1988) reported that in groundnut irrigation favorably increased yield attributes like number and weight of pods per plant over unirrigated control. Ghadekar et al. (1993) observed that the number and dry weight of pods per plant were highest when irrigated at 75 mm CPE and these declined under drier regimes i.e. 100 mm, 125 mm and 150 mm CPE. Several other workers also reported increase in 100 pod weight and 100 kernel weight due to irrigation. (Reddy, 1980; Mathew et al; 1982; and Jana et al., 1989 and Patel and Patel, 1995). Muktha (1995) observed that the yield attributes like number of pegs plant^{-1}, number of pods plant^{-1}, weight of pods plant^{-1} and shelling percentage were improved by irrigation at closer intervals (IW/CPE ratios of 0.75 and 1.0). This was in conformity with the work of Patel and Golakiya (1991) and Gulati et al (1999).

2.2.2 Yield

Reddy (1980) noticed the highest pod yield in groundnut with the highest irrigation frequency (irrigation at 20 mm CPE) and the highest depth of water (100 percent of evaporation) tried in the experiment. Groundnut yield was highest in sandy loam soils of Kerala when irrigation was scheduled at 0.9 IW/CPE ratio during January-April (Mathew et al., 1983). The yield obtained was higher under IW/CPE ratio of 0.8 and 1.0 due to higher number of pods plant^{-1} and pod weight plant^{-1} (Gajera and Patel, 1984). The yield of groundnut was highest with IW/CPE ratio of 0.75 in summer rice fallows at Mannuthy in sandy loam soil (Muktha, 1995). Parihar et al. (1999) found that in sandy loam soil, irrigation scheduled at 0.8 IW/CPE throughout crop growth resulted in higher plant growth, which in turn led to higher pod and kernel yield than 0.5 IW/CPE schedule. Taha and Gulati (2001) observed that the pod yield was increased significantly with increasing IW/CPE from 0.2 to 1.2.

2.3 EFFECT OF IRRIGATION ON QUALITY OF KERNEL

2.3.1 Protein content and protein yield

Birajdar and Ingle (1979) obtained significantly higher protein yields by scheduling irrigation at 0.8 IW/CPE ratios. Mathew (1981) was of the opinion that though protein content was not significantly altered by irrigation, total protein yield increased remarkably with increase in irrigation levels. Ravikumar et al. (1987) observed that protein content of kernels decreased with more frequent irrigation. But Umar and Bansal (1997) revealed that quality parameter like protein content was adversely affected by water stress.

2.3.2 Oil content and oil yield

Several workers noticed that irrigation levels had little effect on seed oil content of groundnut (Reddy, 1980 and Garara and Yadav, 1992). But Mathew (1981) was of the opinion that oil content of kernels and oil yields were improved with higher levels of irrigation. Ravikumar et al. (1987) observed that while oil content was not significantly influenced by irrigation schedules, oil yield differed significantly by withholding irrigation at the pod formation, pod development or pod maturation stages. Muktha (1995) also observed that the different irrigation frequencies did not influence the oil content in groundnut significantly. Patel and Patel (1996) found that the oil yield was highest with an IW/CPE ratio of 1.2 compared with that of 0.8 and 1.0. Umar et al (1997) reported that water stress had adverse effect on oil content.

2.4 EFFECT OF IRRIGATION ON NUTRIENT CONTENT AND UPTAKE IN PLANTS

Maintenance of adequate available soil moisture in the root zone depth was conducive for uptake of nutrients thereby resulting in better pod filling with high frequency of irrigation (Reddy and Tanner, 1981). Rao and Singh (1985) reported that plants getting more irrigation utilized comparatively more native phosphorus than with limited or, no supplement watering. But Ke *et al.* (1999) reported that the response of P decreased with the increment of soil water. The interaction between P application and irrigation was significant for the total yield (Khan *et al.* 1993). K is luxuriantly absorbed by groundnut at their higher levels in stems, shells, but not in seeds as seed do not require much K unlike N (Singh et al., 1994). Irrigation improved air-water-relationship in soil and beneficial effect of irrigation on water and nutrient availability to crops had contributed to their increased yield (Jana *et al.*, 1989 and Saren and Jana, 1999).

Mathew *et al.* (1983) observed a significant influence of irrigation on K uptake and irrigation at an IW/CPE ratio of 0.75 resulted in the highest N, P and K uptake by groundnut as well as in different parts of groundnut. Removal of N, P and K was significantly more under irrigated conditions than dry land conditions (Pawar *et* al., 1995). Tiwari *et al.* (1997) reported that water use efficiency was increased with increased rate of K application and frequency of irrigation. (Ghatak *et al.*, 1997). Umar *et al.*, (1997) observed that in groundnut K application decreased the effects of water stress on growth, yield and quality. Irrigation scheduled at 0.75 IW/CPE ratio gave higher uptake of nutrients and higher soil available N, P and K compared to 0.6 IW/CPE (Lourduraj and Rajagopal ., 1999). Parihar *et al.* (1999) reported higher uptake of nutrients.with 0.8 IW/CPE ratios. Saren and Jana (1999) noticed, in maize and groundnut based inter cropping system that the uptake of N and P in whole groundnut plant was increased by irrigation.

2.5 EFFECT OF NUTRIENTS ON GROWTH CHARACTERS, YIELD AND KERNEL QUALITY

2.5.1 Nitrogen

The increase in production of branches in groundnut with increasing levels upto 40 kg N ha^{-1} and increase in leaf area index up to 30 kg N ha^{-1}were reported by Reddy and Krishnamurthy (1984). Recommended doses of N vary from place to place and are in between 8-20 kg for rainfed crop (ICAR, 1987). Saradhi et al., (1990) reported significant increase in plant height upto 20 kg N ha^{-1} and after that it was not significant.

Lal and Saren (1988) found that the pod yield responded significantly to nitrogen application only upto 20 kg ha^{-1} and marked increase in protein content was noted with each increase in N dose upto 40 kg ha^{-1}. But nitrogen had significant influence on number of pods per plant and number of filled pods per plant which was because of production of more number of flowers and peg at higher doses of nitrogen (Saradhi et al., 1990). The uptake of N increased with successive increase in N application and maximum was with 40 kg N ha^{-1}. But the shelling per cent was not improved by N application (Patra et al., 1995). The dry pod and haulm yields were increased with higher fertilization and maximum yields were obtained with 50 kg N ha^{-1} (Deshmukh, 1999).

Chawale et al. (1995) observed increase in protein content of kernel with increase in level of nitrogen. The higher N rate increased the protein content compared with the lower rates (Mali et al, 1988). Jana et al. (1990) observed increase in oil content of kernel with increase in level of nitrogen. Fertilizer application increased seed protein content (Lakshmamma et al., 1996).

2.5.2 Phosphorus

Saradhi et al. (1990) reported significant increase in plant height upto 80 kg P_20_5 ha^{-1} and after that it was not obvious. Deshmukh et al. (1999) found that plant height was increased with increase in the fertilizer levels and the maximum plant height was obtained by the application of 100 kg P_20_5 ha^{-1}. The highest number of branches in groundnut was reported with 40 kg P_20_5 ha^{-1} (Chauhan et al., 1987). The P application increased the dry matter production at different levels upto 40 kg P_2 0_5 ha^{-1}. It also influenced the root proliferation (Saradhi et al., 1990 and Prasad et al., (1996). Mahakulkar et al., (1992) reported that there was increased leaf area with 25 kg P_2 0_5 over no fertilizer level. Experiment conducted on sandy loam soil during summer season revealed that application of P brought about significant improvement in LAI at all the stages except at 30 DAS. Phosphorus plays an important role in root production and nodule formation (Singh et al., 1994) and it is necessary for the proper function of the nodules (Yadav et al., 1998).

The application of phosphorus increased number of pods $plant^{-1}$ number of kernels pod^{-1} and 100 kernel weight of groundnut. Among the major nutrients, application of phosphorus increased groundnut yield considerably (Chavan and Kalra, 1983; Mathew et al., 1983; Patel et al; 1983). Lal and Saren (1988) found that the pod yield responded significantly to phosphorus application only upto 40 kg ha^{-1}. Jana et al., (1990) observed that the optimum dose of P was 37.3 kg ha^{-1}. Mahakulkar et al. (1992) was of the opinion that pod yield increased considerably upto 50 kg P_2 0_5 ha^{-1}. But application of 20 kg P_2 0_5 ha^{-1} resulted in highest pod and haulm yield and when the level was increased further, there was decrease in both (Metha and Rao, 1996). Giridhar and Giri (1999) reported that in the sandy loam soil, application of phosphorus increased the dry matter production by 30 percent over control at all stages of growth.

In laterite soils of India, the critical level of available P is reported to be 5 to10 ppm for groundnut (Dwivedi and Bapat, 1988). Mishra (1998) was of the opinion that application of phosphorus as high as 60 kg ha^{-1} significantly increased the pod and haulm yield of groundnut. Studies conducted by Desmukh (1999) revealed that the dry pod and haulm yields were increased with higher fertilization and maximum yields were obtained with 100 kg P_2O_5 ha^{-1} .The average P uptake of groundnut was 36.0 kg ha^{-1} in laterite soil (Senthil, 2000).

The protein content of kernel increased with increasing levels of phosphorus (Chowdhery *et al.*, 1991). Singh *et al.* (1994) noticed that oil content improved considerably with the application of phosphorus and increase in the dose of P_20_5 beyond 15 kg ha^{-1} did not improve the oil content. Patra et al. (1995) found that the oil yield was increased by 46 per cent when P was applied at 60 kg P_2O_5 ha^{-1} compared to no application. But Patel and Thakur (1997) observed that protein and oil content of kernel increased with increasing levels of phosphorus and the maximum was obtained with application of 90 kg P_20_5 ha^{-1}. Groundnut being rich in protein may need relatively more phosphorus (Rajendran and Lourduraj, 1998).

2.5.3 Potassium

Nair *et al.* (1982) revealed that application of 50 and 75 kg K_20 ha^{-1} increased the plant height and number of leaves $plant^{-1}$ in red loam soil with low available K. An investigation conducted in sandy loam soil with low available K revealed that K application at 75 kg K_2O ha^{-1} increased the dry matter production of groundnut due to increase in plant height and number leaves $plant^{-1}$. Among the major nutrients, application of K increased groundnut yield considerably (Chavan and Kalra, 1983; Mathew *et al.*, 1983 and Patel *et al.*, 1983). Jana et al. (1990) found that the application of potassium increased number of pods $plant^{-1}$, number of kernels, pod weight, 100 kernel weight and the optimum dose of K was 50 kg K_2O ha^{-1}. The increase in yield contributing characters and pod yield of groundnut with an increase in K level was also reported by Singh *et al.* (1994). Plant height increased with K application rate (Ghatake *et al.* 1997).

2.6 Effect of nutrients on content and uptake in plants

Nitrogen accumulation in leaves and stems ceases after the onset of pod development, approximately 70 days after planting (Tonn and Weaver, 1981). Reddy and Krishnamurthy (1984) reported that application of K had no appreciable effect on the uptake of nutrients by groundnut. But application of P and K fertilizers improved the N uptake (Kulkarni et al., 1986). Increasing levels of P and K application resulted in increased P concentration at all stages of growth and in kernel (Jain and Dikshit, 1987). Patel and Patel (1988) observed that when the level of P application was increased the K content declined. The uptake of N was increased with successive increase in N application and maximum uptake was with 40 kg N ha^{-1} (Reddy et al., 1992). Singh et al. (1994) reported that increasing the level of N in the nutrient solution, increased the concentration of P, K, Ca and Mg in leaves, but it did not affect S.

2.7 Soil solution studies

Even though soil solution studies are very limited in India, some of the findings in abroad on the soil solution characters are reviewed here under.

According to Pearson (1971), soil solution is the best expression of the soil environment that immediately governs plant response and defines soil solution as a quasi-equilibrium solution of electrolytes that occurs in the soil under unsaturated moisture conditions. The soil solution is the mobile phase that is responsible for redistributing solutes within the soil and hence, controlling and differentiation of nutrients in the soil profile. The soil solution also provides the immediate source of nutrients for plants and microorganisms and acts as a temporary sink for some of their waste products (Campbell *et al.*, 1989).

A comprehensive analysis of soil solution is diagnostically useful for predicting the availability of biogeochemically consequential chemicals to plants or to ground and surface water (Adams, 1971 and Sparks, 1984). Most soil chemical reactions occur in soil solution, which is also the phase in which solutes move through the soil (Adams, 1974). Measurement of soil solution chemistry can, therefore, provide a valid measure of the nutritional status of a soil (Adams and Odom, 1985) and is particularly useful for monitoring the effects of various soil amendments (Simard *et al.*, 1988).

In most of the cases, increase in frequency of irrigation increased the growth ,yield and quality of groundnut . Among the nutrients, N requirement for the groundnut was comparatively less than other nutrients. But in the case of phosphorus, it ranges from 20 to 60 kg depending upon the nutrient status of the particular soil. Potassium requirement is considered to be higher than the other nutrients. Most of the studies also indicated that irrigation favours the uptake of nutrients.

Materials and Methods

3. MATERIALS AND METHODS

An investigation to study the response of groundnut to levels of nutrients under different moisture regimes was undertaken at the College of Horticulture, Vellanikkara. The materials used and methods adopted are detailed below.

3.1. DETAILS OF THE EXPERIMENT

3.1.1 Experimental site

The experiment was conducted in the field attached to the Department of Agronomy, College of Horticulture, KAU, Vellanikkara. The site is located at 13° 31' N latitude and 76° 3'E longitude and at an altitude of 22.3 m above MSL.

3.1.2 Soil

The soil of the experimental field was lateritic, gravelly sandy clay loam in texture, of the oxisol group. The physical and chemical properties of the soil are presented in Table 1.

3.1.3 Season

The area of experimental site enjoys a tropical climate with an average rainfall of 2870 mm per year. The important weather parameters observed during the experimental period is presented in Fig. 1 and Appendix 1.

3.2 MATERIALS

3.2.1 Crop and Variety

The test variety was TMV-2, a bunch variety with no dormancy and matures in about 105 days. The pods are small and one to two seeded. It can be grown both as rainfed and irrigated crop. The seed materials for the experiment were obtained from Tamil Nadu Agricultural University, Coimbatore.

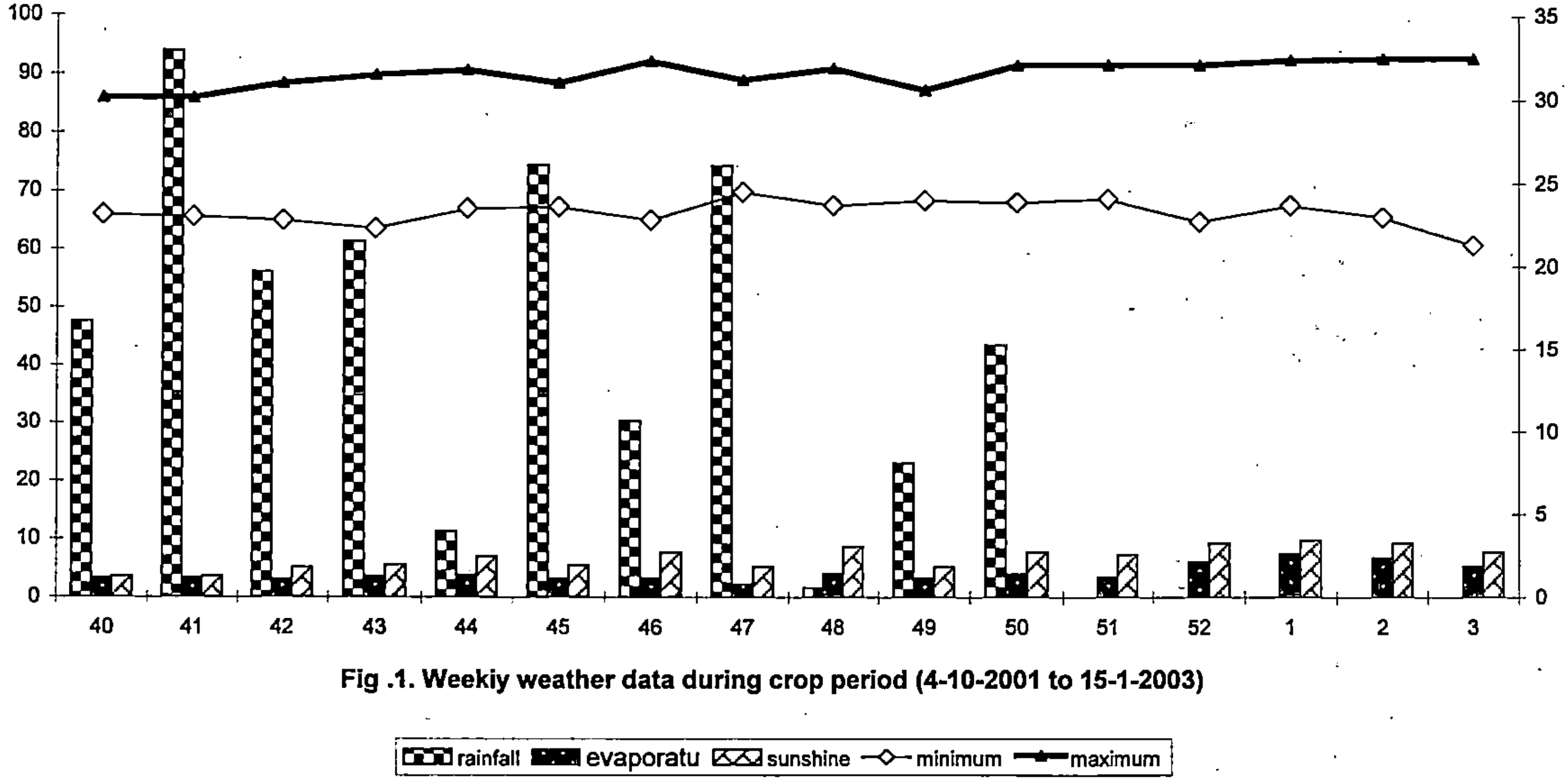


Fig .1. Weekiy weather data during crop period (4-10-2001 to 15-1-2003)

Table 1. Physico - chemical properties of the experimental site

A. Physical Properties

Mechanical analysis	Per cent composition	Method	Reference
Coarse sand	26.0	Robinson International pipette method	Piper, 1942
Fine sand	23.1		
Silt	21.2		
Clay	29.7		

B. Chemical properties

Available N (kg ha^{-1})	340.8	Alkaline permanganate method	Subbiah and Asija, 1956
Available P_2O_5(kg ha^{-1})	25.9	Ascorbic acid reduced molybdo phosphoric blue colour method	Watnabe and Olsen, 1965
Available K_2O (kg ha^{-1})	440.5	Using 1 N Neutral Normal NH_4 Ac extract by Flame photometer	Jackson, 1958
Organic Carbon (%)	1.24	Walkely-Black method	Walkely and Black, 1934
pH	5.78	Using 1:2.5 Soil Water suspension by pH meter	Hesse, 1971
EC (dS m^{-1})	0.41	Using 1:2.5 Soil -water suspension by conductivity bridge	Jackson, 1958

3.2.2 Manures and Fertilizers

Cattle manure with nutrient contents of 0.5 % N, 0.3 %P_2O_5 and 0.2 % K_2O was applied as basal @ 2 t ha^{-1}as per the Package of Practices recommendation (POP) recommendations (KAU, 1996). The chemical fertilizers, urea (46% N), mussoriephos (20% P_2O_5) and muriate of potash (60% K_2O) were applied as basal as per the treatment. Lime was applied @ 1.5 t ha^{-1}.

3.3 EXPERIMENTAL METHODS

3.3.1 Layout and design

The experiment was laid out in split plot design with 3 replications (Fig 2).

The treatments included 3 main plots and 5 subplots.

The main plot treatments were 3 frequencies of irrigation.

Irrigation frequencies

I_1 = Irrigation at IW/CPE ratio of 0.5

I_2 = Irrigation at IW/CPE ratio of 0.75

I_3 = Irrigation at IW/CPE ratio of 1.0

Depth of irrigation given was 50 mm.

The subplot treatments were 5 levels of nutrients.

F_0 - control (Without fertilizer)

F_1 - 10-75-75 kg ha^{-1} N, P_2O_5, and K_2O (POP recommendation)

F_2 - 10- 0-75 kg ha^{-1} N ,P_2O_5, and K_2O,

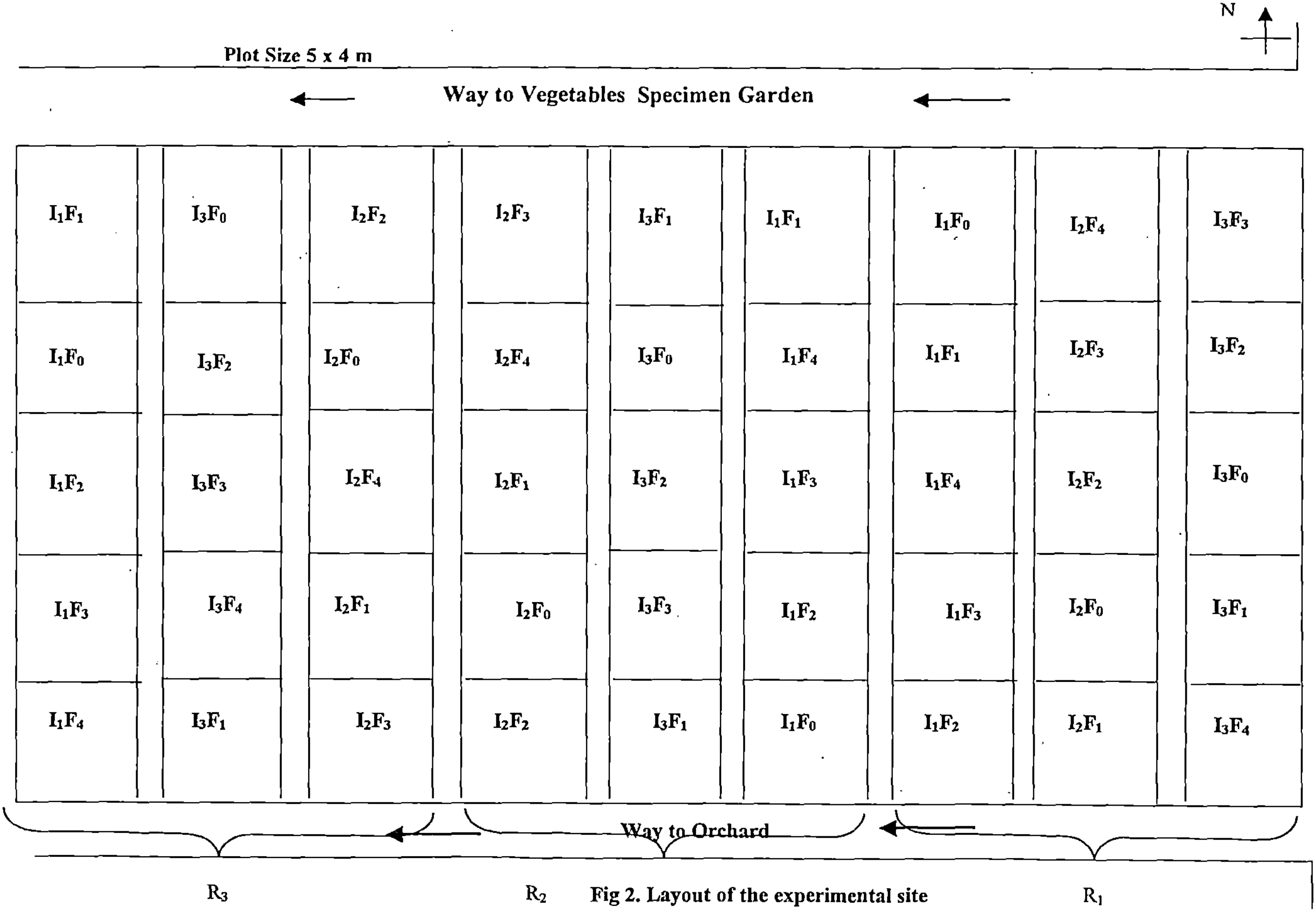
F_3 - 10-37.5-75 kg ha^{-1} N, P_2O_5 and K_2O,

F_4 - 10-75-150 kg ha^{-1} N, P_2O_5 and K_2O.

Plot size Gross : 5.0 m x 4.0 m; Net: 4.2 m x 3.2 m

Spacing : 20 cm x 20 cm

Layout of the experiment is given in Fig. 1. and Plate 1.



I_1F_1	I_3F_0	I_2F_2	I_2F_3	I_3F_1	I_1F_1	I_1F_0	I_2F_4	I_3F_3
I_1F_0	I_3F_2	I_2F_0	I_2F_4	I_3F_0	I_1F_4	I_1F_1	I_2F_3	I_3F_2
I_1F_2	I_3F_3	I_2F_4	I_2F_1	I_3F_2	I_1F_3	I_1F_4	I_2F_2	I_3F_0
I_1F_3	I_3F_4	I_2F_1	I_2F_0	I_3F_3	I_1F_2	I_1F_3	I_2F_0	I_3F_1
I_1F_4	I_3F_1	I_2F_3	I_2F_2	I_3F_1	I_1F_0	I_1F_2	I_2F_1	I_3F_4

Fig 2. Layout of the experimental site

Plate I. A general view of experimental plot at 80 DAS

Plate II. Plants showing wilting symptom at IW/CPE ratio of 0.5

3.3.2 Field culture

The field was ploughed well with a power tiller. After removing the stubbles, the soil was brought to a fine tilth. The field was then leveled and laid out into 3 main plots with 5 subplots replicated three times. To prevent seepage of water from neighboring plots, a buffer area of 30 cm was left all around the main plot.

Basal application of FYM was done as per(POP) recommendations (KAU, 1996) and mixed well with soil. The chemical fertilizers were applied as basal, based on the treatments.

3.3.3 Sowing

Sowing was done on 4th October 2001. Seeds were dibbled in lines at a depth of 5cm and at a spacing of 20 x 20 cm. Gap filling was done at 7 Days After Sowing (DAS) to ensure uniform crop stand.

3.3.4 After cultivation

Hand weeding was done at 20 DAS. At flowering stage, lime was applied as per POP recommendations (KAU, 1996).

3.3.5 Levels of irrigation

Irrigation was given uniformly to all plots one day after sowing. There was frequent rainfall upto 42 DAS. So the irrigation treatments were applied based on IW/CPE ratios from 42 DAS onwards. Data on pan evaporation were collected daily. The treatments I_1, I_2 and I_3 were applied at cumulative pan evaporation of 100 mm, 66.6 mm and 50 mm respectively.

3.3.6 Plant protection

Plant protection measures were taken as and when required. The pests observed were leaf eating caterpillars and plant hoppers. Spraying 0.05 per cent monocrotophos controlled these. Diseases observed were tikka disease and rust. One per cent Bordeaux mixture was applied for the control.

3.3.7 Harvesting

The duration of the crop was 103 days. The crop was harvested at 15th January 2002. Plants were uprooted by hand and pods were separated on the same day of harvesting. The weight of the fresh haulm was taken and sun dried for a week and dry weight was recorded at minimum moisture level (10 per cent).

3.4 OBSERVATIONS

Observations on growth characters were taken from five randomly selected plants in each subplot at 20, 40, 60 and 80 DAS and at harvest.

3.4.1 Plant height

Height was measured from ground level to the growing point of the plant and mean plant weight was expressed in cm.

3.4.2 Number of leaves per plant

The number of compound leaves produced per plant was counted and average was expressed.

3.4.3 Number of branches per plant

Number of branches produced per plant was counted and the average was expressed at 20 days interval.

3.4.4 Shoot: root ratio

Shoot: root ratio was calculated from the weight of shoots and roots of oven-dried samples at 20 days interval and at harvest.

3.4.5 Dry matter production per plant

From each plot, three plants were uprooted for destructive sampling. Their roots were washed well and the plants were dried at 80°C to a constant weight and the average weight was recorded in g.

3.4.6 Number of nodules

Observation on number of nodules per plant was taken at 20, 40, 60 and 80 DAS and at harvest by separating the nodules from the roots and the mean number of nodules per plant was calculated and recorded.

3.4.7 Leaf area Index

Leaf area was determined by using the equation formulated by Saxena *et al.* (1972). Leaf area measurements were made at 20, 40, 60, 80 DAS and at harvest on the fourth compound leaf from the top of the central shoot.

Leaf area per plant = Length x Breadth x 0.765 x number of leaflets per plant

3.4.8 Chlorophyll content

Chlorophyll content of index leaf (3rd leaf from growing tip) was estimated calorimetrically by using spectronic-20 spectro photometer suggested by Hiscox and Israelstam (1979) at flowering and 80 DAS. The formula used for calculation of chlorophyll was as follows.

Chlorophyll 'a' content (mg g^{-1}) = [12.7 (A663)-2.69(A645)] V/(1000 x W)

Chlorophyll 'b' content (mg g^{-1})= [22.9 (A645)-4.68(A663)] V/(1000XW)

Total chlorophyll (mg g^{-1}) = 20.2 (A645) + 8.02 (A663)] V/(1000 XW)

Where,

A 645 and A 663 - the absorbency values at wavelength 645 and 663 nm respectively.

W - Fresh weight of sample (g)

V - the volume of the extract (ml)

3.4.9 Cell sap pH

Cell sap p^H was estimated by using a p^H meter. 1: 2.5 leaf sample and water suspension was utilized for estimation (Jackson, 1958).

3.5 YIELD ATTRIBUTES AND YIELD

3.5.1 Days to 50 per cent flowering

The number of days taken for 50 per cent of the plant population for flowering was observed from each plot and recorded.

3.5.2 Harvest index

The proportion of biological yield to economic yield is called as harvest index (HI). It is characterized by the movement of dry matter to economic part of the plant. The HI was calculated by the formula given by Redford (1967).

$$HI = Y_{Econ} / Y_{Bio}$$

Where, Y_{Econ} and Y_{Bio} - The economic and biological yield respectively.

The details of the observations taken with regard to yield and other yield related characters are given in the Table 2.

Table 2. Observations on yield and related characters

Sl. No.	Attributes	Descriptions
1.	Weight of pods per plant	Mean of 3 random plants per plot were taken
2.	Number of pods per plant	Mean of 3 random plants per plot were taken
3.	100 pod weight	Weight of randomly taken 100 pods per plot
4.	100 kernel weight	Weight of randomly taken 100 kernels per plot
5.	Shelling percentage	Shelling of randomly selected, weighed 100 pods
6.	Pod yield (kg ha^{-1})	At 10 per cent moisture level
7.	Kernel yield (kg ha^{-1})	At 10 per cent moisture level
8.	Haulm yield (kg ha^{-1})	At 10 per cent moisture level
9.	Haulm: pod ratio	At 10 per cent moisture level

3.6 QUALITY PARAMETERS

3.6.1 Protein content (%)

Protein content of kernels was worked out by multiplying nitrogen content of kernels with the constant 5.46 (Jones, 1931 and Sadasivam and Manickan, 1996).

3.6.2 Protein yield (kg ha^{-1})

This was calculated from protein content of kernel (%) and kernel yield (kg ha^{-1}).

3.6.3 Oil content of kernels (%)

Oil content of kernels was determined by using the instrument Oxford 4000 Nuclear Magnetic Resonance (NMR) as suggested by Balasubramaniyan (1997).

3.6.4 Oil yield (kg ha^{-1})

This was calculated by multiplying kernel yield (kg ha^{-1})and oil content of kernels (%).

3.7 UPTAKE STUDIES

N, P, K, Ca, Mg, S and Fe concentrations of stem and leaf were studied at flowering and harvesting stages separately. Shell and kernel concentration of N,P and K calculated at harvesting stage. The uptake of nutrients at flowering and harvest was calculated from the nutrient concentration at respective stages and dry matter production. The destructive samples collected from each plot were oven dried and powdered. The estimation was done by using the following procedures (Table 3).

Table 3. Methods used for plant nutrient analysis

Sl.No	Nutrient	Method	Reference
1.	Nitrogen	Micro kjeldhal digestion and distillation method	Jackson, 1958
2.	Phosphorus	Vanadomolybdo phosphoric yellow colour method- spectronic 20	Jackson, 1958
3.	Potassium	Diacid extract using a flame photometer	Cheng and Bray,1951
4.	Calcium	Diacid extract by direct titration with EDTA	Hesse, 1971
5.	Magnesium	Diacid extract by direct titration with EDTA	Hesse, 1971
6.	Sulphur	Turbido metric method using spectronic- 20	Hart, 1961
7.	Iron	Diacid extract using AAS	Jackson, 1958
8.	Manganese	Diacid extract using AAS	Jackson 1958

3.8 SOIL STUDIES

3.8.1 Soil moisture characteristics

Soil samples were collected from depths of 0-15 cm, 15-30 cm and 30-45 cm before applying irrigation treatment and also 48 hours after irrigation. After recording the fresh weight, soil samples were oven dried at 105°C to a constant weight. Moisture content was expressed as percentage of dry weight of soil. Consumptive use for the period between two successive irrigations was found out by using the following equation (Michael, 1978).

$$U = \sum_{i=1}^{n} \frac{M_{1i} - M_{2i}}{100} \times A_i D_i$$

where,

U - Water use from the root zone for successive sampling periods (in) within one irrigation cycle in mm

n - Number of soil layers sampled in the root zone depth D

M_{1i} - Soil moisture percent at the time of the first sampling in the i^{th} layer

M_{2i} - Soil moisture percent at the time of the second sampling in the i^{th} layer

A_i - Apparent specific gravity of the i^{th} layer of the soil (g cc^{-1})

D_i -Depth of the i^{th} layer of the soil, mm

Consumptive use values of each sampling interval were added to find out the total water used by the crop. Details of irrigation given during the cropping period are presented in Table 4.

Table 4. Details of irrigations given

Details	Irrigation frequencies (IW/CPE)		
	0.5	0.75	1.00
First	3-10-2001	3-10-2001	3-10-2001
Second	5-12-2001	28-11-2001	25-11-2001
Third	22-12-2001	10-12-2001	5-12-2001
Fourth	6 -1-2002	22-12-2001	14-12-2001
Fifth		1-1-2002	22-12-2001
Sixth		11-1-2002	30-12-2001
Seventh			6-1-2002
Eight			12-1-2002
Total number of irrigations given	4	6	8
Quantity of irrigation water applied (mm)	200	300	400
Mean irrigation interval (days)	16	11.66	8.4
Quantity of irrigation water plus rainfall during the crop period (mm)	530.5	630.5	730.5

Irrigation treatments could not be imposed during the first 42 DAS due to the intermittent rainfall received.

Soil moisture determination was done 48 hours after each irrigation. PET obtained by multiplying pan evaporation value with crop factor 0.6 and effective rainfall calculated based on soil moisture content were taken into account for computing consumptive use.

3.8.2 Field Water Use Efficiency (FWUE) and Crop Water Use Efficiency (CWUE)

Field Water Use Efficiency (FWUE) and Crop Water Use Efficiency (CWUE) were computed by using the following formulae and are expressed as kg ha mm^{-1}.

$$\text{Field WUE} = \frac{\text{Pod yield (kg ha}^{-1}\text{)}}{\text{Total water applied (ha mm)}} \quad \text{kg ha mm}^{-1}$$

$$\text{Crop WUE} = \frac{\text{Pod yield (kg ha}^{-1}\text{)}}{\text{Consumptive use (ha mm)}} \quad \text{kg ha mm}^{-1}$$

3.9 ANALYSIS OF SOIL

Rhizosphere soil was collected from each plot at three weeks after planting and at harvest. It was dried and sieved through 2.0 mm sieve and then used for analysing chemical characteristics. The method used for the various analyses are given below in Table 5.

Table 5. Method used for soil chemical analysis

Sl. No	Analysis	Method	Reference
1	Soil reaction (pH)	Using 1:2.5 Soil water suspension by pH meter – Elico	Hesse, 1971
2	Available N	Alkaline permanganate method	Subbiah and Asija, 1956
3	Available P_2O_5	Ascorbic acid reduced molybdo phosphoric blue colour method	Watnabe and Olsen, 1965
4	Available K_2O	Using 1N Neutral normal NH_4 Acetate extract by flame photometer	Jackson, 1958
5	Exchangeable Ca	Using 1N Neutral Normal NH4 Acetate extract by titration with EDTA	Jackson, 1958
6	Exchangeable Mg	Using 1 Neutral Normal NH_4 Acetate extract by titration with EDTA	Jackson, 1958
7	Available S	Using 0.1 $CaCl_2$ extract by turbidometry method	Chesnin and Yien, 1951
8	Available Fe	Using DTPA extract by AAS	Lindsay and Norvell, 1978
9	Available Mn	Using DTPA extract by AAS	Lindsay and Norvell, 1978

3.10 SOIL SOLUTION STUDIES

3.10.1 Soil

Soil samples from rhizosphere were collected at a depth of 15 cm from all the treatments at 24, 48 and 72 hours after irrigation. The soil samples were kept in a humid chamber to avoid evaporation.

3.10.2 Soil solution extraction

There are several ways of extracting soil solution viz., centrifugation, solution displacement and compaction. Each method was found to have advantage as well as disadvantages. However extraction by centrifugation is preferred for its simplicity, rapidity and that the pressure applied is mild and well within the available moisture range (Moris, 1991). Hence, the soil solution was extracted by centrifugation technique in the present study. In a specially fabricated stainless steel centrifugal filter, a disc of Whatman No.42 filter paper was placed and over that 50-g soil (rhizosphere soil 24, 48, 72 hours after irrigation) was kept. The centrifugal filter used (Fig.3) in the present study was a modified version of that used by Moris (1991). The modified stainless steel filter could be fabricated with local facilities at reduced cost and could be used with commonly available centrifuging apparatus. The filters were placed in the centrifuge and extracted the soil solution at 4000 rpm for 20 minutes. The pH was measured immediately. The soil solution was subsequently analysed for available N, available P_2O_5, available K_2O, exchangeable Ca and S by methods mentioned earlier.

3.10.3 Statistical analysis

The data were subjected to statistical analyses of variance, as suggested by Panse *et al.* (1985) and by using the statistical package of MSTAT.

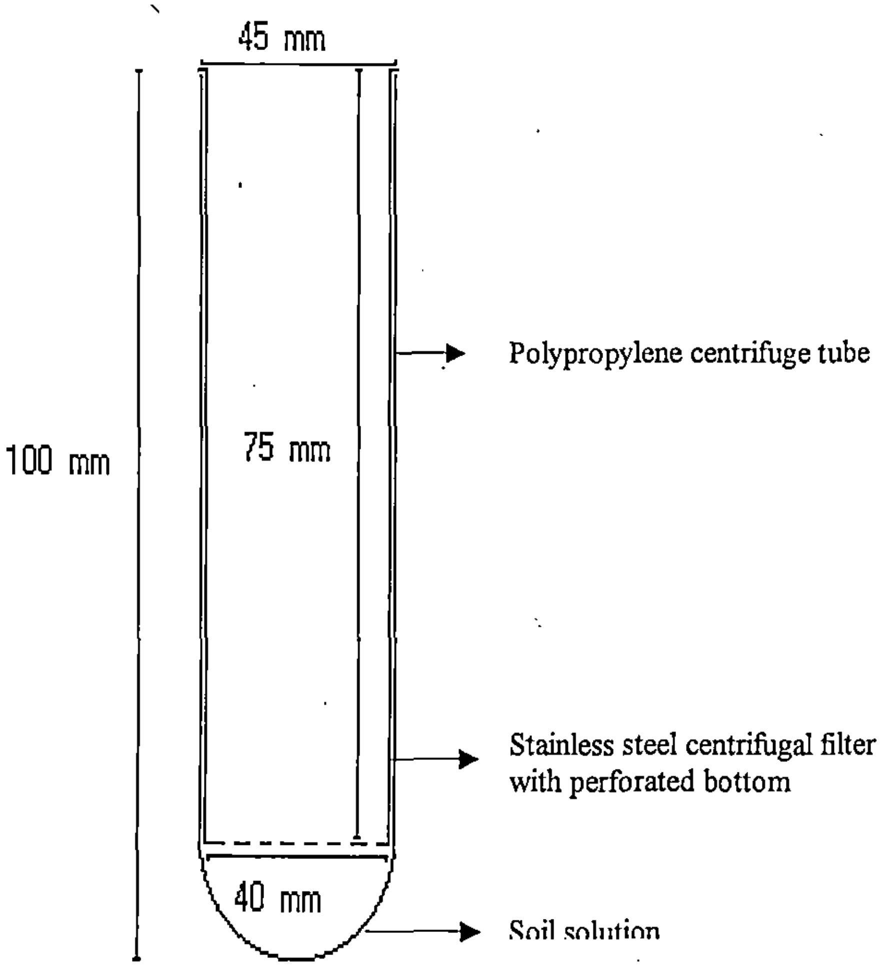


Fig. 3. Centrifugal filter assembly

Results

4. RESULTS

The field investigation on "Water- nutrient interaction on productivity of groundnut" was carried out as per the details described in the previous chapter. The observations recorded were compiled, analysed and tabulated. This chapter deals with results obtained from the observations recorded during the course of investigation.

An abnormally high rainfall totalling to 331 mm was received from sowing to 42 DAS. During the last four years the crop season of the experimental period (from 1997-2001) average weekly rainfall was only 21.2 mm but during the crop season of the experimental period (2001-2002) the average weekly rainfall received was 32.4 mm and the rainfall was concentrated upto 42 DAS. All other parameters were almost similar as that of previous four years of the same season. Due to frequent rainfall, irrigation treatment could not be imposed during the early stages of growth.

4.1 GROWTH CHARACTERS

4.1.1 Plant height (Table 6)

The effect of irrigation had no marked influence on plant height in the early stages of crop growth (upto 42 DAS). However significant difference was noticed at later stages of crop growth upto harvest. The plants that received irrigation at IW/CPE of 1.0 were remarkably taller (39.8 cm) than those received irrigation at IW/CPE of 0.5 (31.3 cm) and 0.75 (37.2 cm) at 60 DAS. The plants that received irrigation at IW/CPE ratio of 0.5 levels were the shortest (55.6 cm) and the plants with IW/CPE ratio of 1.0 were the tallest (74.0 cm).

The different levels of nutrients had not contributed towards significant variation in plant height.

4.1.2. Number of leaves (Table 7)

It is evident from the data that the leaf production increased with increase in frequency of irrigation, even though the effects were more pronounced at later stages of crop growth (60 and 80 DAS). At 60 DAS, leaf production was highest (48.2) at IW/CPE ratio of 0.75 and it was on par with IW/CPE ratio of 0.75. At 80 DAS, the

Table 6 . Plant height of groundnut as influenced by irrigation and fertilizers, cm

Treatments	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
Irrigation (IW/CPE)					
0.50	7.3	20.0	31.3	44.7	55.6
0.75	8.0	22.1	37.2	53.3	65.2
1.00	7.6	20.8	39.8	60.4	74.0
CD (0.05)	NS	NS	2.7	10.3	13.3
Fertilizers ($N\ P_2O_5\ K_2O$ kg ha^{-1})					
Control	7.0	19.0	34.2	51.1	62.1
10-75-75	7.7	20.6	36.6	52.2	64.3
10-0-75	7.7	21.8	36.9	53.4	66.2
10-37.5-75	7.9	22.1	36.2	53.5	66.1
10-75-150	7.9	21.4	36.3	53.8	66.1
CD (0.05)	NS	NS	NS	NS	NS
I X F	NS	NS	NS	NS	NS

Table 7. Number of leaves plant^{-1}of groundnut as influenced by irrigation and fertilizers

Treatments	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
Irrigation (IW/CPE)					
0.50	10.3	31.8	45.6	60.1	54.9
0.75	11.3	34.9	48.2	71.3	61.4
1.00	10.7	34.3	50.1	76.1	65.1
CD (0.05)	NS	NS	3.1	9.8	7.6
Fertilizers (N P_2O_5 K_2Okg ha^{-1})					
Control	10.0	31.8	48.3	68.2	58.3
10-75-75	10.8	33.7	47.5	69.9	61.7
10-0-75	10.9	33.7	47.4	69.5	59.6
10-37.5-75	11.1	35.0	47.8	68.5	61.5
10-75-150	11.1	34.1	48.9	71.4	61.5
CD (0.05)	NS	NS	NS	NS	NS
I X F	NS	NS	NS	NS	NS

effect was consistent and the number of leaves was maximum (76.1) in plants that were irrigated frequently (IW/CPE of 1.0) compared to other two levels of irrigation. With respect to different growth stages, the leaf production was maximum at 80 DAS and thereafter it declined. .

The variation in the number of leaves plant^{-1} at any of the growth stages due to levels of nutrients was not significant.

4.1.3 Number of branches plant^{-1} (Table 8)

The data on number of branches plant^{-1} indicated that irrigation altered the number of branches per plant, though not significantly. The numbers of branches were maximum (9.5) for plants that were irrigated at an interval of 11 days (IW/CPE=0.75) compared to their lower (IW/CPE=0.5) and higher (IW/CPE=1) levels. More number of branches were produced between 20 and 40 DAS and after that there was not much increase in the number of branches.

Levels of fertilizers also showed the same pattern with respect to number of branches per plant.

4.1.4 Shoot: root ratio (Table 9)

The shoot: root ratio was not significantly influenced by irrigation treatments. But levels of fertilizers significantly influenced the shoot root ratio. At 40 DAS, the F_1 (10-75-75 kg N P_2O_5 K_20 ha^{-1}) recorded the highest shoot: root ratio (27.38), which was on par with F_3 (10-37.5-75 kg N P_2O_5 K_20 ha^{-1}) and F_4 (10-75-150 kg N P_20_5 K_20 ha^{-1}). Similar trend was observed at 60 DAS also. The shoot: root ratio was highest (27.15) in the treatment F_2 (10-0-75 kg N P_2O_5 K_2O ha^{-1}) and that was on par with F_3 (10-37.5-75 kg N P_20_5 K_20 ha^{-1}).

The shoot: root ratio of groundnut was maximum at 40 DAS and it showed a decline at 60 DAS and then increased upto harvest. At 60 DAS the shoot: root ratio decreased because of the increase in root weight at higher rate.

4.1.5 Dry matter production (Table 10)

Higher frequency of irrigation had marked influence on DMP of groundnut and the effect was more pronounced towards the maturity of the crop .The highest

Table 8. Number of branches plant^{-1} of groundnut as influenced by irrigation and fertilizers

Treatments	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
Irrigation (IW/CPE)					
0.50	4.2	8.1	8.7	9.0	9.1
0.75	4.5	8.7	9.4	9.5	9.4
1.00	4.3	8.4	9.0	9.2	9.3
CD (0.05)	NS	NS	NS	NS	NS
Fertilizers (N P_2O_5 K_2Okg ha^{-1})					
Control	4.1	7.9	8.5	8.7	8.8
10-75-75	4.4	8.6	9.2	9.4	9.5
10-0-75	4.4	8.4	9.0	9.2	9.3
10-37.5-75	4.5	8.7	9.3	9.5	9.6
10-75-150	4.4	8.6	9.3	9.4	9.2
CD (0.05)	NS	NS	NS	NS	NS
I X F	NS	NS	NS	NS	NS

Table 9. Shoot: root ratio of groundnut as influenced by irrigation and fertilizers

Treatments	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
Irrigation (IW/CPE)					
0.50	9.0	25.6	20.3	21.4	23.8
0.75	10.0	25.9	20.3	21.7	25.4
1.00	9.2	20.6	20.6	22.8	25.8
CD (0.05)	NS	NS	NS	NS	NS
Fertilizers (N P_2O_5 K_2Okg ha^{-1})					
Control	8.7	22.7	18.9	21.1	23.4
10-75-75	10.3	27.4	21.8	23.2	26.7
10-0-75	8.7	25.5	19.3	20.7	23.8
10-37.5-75	10.1	27.2	21.2	22.7	25.1
10-75-150	9.2	26.4	20.9	22.2	25.2
CD (0.05)	NS	1.6	1.4	NS	1.4
I X F	NS	NS	NS	NS	NS

Table 10. Dry matter production of groundnut as influenced by irrigation and fertilizers, g plant^{-1}

Treatments	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
Irrigation					
(IW/CPE)					
0.50	0.864	4.180	6.52	11.43	16.13
0.75	0.923	4.522	7.87	13.94	18.74
1.00	0.922	4.520	7.86	13.68	18.42
CD (0.05)	NS	NS	0.96	1.96	2.10
Fertilizers					
(N P_2O_5 K_2O kg ha^{-1})					
Control	0.838	4.19	7.15	12.51	17.47
10-75-75	0.936	4.55	7.55	13.20	17.84
10-0-75	0.950	4.53	7.55	13.27	17.90
10-37.5-75	0.944	4.53	7.54	13.56	18.20
10-75-150	0.847	4.27	7.30	12.49	17.40
CD (0.05)	NS	NS	NS	NS	NS
I X F	NS	NS	NS	NS	NS

DMP at 60 and 80 DAS and at harvest was obtained when the crop was irrigated at an IW/CPE ratio of 0.75. Fertilizer levels did not show variation in the DMP at any stage of crop growth. However the highest quantity (18.2g plant^{-1}) of dry matter was produced by fertilizer level of 10-37.5-75 kg N P K ha^{-1} at harvest.

4.1.6 Number of nodules plant^{-1} (Table 11)

There was steady increase in number of nodules with a decrease in moisture stress during all the crop stages. The significant difference was noted at 60 DAS. The numbers of nodules were maximum (76.2) in plants having irrigation at 0.75 IW/CPE ratios, which was on par with 1.0.

Fertilizer application had significant influence on the nodule production at initial crop growth (upto flowering) only, and at later stages the effect was marginal. However, the number of nodules increased from 5.57 at 20 DAS to 75.98 at 80 DAS and then decreased at harvest in F_4 (10-75-150 kg N P_2 O_5 ha^{-1}. At 20 DAS treatment control had the significantly lower nodule (4.79) and all the levels were on par. But at 80 DAS F_4 (10-75-150 kg N P_2O_5 K_20 ha^{-1}) had significantly higher nodules, which was on par with fertilizer level of 10-37.5-75 kg N P_2O_5 K_2O ha^{-1}. Towards maturity of the crop there was no considerable variation in nodule number with respect to nutrient levels.

4.1.7 Leaf area index (Table 12)

Leaf area index of groundnut was altered by increase in frequency of irrigation. The highest LAI was obtained at an IW/CPE ratio of 0.75, which was more pronounced during the latter stages (rain free period).

The different levels of nutrients had not contributed towards significant variation in LAI.

4.1.8 Chlorophyll Content

4.1.8.1 Chlorophyll 'a' (Table 13)

The maximum chlorophyll 'a' content was noticed at flowering and decreased towards maturity of the crop. Irrigation had no significant influence on chlorophyll 'a' content of leaf.

Table 11. Number of nodules $plant^{-1}$ of groundnut as influenced by irrigation and fertilizers

Treatments	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
Irrigation					
(IW/CPE)					
0.50	5.3	16.4	34.5	69.8	61.2
0.75	5.5	17.0	36.7	76.2	62.1
1.00	5.6	17.0	36.9	75.5	62.4
CD (0.05)	NS	NS	1.95	NS	NS
Fertilizers					
(N P_2O_5 K_2O kg ha^{-1})					
Control	4.8	15.8	34.4	73.2	60.1
10-75-75	5.7	17.0	35.2	75.0	60.5
10-0-75	5.5	16.3	37.0	69.7	64.6
10-37.5-75	5.8	17.2	36.6	75.4	61.4
10-75-150	5.6	17.7	37.2	76.0	63.0
CD (0.05)	0.76	1.43	NS	NS	NS
I X F	NS	NS	NS	NS	NS

Table 12. Leaf area index of groundnut as influenced by irrigation and fertilizers

Treatments	20 DAS	40 DAS	60 DAS	80 DAS	Harvest
Irrigation (IW/CPE)					
0.50	0.40	1.28	2.54	4.23	2.12
0.75	0.44	1.36	2.69	4.94	2.43
1.00	0.46	1.33	2.75	5.37	2.52
CD (0.05)	NS	NS	0.09	0.132	0.31
Fertilizers (N P_2O_5 K_2O kg ha^{-1})					
Control	0.39	1.24	2.67	4.80	2.26
10-75-75	0.42	1.31	2.63	4.80	2.40
10-0-75	0.43	1.37	2.64	4.80	2.34
10-37.5-75	0.42	1.37	2.66	5.09	2.39
10-75-150	0.43	1.32	2.70	4.81	2.39
CD (0.05)	NS	NS	NS	NS	NS
I X F	NS	NS	NS	NS	NS

But chlorophyll 'a' content varied significantly by fertilizer application at flowering whereas at 80 DAS it had no influence on chlorophyll .The interaction between irrigation and fertilizers was found to be significant at 80 DAS(Table 14). The treatment combination I_1F_4 (IW/CPE =0.5 and 10-75-150 kg N P_2O_5 K_2O ha^{-1}) recorded the highest chlorophyll 'a' content of 556 mg g^{-1} at 80 DAS and I_2F_4 (IW/CPE=0.75 and 10-75-150 kg N P_2O_5 K_2O ha^{-1}) recorded the lowest.

4.1.8.2 Chlorophyll 'b' (Table 13)

Irrigation had no marked effect on chlorophyll 'b' content at flowering. However at maturity (80 DAS) chlorophyll 'b' content was more concentrated in plants that received irrigation at wider intervals (IW/CPE=0.5) and they were significantly superior.

Nutrient addition also showed similar trend at 80 DAS. The treatment 10-0-75 kg N P_2O_5 K_2O ha^{-1} had the highest chlorophyll 'b' content (0.246mg g^{-1}), which was on par with that in treatment F_4(10-75-150 kg N P_2O_5 K_2O ha^{-1}).

Interaction effect of irrigation and fertilizers was found to be significant (Table 14) only at 80 DAS. I_1F_4 (IW/CPE=0.5 and 10-75-150 kg N P_2O_5 K_2O ha^{-1} recorded the highest chlorophyll 'b' content (0.390 mg g^{-1}) and I_2F_4 (IW/CPE=0.75 and 10-75-150 kg N P_2O_5 K_2O ha^{-1}) recorded the lowest.

4.1.8.3 Total chlorophyll (Table 13)

On the contrary to chlorophyll 'a' and 'b', irrigation had contributed remarkably towards the production of total chlorophyll throughout the crop period. Similar to chlorophyll 'a', and 'b', maximum quantity was noticed at flowering and there after it decreased. It was significantly higher in IW/CPE ratio of 1.0 at both stages of growth.

Similar to irrigation, fertilizer effect was also remarkable throughout the crop growth. Treatment control had the highest content (1.60mg g^{-1}), which was on par with 10-75-150 kg N P_2O_5 K_2O ha^{-1}at flowering. But at 80 DAS, F_2 (10-0-75 kg N P_2O_5 K_2O ha^{-1}) recorded significantly superior content of total chlorophyll.

Table 13.Chlorophyll content of groundnut at flowering and 80 DAS as influenced by irrigation and fertilizers, mg g^{-1}

Treatments	Chlorophyll a		Chlorophyll b		Total chlorophyll	
	Flowering	80 DAS	Flowering	80 DAS	Flowering	80 DAS
Irrigation						
(IW/CPE)						
0.50	0.808	0.420	0.543	0.254	1.581	0.731
0.75	0.904	0.386	0.526	0.187	1.422	0.575
1.00	0.894	0.495	0.534	0.252	1.662	0.793
CD (0.05)	NS	0.033	NS	0.016	0.140	0.046
Fertilizers						
(N P_2O_5 K_2O kg ha^{-1})						
Control	0.976	0.416	0.563	0.189	1.602	0.682
10-75-75	0.709	0.429	0.581	0.217	1.532	0.684
10-0-75	0.887	0.455	0.499	0.246	1.486	0.760
10-37.5-75	0.892	0.422	0.532	0.207	1.567	0.675
10-75-150	0.950	0.448	0.495	0.245	1.588	0.696
CD (0.05)	0.17	NS	NS	0.026	0.036	0.364
I X F	NS	Sig.	NS	Sig.	Sig.	Sig.

Table 14. Chlorophyll 'a' and 'b' content as influenced by interaction effect *irrigation and fertilizers*

Treatments	Chlorophyll 'a' 80 DAS (mgg^{-1})				
	F_0	F_1	F_2	F_3	F_4
I_1	0.404	0.396	0.285	0.463	0.556
I_2	0.335	0.435	0.545	0.340	0.273
I_3	0.509	0.456	0.534	0.462	0.515
CD (0.05)	0.059				
	Chlorophyll 'b' 80 DAS (mgg^{-1})				
	F_0	F_1	F_2	F_3	F_4
I_1	0.186	0.217	0.217	0.258	0.390
I_2	0.156	0.172	0.207	0.145	0.108
I_3	0.226	0.261	0.315	0.219	0.237
CD (0.05)	0.045				

Table 15. Total chlorophyll content as influenced by interaction effect of irrigation and fertilizers(mg g^{-1})

Treatments	Flowering					80 DAS				
	F_0	F_1	F_2	F_3	F_4	F_0	F_1	F_2	F_3	F_4
I_1	1.58	1.81	1.18	1.52	1.82	0.703	0.684	0.610	0.811	0.845
I_2	1.28	1.33	1.50	1.47	1.52	0.531	0.600	0.951	0.486	0.406
I_3	1.94	1.45	1.77	1.72	1.42	0.811	0.769	0.820	0.728	0.836
CD (0.05)	0.43					0.063				

The interaction effect was found to be significant at flowering and 80 DAS (Table 15). I_1F_4 (IW/CPE=0.5 and 10-75-150 kg N P_2O_5 K_2O ha^{-1}) recorded maximum total chlorophyll content in both the stages (at flowering and 80 DAS).

4.1.9 Cell sap pH (Table 16)

The cell sap pH of the plant was not influenced by either irrigation or fertilizer or due to their interaction. However cell sap pH decreased to become more acidic with increase in age.

4.2 YIELD ATTRIBUTES AND YIELD (TABLE 17)

4.2.1 Days to 50 per cent flowering

The data showed that the days taken for 50 percent of the plants to flower were not affected by either irrigation or fertilizers or their interactions. It took 30 to 32 days for 50 per cent flowering irrespective of treatments.

4.2.2 Number of pegs plant^{-1}

Irrigation has no marked influence on peg development. Highest numbers of pegs (10.73) were observed at fertilizer level F_1 (10-75-75 kg N P_2O_5 K_2O ha^{-1}) and other levels were on par with this except control (8.83).

4.2.3 Percentage of pegs developed to pods

Irrigation or fertilizer application had no remarkable role in the conversion rate of pegs to pod development. However, when frequency of irrigation was increased, there was increase in the percentage of pegs to pod conversion.

Similarly compared to control, fertilizer application had increased the conversion rate by four per cent though not significantly. In general 75.8 per cent of pegs formed developed into pods.

4.2.4 Number of pods plant^{-1}

An increasing trend in pod number per plant was noticed with increase in irrigation frequency. The number of pods increased from 7.09 to 8.43 when IW/CPE ratio increased from 0.5 to 1.0.

Fertilizer application had significant effect on number of pods plant^{-1}. There was 30 per cent increase in production of pods due to fertilizer application over no

Table 16. Cell sap pH of groundnut as influenced by irrigation and fertilizers

Treatment	Flowering	80 DAS
Irrigation (I)		
I_1	6.36	5.90
I_2	6.34	5.84
I_3	6.43	5.96
CD (0.05)	NS	NS
Fertilizers (F)		
F_0	6.38	5.85
F_1	6.35	5.92
F_2	6.39	5.95
F_3	6.36	5.92
F_4	6.39	5.88
CD (0.05)	NS	NS
IXF	NS	NS

Table 17. Yield attributes of groundnut as influenced by irrigation and fertilizers

Treatments	Days to 50% flowering	No. of pegs plant^{-1}	% of pegs developed to pod	Number of pods plant^{-1}	Total bio mass (kgha^{-1})	100 pod weight (g)	Pod yield (kg ha^{-1})	Haulm yield (kg ha-^{1})	Haulm pod ratio	100 kernel weight (g)	Kernel yield (kg ha^{-1})	Harvest index (%)	Shelling %
I_1	31	9.4	75.3	7.1	3148	129.2	978	2176	2.21	48.8	702	31.1	69.6
I_2	30	10.7	78.4	8.4	3561	122.9	1267	2287	1.91	50.0	829	36.2	65.9
I_3	30	10.6	78.7	8.4	3649	135.5	1261	2297	1.90	48.7	827	35.6	66.3
CD (0.05)	NS	NS	NS	NS	244	NS	225	NS	NS	NS	106	NS	NS
F_0	32.1	8.8	74.9	6.6	3206	128.6	1032	2175	2.23	49.5	697	32.1	67.5
F_1	33.6	10.7	76.9	8.3	3568	123.9	1175	2282	2.02	49.5	768	33.8	65.9
F_2	34.8	10.7	78.1	8.5	3548	130.9	1203	2297	1.89	48.7	820	34.8	67.1
F_3	35.7	10.7	78.9	8.4	3488	133.2	1243	2251	1.93	48.1	831	35.8	67.6
F_4	35.0	10.2	78.3	8.1	3453	128.1	1192	2266	1.96	50.0	814	35.0	68.3
CD (0.05)	NS	1.3	NS	1.2	NS	NS	NS	NS	NS	NS	NS	NS	NS
I X F	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	Sig.

fertilizer. The treatment F_2 (10-0-75 kg N P_2O_5 K_2O ha^{-1}) and F_3 (10-37.5-75 kg N P_2O_5 K_2O ha^{-1}) had the highest number of pods (8.47), which was on par with other treatments except control.

4.2.5 Hundred pod weight

Hundred pod weight was not significantly influenced by both irrigation and fertilizers. But the highest pod weight was recorded when the plants received frequent irrigation. Regarding fertilizers, the highest pod weight was recorded in F_3 (10-37.5-75 kg N P_2O_5 K_20 ha^{-1}) even though it was not significant.

4.2.6 Pod yield

Significant effect was noticed in pod yield with respect to irrigation. The pod yield increased from 978 kg ha^{-1} to 1267.20 kg ha^{-1} when IW/CPE ratio increased from 0.5 to 1.00. However at highest level (IW/CPE=1.0) the yield had no remarkable difference compared to IW/CPE ratio of 0.75.

An increasing trend was noticed in yield with increase in fertilizer level from no fertilizer (control) to F_3 (10=37.5-75 kg N P_2O_5 K_2O ha^{-1}) though not significant. At highest fertilizer level (10-75-75 kg N P_2O_5 K_2O ha^{-1}) the yield showed a decline compared to F_2 and F_3.

Interactive effect was found to be insignificant even though I_3F_3 recorded higher pod yield (1537 kg ha^{-1}) than other treatments (Table 18).

4.2.7 Hundred kernel weight

No significant relationship was noticed between 100 kernel weight and irrigation as well as fertilizer application.

4.2.8 Kernel yield

The data regarding the kernel yield indicated that higher frequencies of irrigation resulted in a higher kernel yield. Highest kernel yield of 829 kg ha^{-1} was obtained when the irrigation was scheduled at an IW/CPE ratio of 0.75 and it was on par with IW/CPE ratio of 1.0

In the case of fertilizer application though an increasing trend in kernel yield was noticed from control to 10-75-150 kg N P_2O_5 K_2O ha^{-1}, the effect was not significant.

I_3F_3 registered the high kernel yield (938 kg ha^{-1}) but the interactive effect was found to be insignificant.

4.2.9 Shelling percentage

Neither the levels of irrigation nor fertilizer significantly influenced the shelling percentage of groundnut.

But the interaction between the irrigation and fertilizer was found to be significant. Among the interactions the I_1F_3 (IW/CPE=0.5X10-37.5-75 kg N P_2O_5 K_2O ha^{-1} was recorded the highest value of 71.62 per cent followed by IW/CPE=0.5X10-75-75 kg N P_2O_5 K_2O ha^{-1} (70.1) and the lowest shelling percentage was 60.96 per cent at I_2F_1 (IW/CPE=0.75X10-75-75 kg N P_2O_5 K_2O ha^{-1}).The shelling percentage was higher at lower levels of irrigation in combination with nutrient levels upto 10-37.5-75 kg N P_2O_5 K_2O ha^{-1}(18).

4.2.10 Haulm yield

Even though irrigation or fertilizer application had no marked influence on haulm yield an increasing trend was noticed with increasing IW/CPE ratio from 0.5to 1.00. With respect to nutrient levels, this increase was noticed up to F_2 (10-0-75 kg N P_2O_5 K_2O ha^{-1}) level only.

4.2.11 Haulm pod ratio

The haulm yield was almost double that of pod yield. With decreased frequency of irrigation, the ratio between haulm and pod tended to decline, though not significant. With respect to levels of fertilizer, there was no remarkable influence on the ratio of haulm to pod. However, the lowest ratio was noticed in F_2 (10-0-75 kg N P_2O_5 K_20 ha^{-1}) and highest in control (2.23).

4.2.12 Total biomass

There was significant difference among irrigation treatments. Highest (3649 kg ha^{-1}) biomass was recorded in the case of IW/CPE ratio of 1.0, which was on par with

Table 18. Shelling percentage of groundnut at harvesting as influenced by interaction effect of irrigation and fertilizers at flowering

Treatments	F_0	F_1	F_2	F_3	F_4
0.50	67.4	70.9	70.5	71.6	67.4
0.75	70.7	60.9	62.3	64.5	70.9
1.00	64.2	65.7	68.5	66.6	66.5
CD (0.05)	3.85				

IW/CPE ratio of 0.75 (3561 kg ha^{-1}). Significant difference was not found in respect of fertilizer treatments.

4.2.13 Harvest index

The harvest index was not affected by varying frequencies of irrigation. However, it varied from 31.08 to 35.55 percent when IW/CPE ratio increased from 0.5 to 1.0. IW/CPE ratio of 0.75 recorded highest HI, which was followed by IW/CPE ratio of 1.0.

Fertilizer levels did not significantly influence the HI. But the maximum harvest index was recorded in F_3 (10-37.5-75 kg N P_2O_5 K_2O ha^{-1}).

4.3. QUALITY OF KERNEL (TABLE 19)

4.3.1. Protein content

Neither irrigation nor levels of fertilizer had influenced the protein content of kernel in groundnut.

4.3.2 Protein yield

Unlike protein content, the higher IW/CPE ratio resulted in significantly higher protein yield. I_3 recorded the highest protein yield of 220 kg ha^{-1}.

Levels of fertilizers had no influence on protein yield of the groundnut.

4.3.3 Oil content

Different irrigation frequencies influenced the oil content in groundnut significantly. The data also indicated that the oil content was highest (43.8 %) in IW/CPE ratio of 0.75, which was on par with that at IW/CPE ratio of 1.0.

Different levels of fertilizers did not contribute towards the oil content of kernels.

4.3.4 Oil yield

Oil yield also showed remarkable variation due to difference in irrigation frequencies. The highest oil yield was obtained when irrigation was scheduled at an IW/CPE ratio of 1.0, which was on par with that at 0.75.

Fertilizer levels did not significantly influence the oil yield. However the highest oil yield was recorded in F_3.

Table 19. Protein content, protein yield, oil content and oil yield of groundnut as influenced by irrigation and fertilizers

Treatments	Protein content (%)	Protein yield (kg ha^{-1})	Oil content (%)	Oil yield (kg ha^{-1})
Irrigation (I)				
I_1	25.3	181.4	40.7	290.7
I_2	26.6	217.9	43.8	353.8
I_3	26.8	220.1	43.4	357.1
CD (0.05)	NS	27.3	0.56	42.6
Fertilizers (F)				
F_0	26.0	180.5	42.4	293.8
F_1	26.4	204.6	42.5	328.2
F_2	26.1	214.4	42.4	348.1
F_3	26.3	219.0	42.6	353.7
F_4	26.4	215.1	42.3	345.6
CD (0.05)	NS	NS	NS	NS
IXF	NS	NS	NS	NS

4.4 PLANT NUTRIENT CONTENT AND UPTAKE

4.4.1 Nitrogen (Table 20)

The results showed that the levels of irrigation did not significantly influence the leaf and stem concentration as well as uptake in the early stage of growth upto flowering. However, with increase in IW/CPE ratio from 0.5 to 0.75, a decreasing trend in the leaf and stem concentration was noticed.

Significant effect due to irrigation was observed with respect to shell nitrogen percent and total uptake of N at harvest. Stem and leaf concentration of N increased with increasing levels of irrigation. The shell N content varied significantly by levels of irrigation. It increased from 0.73 per cent to 0.81 per cent when IW/CPE ratio increased from 0.5 to 1.00. The N content of kernel, though showed an increase with increasing the IW/CPE ratio was not significant. The total plant uptake of N was maximum (173.17) at IW/CPE ratio of 1.0 and IW/CPE of 0.5 showed the lowest.

Fertilizer application had significant influence on leaf and stem concentration as well as total uptake of N at flowering. In leaf, the content was significantly higher in 10-75-150 kg N P_2O_5 K_2O ha^{-1} and all other levels were on par. It recorded the highest (3.35 per cent) stem content, which was on par with 10-37.5-75 kg N P_2O_5 K_2O ha^{-1}. With respect to uptake the maximum accumulation was in 10-0-75 kg N P_2O_5 K_2O ha^{-1} which was on par with other fertilizer levels except control .The total uptake ranged from 8.04 to 10.79 kg ha^{-1}at flowering.

At harvest, leaf and stem content of N, was highest in 10-75-75 kg N P_2O_5 K_2O ha^{-1} and lowest in 10-0-75 kg N P_2O_5 K_2O ha^{-1} though not significant. Nitrogen content of shell also showed the same trend. 10-75-75 kg N P_2O_5 K_2O ha^{-1} had the highest N (4.84 %) content of kernel and control had the lowest. In the case of total uptake, the highest value was recorded by 10-37.5-75 kg N P_2O_5 K_2O ha^{-1}, which was on par with 10-75-75 kg N P_2O_5 K_2O $ha^{-1}$and 10-75-75 kg N P_2O_5 K_2O ha^{-1}. The uptake was significantly lower in control.

Table 20. Content and total uptake of N as influenced by irrigation and fertilizer

Treatments	Content (%)						Uptake (kg ha^{-1})	
	Flowering		Harvesting					
	Stem	Leaf	Stem	Leaf	Shell	Kernel	Flowering	Harvesting
Irrigation (IW/CPE)								
0.50	3.11	1.32	0.91	1.67	0.73	4.64	9.49	145.15
0.75	2.98	1.26	1.05	1.85	0.77	4.87	10.21	166.96
1.00	2.95	1.27	1.06	1.94	0.81	4.92	9.47	173.18
CD (0.05)	NS	NS	NS	NS	0.18	NS	NS	10.64
Fertilizers (N P_2O_5 K_2O kg ha^{-1})								
Control	2.70	1.13	1.01	1.83	0.73	4.75	8.04	149.24
10-75-75	2.98	1.28	0.98	1.805	0.76	4.84	9.63	163.53
10-0-75	2.93	1.25	0.97	1.74	0.76	4.80	10.79	161.04
10-37.5-75	3.11	1.37	1.00	1.81	0.78	4.81	10.25	168.56
10-75-150	3.35	1.43	1.09	1.91	0.82	4.84	9.88	166.42
CD (0.05)	0.41	0.173	NS	NS	0.012	NS	1.42	5.97
I X F	NS	NS	NS	NS	NS	NS	NS	NS

As the growth progressed, the N content which was higher in stem at flowering was traslocated to leaf and leaf maintained the highest N content at harvest compared to stem. Among different parts of groundnut, kernel had the highest N content.

Regarding interaction, I_3F_3 had the higher nutrient uptake where pod and kernel yield was more.

4.4.2 Phosphorus (Table 21)

In the early growth stages, the irrigation had no significant influence on leaf and stem concentrations and total uptake of phosphorus. At harvesting, the leaf concentrations and the total uptake of phosphorus were influenced by irrigation frequencies. Leaf P content was significantly higher in I_3 and it showed an increasing trend with increase in ratio of IW/CPE from 0.5 to 1.00. Similar pattern was also noticed with respect to total uptake. It varied from 9.81 to 13.77 kg ha^{-1}. Kernel content though not significant decreased with increase in frequency of irrigation.

At flowering, with increase in level of fertilizer the increase in leaf and stem P content was noticed up to10-37.5-75 kg N P_2O_5 K_2O ha^{-1} (0.220 per cent and 0.265 per cent respectively) and in 10-75-150 kg N P_2O_5 K_2O ha^{-1} decline was noted .The leaf P content was significantly highest in 10-37.5-75 kg N P_2O_5 K_2O ha^{-1} and lowest in 10-0-75 kg N P_2O_5 K_2O ha^{-1}. The stem P content was also highest in 10-37.5-75 kg N P_2O_5 K_2O ha^{-1} and lowest in control. Translocation of P to leaf was more in F_4 compared to other levels. Uptake was remarkably higher in F_3 and lower in control at flowering.

At harvest also F_3 (10-37.5-75 kg N P_2O_5 K_2O ha^{-1}) recorded the maximum P content in leaf, which was on par with F_2 (10-0-75 kg N P_2O_5 K_2O ha^{-1}) and F_4 (10-37.5-75 kg N P_2O_5 K_2O ha^{-1}). Stem concentration of P as well as the P content of shell and kernel showed not much variation with respect to levels of fertilizers. The treatment 10-37.5-75 kg N P_2O_5 K_2O ha^{-1} had the highest P uptake of 12.81 kg ha^{-1} though not significant Even though the stem and leaf concentration declined with age of the crop, the total uptake of P showed an increase towards maturity

Table 21. Content and total uptake of P as influenced by irrigation and fertilizer

	Content (%)						Uptake (kg ha^{-1})	
Treatments	**Flowering**		**Harvesting**				**Flowering**	**Harvesting**
	Stem	**Leaf**	**Stem**	**Leaf**	**Shell**	**Kernel**		
Irrigation (IW/CPE)								
0.50	0.233	0.180	0.054	0.127	0.041	0.349	8.89	9.8
0.75	0.254	0.198	0.066	0.158	0.042	0.343	10.42	12.8
1.00	0.256	0.204	0.071	0.167	0.041	0.341	10.68	13.7
CD (0.05)	NS	NS	NS	0.007	0.003	NS	NS	1.7
Fertilizers (N P_2O_5 K_2O kg ha^{-1})								
Control	0.220	0.181	0.064	0.146	0.039	0.316	8.51	11.0
10-75-75	0.252	0.198	0.060	0.142	0.041	0.354	10.17	11.8
10-0-75	0.240	0.171	0.063	0.153	0.042	0.346	9.57	12.7
10-37.5-75	0.265	0.220	0.068	0.158	0.042	0.354	12.05	12.8
10-75-150	0.261	0.201	0.066	0.154	0.043	0.352	9.69	12.3
CD (0.05)	0.290	0.017	0.004	0.007	0.002	0.018	0.76	NS
IXF	NS	NS	NS	NS	NS	NS	NS	NS

Interaction effect was found to be insignificant but uptake of P was more in the case of I_3F_3.

4.4.3 Potassium (Table 22)

Irrigation levels did not show significant influence on leaf and stem concentration of K throughout the growth. However, in leaf, the maximum content (1.36 per cent) was noticed in plants having irrigation at IW/CPE of 1.0 whereas in stem the content of K was maximum at lowest level of irrigation (IW/CPE=0.5). The K content of shell and kernel was not influenced by irrigation treatments. Hence there was no variation in total uptake irrespective of crop growth due to irrigation.

At flowering remarkable variation was noticed in the K content of leaf as well as stem due to fertilizer application. The effect of fertilizer application was noticed considerably at highest dose of K (10-75-150 kg N P_2O_5 K_2O ha^{-1}) with respect to leaf and stem concentration (91.49 and 3.55 per cent respectively). But in the case of total uptake there was significant effect due to fertilizer application over no fertilizer. Among the different levels of fertilizers, 10-37.5-75 kg N P_2O_5 K_2O ha^{-1}showed the highest uptake of 11.05 kg ha^{-1} which was on par with, 10-0-75 kg N P_2O_5 K_2O ha^{-1} and, 10-37.5-75 kg N P_2O_5 K_2O ha^{-1}.

At harvest with respect to stem and leaf concentration, maximum effect was noticed in F_4. There was not much variation in K content of both at $F_1$and F_2.The variation in K content of shell was not significant .In the case of kernel K content, the levels of fertilizers were on par except control. The total uptake also showed the same trend.

Interaction effect was found to be insignificant.

4.4.4 Calcium (Table 23)

Ca content of leaf and stem as well as total uptake was not affected by irrigation at flowering. But at harvest, irrigation altered the Ca content of leaf and stem considerably. The stem content of Ca increased with increase in IW/CPE ratio from 0.5 to 0.75 and with respect to stem concentration of Ca, IW/CPE ratio of 0.75 and 1.00 were on par.

Table 22. Content and total uptake of K as influenced by irrigation and fertilizer

	Content (%)						Uptake (kg ha^{-1})	
Treatments	Flowering		Harvesting				Flowering	Harvesting
	Stem	Leaf	Stem	Leaf	Shell	Kernel		
Irigation (IW/CPE)								
0.50	3.38	1.35	1.02	2.17	0.428	0.451	10.02	132.5
0.75	3.22	1.35	1.11	2.44	0.433	0.453	10.32	157.7
1.00	3.19	1.36	1.13	2.31	0.429	0.451	10.22	147.4
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Fertilizers (N P_2O_5 K_2O kg ha^{-1})								
Control	2.93	1.18	0.99	2.06	0.430	0.432	8.56	114.5
10-75-75	3.16	1.34	1.05	2.23	0.427	0.453	10.17	156.1
10-0-75	3.27	1.34	1.09	2.25	0.426	0.454	10.64	156.3
10-37.5-75	3.22	1.40	1.11	2.34	0.436	0.456	11.05	161.1
10-75-150	3.55	1.49	1.18	2.50	0.433	0.463	10.52	168.1
CD (0.05)	0.49	1.17	0.11	0.27	NS	0.143	0.567	18.8
IXS	NS	NS	NS	NS	NS	NS	NS	NS

Table 23. Content and total uptake of Ca as influenced by irrigation and fertilizer

	Content (%)				Uptake (kg ha^{-1})	
Treatments	**Flowering**		**Harvesting**		**Flowering**	**Harvesting**
	Stem	**Leaf**	**Stem**	**Leaf**		
Irrigation						
(IW/CPE)						
0.50	0.896	0.352	0.201	0.477	2.71	28.13
0.75	0.906	0.370	0.227	0.575	2.94	36.98
1.00	0.878	0.397	0.232	0.553	2.99	36.19
CD (0.05)	NS	NS	0.017	0.046	NS	27.37
Fertilizers						
(N P_2O_5 K_2O kg ha^{-1})						
Control	0.688	0.293	0.194	0.466	2.05	27.38
10-75-75	0.901	0.380	0.211	0.558	2.98	35.10
10-0-75	0.954	0.395	0.235	0.557	3.25	36.02
10-37.5-75	0.966	0.407	0.228	0.545	3.19	35.52
10-75-150	0.958	0.390	0.232	0.549	2.95	34.80
CD (0.05)	0.067	0.055	0.021	0.048	0.63	4.01
IXF	NS	NS	NS	NS	NS	NS

But there was remarkable variation in Ca content of leaf and stem due to levels of fertilizers at flowering. The maximum Ca content was noticed in F_3 (0.97%). In the case of stem content of Ca, there was significant variation between different levels of fertilizers and F_3 (10-37.5-75 kg N P_2O_5 K_2O ha^{-1}) recorded significantly higher Ca content (0.407 per cent). Total uptake of Ca also showed variation. The highest uptake was noticed in F_2 (10-0-75 kg N P_2O_5 K_2O ha^{-1}), which was on par with other levels except control.

At harvesting also leaf Ca content was influenced by levels of fertilizers. F_1 recorded the highest Ca concentration in leaf which was on par with F_2 .The Ca content ranged from 0.47 per cent to o.59 per cent. There was significant difference in stem Ca contents also and it was maximum in F_2 (0.235 per cent). Even though all the plots received the equal quantity of lime as a recommended practice, wide variation was noticed from 0.194 to 0.235 per cent between with and without fertilizer application. With respect to age of the crop, Ca content was higher in stem and leaf at flowering and it decreased towards harvest. However, total up take showed an increasing trend with age. F_3 (10-37.5-75 kg N P_2O_5 K_2O ha^{-1}) recorded the highest uptake of Ca at harvesting with respect to different fertilizer levels.

The stem of Ca content decreased from flowering to harvest whereas leaf Ca content showed an increase.

4.4.5 Magnesium (Table 24)

At flowering stage, leaf and stem concentration and total uptake of Mg was not significantly affected by the irrigation treatments. However, uptake of Mg increased with increasing levels of irrigation. But the stem and leaf Mg concentration as well as total uptake varied significantly by irrigation at harvest. Though the leaf content of Mg and uptake at harvest were significantly increased with increase in level of irrigation from IW/CPE ratio of 0.5 to 0.75, further increase to IW/CPE =1.0 did not show considerable effect

At flowering, considerable difference was noticed with levels of fertilizers. With respect to both leaf and stem Mg concentration, F_3 (10-37.5-75 kg N P_2O_5 K_2O

Table 24. Content and total uptake of Mg as influenced by irrigation and fertilizer

Treatments	Content (%)				Uptake (kg ha^{-1})	
	Flowering		Harvesting		Flowering	Harvesting
	Stem	Leaf	Stem	Leaf		
Irrigation						
(IW/CPE)						
0.50	0.11	0.27	0.32	0.13	8.31	19.17
0.75	0.12	0.28	0.42	0.10	9.10	25.80
1.00	0.13	0.27	0.40	0.15	9.18	25.87
CD (0.05)	NS	NS	0.049	0.009	NS	4.73
Fertilizers						
(N P_2O_5 K_2O kg ha^{-1})						
Control	0.09	0.20	0.33	0.12	6.11	19.11
10-75-75	0.12	0.28	0.39	0.14	9.23	24.37
10-0-75	0.12	0.30	0.40	0.15	9.95	25.05
10-37.5-75	0.13	0.30	0.39	0.15	10.07	25.65
10-75-150	0.13	0.29	0.39	0.15	8.92	23.88
CD (0.05)	0.015	0.021	0.035	0.012	1.50	2.48
IXF	NS	NS	NS	NS	NS	NS

ha^{-1}) recorded the highest content (0.133 and 0.303 per cent respectively) at flowering. The total uptake also showed the same trend.

There was considerable variation in leaf concentration of Mg between control and levels of fertilizer application at harvest. But among the levels F_2, F_3 and F_4 did not show much variation. The stem Mg content also increased with increase in levels of fertilizer application over no fertilizer. It was considerably higher in F_2 (0.418 per cent), which was on par with F_4 (10-75-150 kg N P_2O_5 K_2O ha^{-1}). The total uptake had its influence in all levels of fertilizer except control.

At flowering the content of Mg was more in leaf and by the time of harvesting maximum content was noted in stem. The Mg content of leaf and stem as well as the uptake increased with the age of the crop.

4.4.6 Sulphur (Table 25)

At initial stages, the irrigation treatments had no influence on leaf and stem sulphur concentration and their uptake. But later, at harvest the highest leaf concentration and total uptake were observed in IW/CPE ratio of 0.75, which was on par with the IW/CPE ratio of 1.0. Regarding the levels of fertilizers, the significant influence was found at both stages of growth. The variation in S content of leaf and stem was noticed in control and all other levels were on par at flowering. The same trend was noticed with respect to uptake also. At harvest the variation due to fertilizer application was observed with respect to leaf concentration and total uptake In the case of leaf S concentration the highest content was noticed in F_1 (10-75-75 kg N P_2O_5 K_2O ha^{-1}) which was on par with other levels except control. The total uptake also showed the same trend.

Between different growth stages, the S content showed a decline both in stem and leaf content towards maturity. With respect to content at various stages, stem concentration was highest at flowering but towards maturity the stem content declined and the leaf concentration increased compared to stem.

Table 25. Content and total uptake of S as influenced by irrigation and fertilizer

Treatments	Content (%)				Uptake (kg ha^{-1})	
	Flowering		Harvesting		Flowering	Harvesting
	Stem	Leaf	Stem	Leaf		
Irrigation						
(IW/CPE)						
0.50	0.164	0.084	0.028	0.059	0.545	3.69
0.75	0.150	0.084	0.055	0.074	0.530	4.97
1.00	0.151	0.082	0.036	0.072	0.537	4.87
CD (0.05)	NS	NS	NS	0.006	NS	0.55
Fertilizers						
(N P_2O_5 K_2O kg ha^{-1})						
Control	0.137	0.074	0.031	0.064	0.441	3.86
10-75-75	0.163	0.088	0.038	0.071	0.579	4.73
10-0-75	0.153	0.083	0.032	0.068	0.560	4.70
10-37.5-75	0.163	0.088	0.034	0.068	0.588	4.74
10-75-150	0.160	0.085	0.033	0.070	0.517	4.51
CD (0.05)	0.010	0.004	NS	0.004	0.062	0.49
I X F	NS	NS	NS	NS	NS	NS

4.4.7 Iron (Table 26)

At flowering stage, irrigation had no influence on leaf and stem concentration and total uptake of Fe. But towards maturity, the leaf and stem concentrations were influenced by irrigation. At harvest the highest concentration of leaf and stem was noted at IW/CPE ratio of 0.5 which was significantly superior and the other levels were on par with respect to stem and leaf concentration and total uptake.

At flowering F_2 (10-0-75 kg N P_2O_5 K_2O ha^{-1}) recorded the highest content of leaf and stem as well as total uptake. At harvest also the same trend was noticed.

Another observation was that at flowering the Fe content was more concentrated in leaf and lower in stem. But as growth progressed, the Fe content was more in stem compared to leaf.

4.4.8 Mn (Table 27)

The stem concentration of Mn at flowering was affected by irrigation. The highest Mn content in stem was noticed at lowest level of IW/CPE of 0.5 (113 ppm). But the irrigation had no influence on leaf content and uptake of Mn. At harvest also the content of Mn in leaf and stem as well as uptake was significantly higher in the plots receiving irrigation of IW/CPE=0.5.With increasing IW/CPE ratio a drastic decline in the leaf and stem concentration of Mn was noticed.

Mn content in stem and leaf was higher in control (122ppm), which was on par with F_2 (10-0-75 kg N P_2O_5 K_2O ha^{-1}). In F_4, the Mn content of leaf was the lowest. In the case of uptake at flowering, the lowest was in 10-75-150 kg N P_2O_5 K_2O ha^{-1} and on par with10-75-75 kg N P_2O_5 K_2O ha^{-1}. At harvest, the Mn content of stem was higher in F_2, which was on par with control and F_3.The leaf content was lowest in F_4 (44 ppm) and all other levels were on par. With respect to up take, F_2 had the highest up take, which is significantly superior. The Mn content was more at flowering and towards maturity it declined. At flowering Mn content was higher in leaf but at harvest the content was more in stem.

Table 26. Content and total uptake of Fe as influenced by irrigation and fertilizer

Treatments	Content (%)				Uptake (g ha^{-1})	
	Flowering		Harvesting			
	Stem	Leaf	Stem	Leaf	Flowering	Harvesting
Irrigation (IW/CPE)						
0.50	538	862	326	151	310	2022
0.75	531	865	295	135	322	1936
1.00	544	858	301	142	331	1960
CD (0.05)	NS	NS	12	7.0	NS	NS
Fertilizers (N P_2O_5 K_2O kg ha^{-1})						
Control	456	739	267	125	251	1615
10-75-75	488	789	275	131	299	1823
10-0-75	635	1023	361	164	394	2369
10-37.5-75	614	957	347	161	381	2275
10-75-150	495	802	285	135	280	1779
CD (0.05)	28	42	9.0	9.0	46	220
I X F	NS	NS	NS	NS	NS	NS

Table 27. Content and total uptake of Mn as influenced by irrigation and fertilizer

Treatments	Content (%)				Uptake (g ha^{-1})	
	Flowering		Harvesting		Flowering	Harvesting
	Stem	Leaf	Stem	Leaf		
Irrigation						
(IW/CPE)						
0.50	113	528	142	60	96	849
0.75	103	343	118	49	102	751
1.00	101	340	110	44	101	680
CD (0.05)	5.2	NS	6.25	6.09	NS	NS
Fertilizers						
(N P_2O_5 K_2O kg ha^{-1})						
Control	122	378	128	51	105	743
10-75-75	95	334	118	51	93	754
10-0-75	118	361	135	57	110	844
10-37.5-75	102	337	127	51	105	785
10-75-150	94	305	112	44	86	676
CD (0.05)	5.39	NS	7.49	6.0	13.7	97.5
I X S	NS	NS	NS	NS	NS	NS

4.5 SOIL STUDIES

4.5.1 Consumptive use (Table 28)

The soil moisture content was estimated after the first irrigation treatment. Because of frequent rainfall the irrigation treatments were imposed from 42 days onwards. Consumptive use was higher in the case of frequent irrigation (IW/CPE=1.00). The higher consumptive use was recorded in the case of I_3 than the other treatments ($I_1$and I_2) and regarding fertilizer, there was no much difference between the treatments. But the lowest was recorded (114.3) in the case of F_2 (10-0-75 kg N P_2O_5 K_20 ha^{-1} where the P fertilizer was not applied.

4.5.2 Field water use efficiency (Table 29)

The field water use efficiency was highest (1.98 kg $hamm^{-1}$) recorded in IW/CPE ratio of 0.75 and the field water use efficiency decreases when the irrigation was given at higher frequency of 8 days.

4.5.3 Crop water use efficiency (Table 29)

In the case of crop water use efficiency, the highest was recorded (16.3 kg ha mm^{-1}) for those treatments, which received less frequency of irrigation (IW/CPE=0.5) and it showed a decreasing trend when the frequency of irrigation was increased.

4.5.4 Nutrient content of soil

4.5.4 Available nitrogen (Table 30)

Variation in irrigation significantly altered the available N content of soil throughout the growth. Higher content of available N (321 kg ha^{-1}) was noticed in plants, which receive irrigation at an IW/CPE ratio of 1 followed by that of 0.75 over the lowest level at flowering. The same trend was noticed at harvesting also. In both the stages, F_3 (10-37.5-75 kg N P_20_5 K_20 ha^{-1}) recorded the highest N content in the soil (314 kg ha^{-1}) which was on par with that of F_1(10-75-75 kg N P_20_5 K_20 ha^{-1}) and F_4(10-75-150 kg N P_20_5 K_20 ha^{-1}). The available N content was highest at flowering and showed a decline towards harvesting.

Interaction between irrigation and fertilizer was observed to be significant at flowering stage. The highest available N content of soil was at the highest level of

Table 28. Consumptive use of groundnut as influenced by irrigation and fertilizers, mm

Treatments	I_1	I_2	I_3	Mean
F_0	58.6	120.8	182.0	120.5
F_1	60.2	116.4	173.1	116.5
F_2	61.2	109.9	171.8	114.3
F_3	59.5	118.1	182.3	119.9
F_4	59.6	121.2	174.9	111.9
Mean	79.8	117.3	176.8	

Table 29. Field Water Use Efficiency (FWUE) and Crop Water Use Efficiency (CWUE) as influenced by irrigation

Treatment	FWUE (kg ha mm^{-1})	CWUE (kg ha mm^{-1})
I_1	1.85	16.37
I_2	1.98	10.84
I_3	1.73	7.14
CD (0.05)	NS	0.40

irrigation and highest level of P and K (IW/CPE = 1.0X 10-75-150 kg N P_2O_5 K_2O ha^{-1}) and it was on par with I_3F_1 and I_3F_3 (Table 33). At lowest frequency of irrigation (IW/CPE=0.5) the available N content was lowest with no fertilizer application (I_1F_0) and it was on par with other levels of fertilizers.

4.5.4.2 Available phosphorus (Table 30)

There was significant variation between different levels of irrigation both at flowering and harvest. Available phosphorus increased considerably with decrease in the frequency of irrigation. At flowering the available P content increased significantly from 18.88 kg ha^{-1} to 21.66 kg $ha^{-1}$when irrigation level increased from IW/CPE ratio of 0.5 to 1.0. At harvest the available P content was maximum at lowest IW/CPE ratio of 0.5 and decreased there after.

Fertilizer application also had significant influence on available P content at flowering as well as at harvesting. At flowering plants at F_1 (10-75-75 kg N P_2O_5 K_2O ha^{-1}) had the highest level of P. At harvesting the available P content was highest at F_1 (16.76 kg ha^{-1}), which was on par with F_4. The available P content was higher at flowering and it decreased towards harvest.

The available P content in the rhizozsphere was lowest for plants of treatment combinations of I_1F_0, which was on par with (I_1 F_2). The highest content of P was noticed at I_3F_1, which was on par with I_3F_4 (Table 31).

4.5.4.3 Exchangeable K (Table 30)

Irrigation as well as fertilizer application did not contribute to variation in exchangeable K at flowering. At harvesting the exchangeable K content varied with levels of fertilizers. The K content increased with increase in P and K application. It increased from 236.71 kg ha^{-1} at F_0 to 245.58 kg ha^{-1}at F_1, which was on par with that in F_4. Exchangeable potassium also decreased from flowering to maturity of crop.

4.5.4.4 Exchangeable calcium (Table 32)

There was no significant variation between different levels of irrigation on the exchangeable calcium content in the soil both at flowering and harvesting stages.

Table 30. Status of major nutrients in rhizosphere soil as influenced by irrigation and fertilizer

Treatments	Available nitrogen (kg ha^{-1})		Available phosphorus (kg ha^{-1})		Exchangeable K (kg ha^{-1})	
	Flowering	Harvesting	Flowering	Harvesting	Flowering	Harvesting
Irrigation (IW/CPE)						
0.50	300.1	286.4	18.9	16.0	346.8	251.4
0.75	315.5	293.9	21.0	14.2	340.3	236.0
1.00	321.0	299.0	21.7	14.3	342.1	232.1
CD (0.05)	3.59	2.72	0.26	0.84	NS	NS
Fertilizers (N P_2O_5 K_2O kg ha^{-1})						
Control	308.4	290.2	19.5	13.9	342.2	236.7
10-75-75	313.5	294.2	23.1	16.8	347.0	245.6
10-0-75	312.0	291.7	18.4	13.5	340.5	236.5
10-37.5-75	314.0	295.2	18.8	13.9	340.3	235.0
10-75-150	313.8	294.3	22.6	16.2	345.4	245.4
CD (0.05)	2.64	2.65	0.69	0.53	NS	6.74
I X F	Sig.	NS	Sig.	NS	NS	NS

Table 31. **Available N and P of soil at flowering as influenced by interaction effect of irrigation and fertilizers, kg ha^{-1}**

Treatments	Available N				
	F_0	F_1	F_2	F_3	F_4
I_1	296.8	303.3	298.1	303.2	298.2
I_2	313.1	317.7	319.0	313.8	317.5
I_3	315.5	323.5	316.0	324.8	325.0
CD (0.05)	4.58				
	Available P				
	F_0	F_1	F_2	F_3	F_4
I_1	17.5	21.7	18.3	18.0	20.8
I_2	20.3	23.4	19.1	19.5	22.5
I_3	20.8	24.3	19.9	18.8	24.5
CD (0.05)	1.08				

With increasing IW/CPE ratio increased the Ca content of soil was increased at harvesting stage.

But the levels of fertilizers had significant influence at harvesting stage. At flowering, highest content was noticed at 10-75-150 kg N P_2O_5 K_20 ha^{-1} and lowest in control though not significant. Exchangeable Ca also decreased with increasing age of crop. The treatment F_4 had the highest exchangeable Ca of 114.1kg ha^{-1} and it was on par with F_0. The treatment F_2 recorded the lowest Ca content in soil.

4.5.4.5 Exchangeable Mg (Table 32)

There was no significant difference in the quantity of exchangeable Mg of rhizosphere soil at flowering stage due to irrigation. However, a steady increase was noticed with increasing the IW/CPE ratio from 0.5 to 1.0. But at harvesting the highest amount of exchangeable Mg (95.05 kg ha^{-1}) was found in the plots having the lowest level of irrigation (IW/CPE=0.5).

Fertilizer levels also did not significantly influence the exchangeable Mg content at flowering, though the highest content was noted at F_4 (95.56 kg ha^{-1}). At harvesting the treatment F_4 had the highest exchangeable Mg content in soil, which was on par with control.

4.5. 4.6 Sulphur (Table 32)

The S content was highest (19.13 kg ha^{-1}) in plots receiving irrigation at IW/CPE=0.5 at flowering. With increase in the level of irrigation, S content in soil was found to decline. Slight variation was noticed as the crop reached maturity. It increased from 19.13 kg ha^{-1} at IW/CPE ratio of 0.5 to 15.37 kg ha^{-1} at IW/CPE ratio of 1.0. At harvesting the S content was higher in IW/CPE ratio of 0.75 compared to 0.5 and 1.0 though not significant.

Levels of fertilizers showed significant influence on exchangeable S content of soil at flowering and harvesting. Fertilizer level of 10-0-75 kg N P_2O_5 K_20 ha^{-1} recorded the lowest content of S, which was on par control (F_0). The highest content of 17.67 kg ha^{-1} was noticed in the treatment 10-0-75 kg N P_2O_5 K_20 ha^{-1}. The same trend was observed at harvesting also and the highest content was noted in F_1.

Table 32. Content of secondary nutrients in rhizosphere soil as influenced by irrigation and fertilizer

Treatments	Exchangeable Ca (kg ha^{-1})		Exchangeable Mg (kg ha^{-1})		$CaCl_2$ extractable Sulphur (kg ha^{-1})	
	Flowering	Harvesting	Flowering	Harvesting	Flowering	Harvesting
Irrigation (IW/CPE)						
0.50	137.4	109.2	106.0	95.1	19.1	21.7
0.75	137.0	111.0	105.5	87.9	16.3	22.5
1.00	137.5	111.8	105.8	87.7	15.4	21.6
CD (0.05)	NS	NS	NS	1.85	0.59	NS
Fertilizers ($N\ P_2O_5\ K_2O$ kg ha^{-1})						
Control	136.9	113.6	103.5	93.8	16.2	21.0
10-75-75	138.6	109.4	106.4	88.4	17.7	22.8
10-0-75	135.5	106.9	107.1	87.8	16.0	20.8
10-37.5-75	135.7	109.5	108.5	85.3	17.7	22.7
10-75-150	139.8	114.1	110.9	95.6	17.1	22.5
CD (0.05)	NS	4.93	NS	4.89	0.85	1.01
I X F	NS	NS	NS	NS	NS	NS

In the case of Mg towards maturity of crop the available content in the soil decreased whereas, with respect to S, an increase was noted as the crop reached harvesting stage.

4.5.4.7 Available Iron (Table 33)

Among the different stages of growth, levels of irrigation had influenced the available Fe content at harvesting stage only. At flowering the lowest content of Fe was noted in IW/CPE ratio of 1.0 and highest in IW/CPE of 0.75. A declining trend in available Fe content of soil was noticed with decrease in frequency of irrigation at harvesting. It increased from 320 ppm to 303 ppm when IW/CPE ratio increased from 0.5 to 1.00.

The fertilizer application had no influence on available Fe content of soil at both the stages. The available Fe was lowest in F_2 and highest in F_3 at flowering as well as harvesting. There was variation in available Fe content at different growth stages. It decreased from flowering to harvesting.

4.5.4.8 Available Mn (Table 33)

Irrigation had its influence on available Mn content of soil at harvesting stage. Though the lowest level of irrigation (IW/CPE=0.5) had the highest Mn content of 30.67ppm, the levels did not show significant variation.

Application of fertilizer showed a significant variation on available Mn content of soil at both the stages. At flowering, treatment 10-75-150 kg N P_2O_5 K_20 ha^{-1} recorded the highest Mn content of soil which was significantly (38.72 ppm) superior and all other levels were on par. The same treatment F_4 had the highest Mn content at harvesting also. Mn content in soil also showed a declining trend when the crop reached maturity.

4.5.5 Soil solution studies

4.5.5.1 pH (Table 34)

Soil solution pH was higher than the bulk soil pH.. Solution phase pH was higher at 24 hours after irrigation compared to 48 and 72 hours after irrigation. At 24

Table 33. Contents of micronutrients in rhizosphere soil as influenced by irrigation and fertilizers

Treatments	Available Fe (ppm)		Available Mn (ppm)	
	Flowering	Harvesting	Flowering	Harvesting
Irrigation (IW/CPE)				
0.50	336.8	320.3	35.7	30.67
0.75	337.7	305.5	37.0	28.27
1.00	335.1	303.6	35.1	26.60
CD (0.05)	NS	8.29	NS	3.22
Fertilizers (N P_2O_5 K_2O kg ha^{-1})				
Control	337.8	308.8	33.9	26.44
10-75-75	334.3	306.6	38.3	29.22
10-0-75	327.4	304.0	33.7	27.11
10-37.5-75	344.1	319.7	35.4	28.44
10-75-150	339.0	310.0	38.7	31.33
CD (0.05)	NS	NS	3.33	2.51
IXF	NS	NS	NS	NS

Table 34. Soil exchangeable phase pH and solution phase pH at different periods of observations

Treatments	Exchangeable phase pH at 80 DAS	Solution phase pH at 80 DAS		
		24 h after irrigation	48 h after irrigation	72 h after irrigation
Irrigation(IW/CPE)				
IW/CPE=0.5	5.83	6.75	7.11	6.95
IW/CPE=0.75	5.82	6.88	6.82	6.89
IW/CPE=1.00	5.81	6.81	6.81	6.75
Fertilizer(kg ha^{-1})				
Control	5.83	6.8	7.11	6.83
10-75-75 N P_2O_5 K_20	5.81	6.86	6.95	7.02
10-0-75 N P_2O_5 K_20	5.82	6.79	6.87	6.84
10-37.5-75 N P_2O_5 K_20	5.82	6.87	6.91	6.89
10-75-150 N P_2O_5 K_20	5.83	6.74	6.71	6.84

and 48 hours after irrigation IW/CPE ratio of 0.75 had higher pH (near neutral pH). With respect to nutrient levels, the lowest pH was noted in F_4.

4.5.5.2 Nutrient content of soil solution

Soil solution was extracted from soil 24,48 and 72 h after irrigation and analyzed for different nutrients. Soil solution phosphorus could not find out any one the above cases due to it's meager amount in the soil solution.

4.5.5.3 Nitrogen (Table 35)

Nitrogen content of solution was more at 24 hours after irrigation compared to 48 and 72 hours after irrigation. When the irrigation was given at frequent intervals the N content was varied though not consistent. However N content in soil solution decreased considerably from 24 to 72 hours after irrigation. The lowest content was noticed at 72 hours after irrigation.

Highest N content in soil solution was recorded at lowest frequency of irrigation at 24 and 48 hours after irrigation and the variation was not consistent between IW/CPE ratio of 0.75 and 1.0.Among the nutrient levels, the treatment 10-75-150 kg N P_2O_5 K_20 ha^{-1} had the highest content of N (448 ppm) at 24 hours after irrigation. The same trend was noted at 48 and 72 hours after irrigation even though the quantity of applied N was the same.

4.5.5.4 Potassium (Table 36)

Potassium content was highest at highest frequency of irrigation compared to lower levels at 24 hours after irrigation. But 48 hours after irrigation the reverse trend was noticed. However, the K content decreased when the duration after irrigation increased .It decreased from 27 ppm at 24 hours after irrigation to 8 ppm at 72 hours after irrigation.

Table 35. Nitrogen content in the soil solution at 80 DAS, ppm

Treatments	24 Hours after irrigation	48 Hours after irrigation	72 Hours after irrigation
Irrigation (I)			
I_1	436	252	190
I_2	392	235	257
I_3	431	190	123
Fertilizer (F)			
F_0	448	205	130
F_1	401	214	196
F_2	392	186	224
F_3	354	233	177
F_4	504	289	224

Table 36. Potassium content in soil solution at 80 DAS, ppm

Treatments	24 Hours after irrigation	48 Hours after irrigation	72 Hours after irrigation
Irrigation			
I_1	17	16	13
I_2	26	15	17
I_3	27	12	08
Fertilizer			
F_0	21	13	09
F_1	21	14	14
F_2	18	11	16
F_3	24	15	12
F_4	16	18	14

The treatment 10-37.5-75 kg N P_2O K_20 ha^{-1} recorded the maximum K content (24ppm) at 24 hours after irrigation. F_4 recorded the highest content at 48 hours after irrigation and lowest was noted in F_2 (10-0-75 kg N P_2O_5 K_20 ha^{-1}. But F_2 recorded the highest content at 72 hours after irrigation.

4.5.5.5 Calcium (Table 37)

High content of calcium was noted at all levels compared to other nutrients and calcium content increased with increase in duration after irrigation up to 48 hours after irrigation and then decreased. Even though calcium content was highest in I_2 at 24 hours after irrigation and it was lowest in IW/CPE ratio of 0.75 at 48 and 72 hours after irrigation. However, IW/CPE ratio of 0.5 recorded the highest Ca content at 48 and 72 hours after irrigation. Irrespective of duration after irrigation, highest content was noted in F_4 and control recorded lower Ca content.

4.5.5.6 Magnesium (Table 38)

In the case of Mg content, it increased from 24 to 48 hours after irrigation and then decreased. The Mg content increased with increase in frequency of irrigation from IW/CPE ratio 0.5 to 1.0. Among the levels of nutrients, 10-0-75 kg N P_2O_5 K_20 ha^{-1} recorded the highest Mg content at 24 and 72 hours after irrigation. But at 48 hours after irrigation, F_3 had the highest Mg content.

4.5.5.7 Sulphur (Table 39)

The sulphur content of soil solution was higher at 24 hours after irrigation compared to 48 and 72 hours after irrigation. It decreased with increase in frequency of irrigation .It decreased from 17.68 ppm in IW/CPE ratio of 0.5 to 15.2 ppm in IW/CPE ratio of 1.0 at 24 hours after irrigation.

With respect to different levels of fertilizers, nutrient content was highest in F_3 at 24 hours after irrigation and there after F_1 had recorded the highest content of S.

Table 37. Calcium content in soil solution at 80 DAS, ppm

Treatments	24 Hours after irrigation	48 Hours after irrigation	72 Hours after irrigation
Irrigation			
I_1	841	4806	2645
I_2	962	3847	2404
I_3	761	4569	2565
Fertilizer			
F_0	802	3206	2271
F_1	868	4408	2538
F_2	801	3340	2538
F_3	801	4275	2538
F_4	1002	4809	2805

Table 38. Mg content in soil solution at 80 DAS, ppm

Treatments	24 Hours after irrigation	48 Hours after irrigation	72 Hours after irrigation
Irrigation			
I_1	194	1361	695
I_2	292	1461	875
I_3	291	1507	875
Fertilizer			
F_0	243	1540	811
F_1	324	1297	892
F_2	324	1378	1054
F_3	203	1459	648
F_4	162	1540	892

Table 39. Sulphur content in soil solution at 80 DAS, ppm

Treatments	24 hours after irrigation	48 hours after irrigation	72 hours after irrigation
Irrigation			
I_1	17.68	16.04	10.24
I_2	16.94	10.46	9.90
I_3	15.20	10.66	9.60
Fertilizer			
F_0	15.33	14.00	8.96
F_1	14.80	13.20	11.20
F_2	15.33	12.90	9.93
F_3	18.86	10.50	7.26
F_4	18.26	11.20	9.20

Another fact was that at 24 after irrigation F_1 had the lowest content and it increased to the highest content after 48 and 72 hours after irrigation

4.6 CORRELATION STUDIES

4.6.1 Correlation between yield attributing characters and yield (Table 40)

Pod yield was positively correlated with total biomass, 100 pod weight, number of pods per plant, haulm yield and kernel yield. But it was negatively correlated with haulm pod ratio, haulm kernel ratio and shelling percentage. Total biomass also had similar relationship with other yield attributing characters except 100 kernel weight where it was negatively correlated. Haulm: pod ratio was negatively correlated with 100 pod weight, 100 kernel weight, and number of pods per plant and kernel yield. But it had positive relationship with haulm: kernel ratio, number of pods per plant, and haulm yield.

Regarding haulm kernel ratio, it was negatively correlated with 100 pod weight, 100 kernel weight, number of pods per plant and kernel yield and showed positive relationship with shelling percentage and haulm yield. Hundred pod weight was negatively correlated with kernel yield and number of pods per plant.

4.6.2 Correlation between plant nutrient uptake and yield (Table 42)

Kernel yield and pod yield were positively correlated with the uptake of N, K, P, Mg and S. Nitrogen was having positive relationship with P, K, Mg and S. But it had negative relationship with Mn. Phosphorus had the positive relationship with K, Mg and S. Potassium showed positive relationship with Mg and S and Mg had positive relationship with S and Fe .In the case of Fe, it had positive effect on Mn.

Table 40.Correlation between different yield attributes

	Pod yield	Total biomass	Haulm;pod ratio	Haulm;kernel ratio	100 Pod weight	Shelling percentage	100 Kernel weight	Number of pods per plant	Haulm yield
Total biomass	0.8682**								
Haulm;pod ratio	-0.6897**	-0.6680**							
Haulm;kernel ratio	-0.5637**	-0.5514**	0.9109**						
100 Pod weight	0.6821**	0.8419**	-0.5424**	-0.4748**					
Shelling percentage	-0.4171**	-0.2990*	0.3966**	0.1205	-0.2373				
100 Kernel weight	0.6527**	-0.8923**	-0.5847**	-0.4752**	-0.8426**	-0.2728			
Number of pods per plant	0.9366**	0.9165**	0.7197**	-0.5817**	0.6911**	-0.3225**	0.7159**		
Haulm yield	0.0774*	0.0807	.5857**	0.6972**	0.0049	0.1396	.00065	0.0794	
Kernel yield	0.8953**	.8630**	-0.6205**	-0.5968**	0.6747	-0.0134	0.6543**	0.9105**	0.1330

Table 41. Direct and indirect effect of yield attributes on pod yield per ha

	Total biomass	Haulmm pod ratio	Haulm kernel ratio	100pod weight	Shelling percentage	100 kernel weight	number of pods per plant	Haulm yield	Kernel yield	R value
Total biomass	-0.0931	-0.1030	-0.0120	0.0394	0.1361	-0.0490	0.0854	-0.0080	0.8723	0.8682
Haulmm pod ratio	0.0622	0.1541	0.0198	-0.0254	-0.1805	0.0321	-0.0670	-0.0578	-0.6272	-0.6897
Haulm kernel ratio	0.0513	0.1404	0.0217	-0.0222	-0.0548	0.0261	-0.0542	-0.0688	-0.6032	-0.5637
100pod weight	-0.0784	-0.0836	-0.0103	0.0468	0.1080	-0.0463	0.0644	-0.0005	0.6820	0.6821
Shelling percentage	0.0278	-0.0611	0.0026	-0.0111	-0.4552	0.0150	-0.0300	-0.0138	-0.0136	-0.4171
100 kernel weight	-0.0830	-0.0901	-0.0103	0.0395	0.1242	-0.0550	0.0667	-0.0006	0.6614	0.6527
number of pods per plant	-0.0853	-0.1109	-0.0126	0.0324	0.1468	-0.0393	0.0931	-0.0078	0.9203	0.9366
Haulm yield	-0.0075	-0.0903	0.0152	0.0002	-0.0635	-0.0004	0.0074	-0.0987	0.1344	0.0774
Kernel yield	-0.0803	-0.0956	-0.013	0.0316	0.0061	-0.0360	0.0848	-0.0131	0.0108	0.8953

R^2 =0.971
RESIDUAL=0.0288

Table 42. Correlation between plant nutrient uptake and yield

	N	P	K	Mg	S	Fe	Pod yield
P	0.666**						
K	0.577**	0.603**					
Ca	0.068	-0.091	-0.009				
Mg	0.621**	0.802**	0.645**				
S	0.749**	0.780**	0.702**	0.721**			
Fe	-0.043	0.134	0.281	0.312*	0.241		
Mn	-0.447**	-0.015	-0.013	-0.043	-0.179	0.536**	
Pod yield	0.636**	0.853**	0.579**	0.805**	0.669**	0.239	
Kernel yield	0.483**	0.731**	0.569**	0.754**	0.581**	0.270	0.889**

Discussion

5. DISCUSSION

The experiment was intended to study the interacting influence of the availability, absorption and functional efficiency of applied and native elements and to develop a comprehensive technology for high nutrient use efficiency and crop productivity. The results obtained in this study are discussed here under.

5.1 GROWTH PARAMETERS

5.1.1 Effect of irrigation

Remarkable variation in plant height as well as leaf production due to irrigation was noticed at 60 DAS. There was heavy rainfall of 331.5mm at early stages of growth and hence the irrigation treatments could not be imposed upto 42 DAS. So, upto flowering, the plants were in good vegetative growth irrespective of different levels of irrigation. Even though the plant height (Fig. 4) increased up to harvest, the increase in leaf production (Fig. 5) was observed upto 80 DAS. The decrease in leaf number at harvest was due to leaf senescence and leaf fall after physiological maturity. Similar results were also recorded by Senthil (2000). Among the different levels of irrigation, there was no difference in plant height and number of leaves between IW/CPE ratios of 0.75 and 1.0 at different growth stages of groundnut. The number of branches produced per plant also showed similar pattern. This indicates irrigating with IW/CPE ratio of 0.75 may be enough for metabolic activities of plant during the growth of crop. This was in conformity with the findings of Muktha (1995).

Shoot: root ratio was not significantly influenced by irrigation levels. The shoot root ratio was very less upto 20 DAS but between 20 and 40 DAS, a drastic increase was noticed and it was due to high shoot weight of the plant during the active vegetative growth phase. The results had also shown that the irrigation had remarkably contributed to the growth of groundnut and the effect was more pronounced at higher levels of irrigation (IW/CPE=0.75 or 1.00).

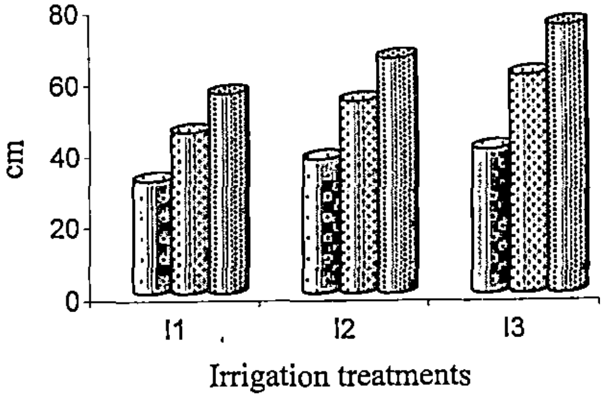


Fig. 4. Plant height as influenced by irrigation treatments

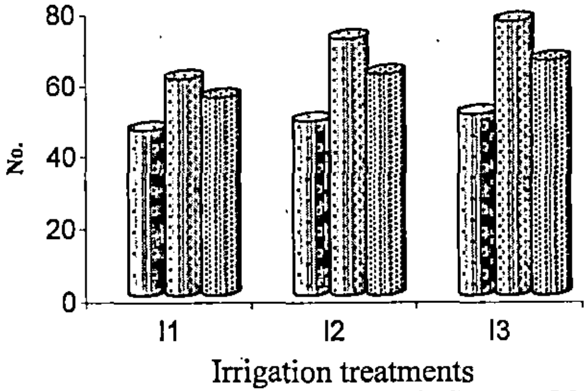


Fig. 5. Number of leaves as influenced by irigation treatments

The dry matter production increased with increase in frequency of irrigation upto I_2 (IW/CPE=0.75). The effect was more prominent after flowering (60 DAS). This may be due to frequent rainfall received during early stages of growth, which had resulted in better vegetative growth irrespective of irrigation treatments. After flowering i.e. 60 DAS, the dry matter production was consistently higher in plants that were irrigated at an interval of 11 days (IW/CPE=0.75), which again indicate that the irrigation of groundnut at IW/CPE ratio of 0.75 was enough for growth and yield. An increase in growth characters like height, number of leaves and shoot: root ratio at higher levels of irrigation had contributed to the increased dry matter production. However maximum dry matter accumulation was recorded between 80 DAS and harvesting stage. Similar observations were made by Ali et al. (1932) indicating that the maximum dry matter accumulation was between 56 and 97 DAS in bunch varieties.

Irrigation had a dominant role on number of nodules produced per plant at 60 DAS. Due to frequent rainfall in early stages of crop growth, the irrigation effect was not found to be significant. The number of nodules per plant progressively increased from 60 DAS to 80 DAS and then there was a slight decrease towards harvest .The decrease in nodule number at harvest might be due to senescence and disintegration of nodules after the maturity. Rao (1997) and Lakshmamma and Raj (1996) had also reported the similar results. At the same time the plant retained appreciable number of nodules even at harvest, because of the continuous formation of nodules up to harvest.

It is evident from the data that leaf area index of groundnut increased with increase in frequency of irrigation (60 DAS). In the initial stages due to the incessant rainfall the effect was not evident. The lower LAI at wider intervals of irrigation may be due to production of lesser number of leaves and reduction in leaf area as a result of inhibition of cell enlargement caused by water stress. Decrease in number of leaves produced at low soil moisture levels also might have lowered the LAI. The increase in total leaf area per plant was up to 80 DAS and decreased towards harvest due to leaf fall.

The total chlorophyll content showed an increase upto flowering and decreased thereafter. It was higher in plants receiving irrigation at IW/CPE ratio of 0.75 and 1.00, throughout the crop period. Chlorophyll is the site of photosynthesis and as such should reflect in pod yield. This was found to be true in the present study also.

5.1.2 Effect of nutrient levels

The nutrient levels did not show a significant influence on plant height, number of leaves, number of branches and LAI. However an increase in all these characters were noticed over no fertilizer application. There was not much variation between the different levels of nutrients with respect to growth characters.

As in the case of levels of irrigation, increase in growth characters was noticed up to 80 DAS and growth decreased towards maturity. This may be due to the pod development and diversion of photosynthates to the developing pods as reported by Forestier (1973). The nutrient levels had remarkable influence on shoot: root ratio from 40 DAS. The treatment F_3 had the higher shoot: root ratio irrespective of growth stages. The nutrient availability might be more at the particular combinations of fertilizers. However, F_1 (10-75-75 N P_2O_5 K_2O kg ha^{-1}) and F_4 (10-75-150 kg N P_2O_5 K_2O ha^{-1}) also have comparable shoot: root ratio. The nutrient level at F_3 (10-37.5-75 kg N P_2O_5 K_2O ha^{-1}) had recorded higher dry matter production and it is because of high shoot root ratio at all stages of growth at this level of nutrients.

The variation in shoot: root ratio was maximum between 20 and 40 DAS and after 40 DAS rate of increase was rather low. But rate of increase in dry matter production was steadily increasing. The rate of root growth may become faster by 40 DAS. This may be attributed to increased DMP towards later stages of growth. But DMP was found to be higher in F_3.

The effect of nutrient levels on nodule number was more prominent upto flowering. The plants, which received more P and K, were found to be more efficient with respect to nodule production. It was also noticed that the plants that received nutrients @10: 37.5: 75 kg N: P_2O_5: K_2O ha^{-1} (F_3) were efficient in nodule production as well as dry matter production. This means that plants that received F_3 treatment might have produced more photosynthates than F_4 and hence more nodules as well as dry matter production.

Chlorophyll 'a' as well as total chlorophyll were higher in F_4 at flowering. Chlorophyll is the site of photosynthesis, which should register a corresponding increase in DMP. But it was not reflected in this experiment. F_3 had recorded higher DMP even though chlorophyll was higher in F_4. It may be because of higher production of nodules in F_4, which divert the photosynthates for their production and hence low DMP.

5.2 YIELD ATTRIBUTES AND YIELD

5.2.1 Effect of irrigation

The time taken for 50 per cent of the plants to flower varied from 30 to 31 days irrespective of the irrigation. Likewise, the number of pegs per plant and the conversion of peg to pod were also not affected by the levels of irrigation. However, irrigation had contributed remarkably towards pod development and yield. The plants that were irrigated at an IW/CPE ratio of 0.75 had recorded the highest pod and kernel yield (1267, 829 kg ha^{-1}respectively) .The levels of irrigation also failed to register remarkable influence on yield attributing characters such as haulm: pod ratio, 100 kernel weight, shelling per cent and harvest index. In all these characters there was variation with respect to IW/CPE ratios of 0.5 and 0.75. Eventhough, the conversion percentage of peg to pod and number of pods per plant were higher in plants irrigated at IW/CPE ratio of 1.00, filling of pods and hence the kernel weight was more in plants that were irrigated at IW/CPE ratio of 0.75. This might have contributed to higher pod yield in the level I_2 (IW/CPE=0.75).

In the case of IW/CPE=0.5, low vegetative growth and less bio mass production were low in addition to low haulm: pod ratio, which might have contributed to low yield. The water received at this level might not have been enough for growth and development of pods.

5.2.2 Effect of nutrient levels

The different levels of nutrients failed to register a remarkable variation in yield attributing characters. The number of pegs plant^{-1} and number of pods plant^{-1} produced were significantly different in fertilizer and no fertilizer application treatments. The number of pegs as well as pods were higher with F_3 (10- 37.5- 75 kg N P_2O_5 K_2O ha^{-1}) compared to other levels. Peg to pod conversion was not affected by the changes in the levels of major nutrients. Haulm yield was higher in F_2 where no P fertilizer was applied. Pod and kernel yield also showed the similar pattern in respect of levels of nutrients .The highest pod and kernel yield were recorded in plants that received nutrients @10- 37.5- 75 kg N P_2O_5 K_2O ha^{-1} which may be due to favourable environment for the nutrient availability and absorption at this particular level of nutrient combination. Haulm: pod ratio was low in F_3, which resulted in high harvest index at the very same nutrient combination of 10- 37.5- 75 kg N P_2O_5 K_2O ha^{-1}.

It was seen from Table (40) that the relationship between haulm: pod ratio and pod yield were negatively related with a correlation coefficient of -0.6897^{**}. Haulm: pod ratio was found to be significantly negatively correlated with 100 pod weight, 100 kernel weight, number of pods per plant and kernel yield. This might also have contributed to high pod yield in F_3.

In the path analysis of yield relative characters with pod yield (Table 41), it was noticed that the direct effect of pod yield to haulm: pod ratio was low.

The direct effect of kernel yield was also not found to be prominent. But the indirect effects through 100 pod weight, 100 kernel weight and number of pods per plant were high. The pod yield was always positively correlated with kernel yield and the same also followed in this experiment with a correlation coefficient of 0.8953.

The direct effect of shelling percentage was found to be negative and high. But its indirect effects through 100 kernel weight, 100 pod weight and number of pods per plant were positive and low and it had a correlation of –0.4171** with pod yield. The kernel yield had higher positive correlation with number of pods per plant and total biomass. The lower biomass and higher haulm: pod ratio resulted in low pod yield. The path analysis explains the variability to the tune of 97 per cent.

Nutrient uptake of N, P, K, Mg and S had positive correlation with pod and kernel yield. So, the uptake of nutrients had contributed to the economic yield of the crop. Native elements of Fe and Mn had positive relationship between them in the uptake of nutrients.

Protein content did not show much variation with irrigation. However, irrigation had a role on protein yield due to increased pod and kernel yield. When the frequency of irrigation was more, naturally the plants absorb more water and hence nutrients, which resulted in increased growth and pod yield. Forbes and Watson (1992) reported increased protein content with increased irrigation. Higher oil content was recorded with I_2 (IW/CPE=0.75). In the case of IW/CPE =0.5, the general performance of the crop was poor due to decreased availability of water, which resulted in low oil content also.

With respect to nutrient levels, the oil yield was higher in F_3 (10- 37.5- 75 kg N P_2O_5 K_20 ha^{-1} followed by F_4 (10- 75- 150 kg N P_2O_5 K_20 ha^{-1}). N, P and S are involved for fatty acid synthesis and increase in these nutrients result in increased production of phospholipids and fatty acids. (Munshi et al., 1983 and Kaur et al., 1994).

5.3 NUTRIENT CONCENTRATION AND IT'S UPTAKE

Nutrient concentration in the plant is directly linked to the yield and vary with soil, crop, climate and management practices. Irrigation improved air water relationship in soil and beneficial effect of irrigation of water and nutrient availability to the crops. contributed to their increased yield (Saren and Jana, 1999). But in this study, irrigation had little influence on nutrient concentration in plant. However, increase in nutrient content with increased frequency of irrigation was noticed (Fig.6, 7and 8). When frequency of irrigation was more, the plant root zone will get sufficient moisture for bringing nutrients into the solution and plants can extract nutrients for their growth and development. This may be one of the reasons for better vegetative growth and yield at higher ratios of IW/CPE.

The effect of irrigation was more pronounced on nutrient concentration at later stages of crop growth towards maturity. This was especially true in the case of Ca, Mg, Fe, Mn and S. Lime was applied at flowering stage as per the recommended practice. So, the effect of Ca availability may alter the availability of other nutrients especially, secondary and micronutrients after flowing.

The uptake of macro and micronutrients also followed similar trend and was higher at high ratios of IW/CPE because of increased nutrient content in plant parts. Unlike irrigation, levels of fertiliser had remarkably altered the content as well as uptake of nutrients.

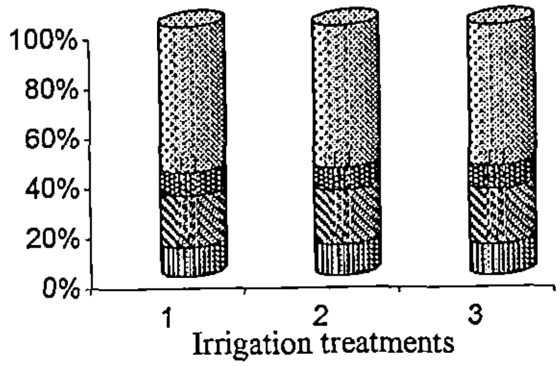


Fig .6. Nitrogen content at different plant parts as influenced by irrigation treatments at

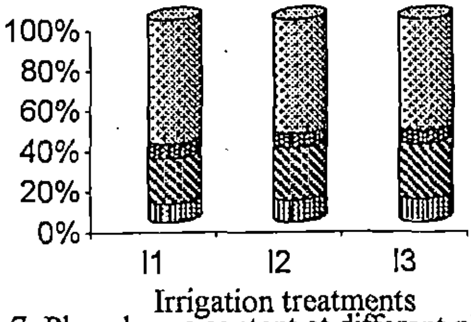


Fig .7. Phosphorus content at different plant parts as influenced by irrigation treatments at harvesting

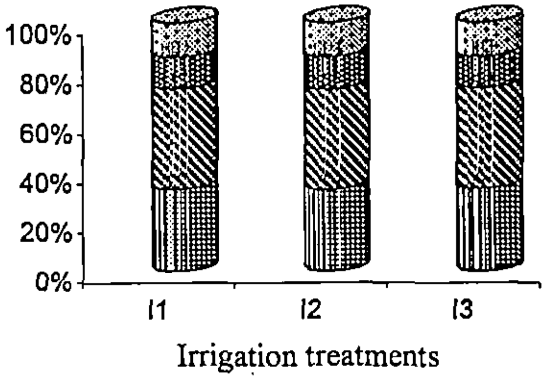


Fig .8. Potassium content at different plant parts as influenced by irrigation treatments at

5.3.1 Major nutrients

The nutrient levels had their influence on N content at flowering stage only. The N content was higher in F_4 (10-75-150 kg N P_2O_5 K_2O ha^{-1}) even though all levels of nutrients had the same quantity of applied N (10 kg N ha^{-1}) and it was on par with F_3 (10-37.5-75 kg N P_2O_5 K_2O ha^{-1}). However, the uptake and pod yield were higher in F_3. The content of kernel was fairly higher irrespective of treatments and hence higher protein yield was recorded. The total uptake of N at harvest was high in F_3 because of higher pod as well as haulm yield and higher N content of plant parts.

The nitrogen content of the plant increased with age of the plant. At flowering, the N content was higher in stem but at harvest, higher N content was noticed in leaves. This shows that the absorbed nutrients are translocated to leaves, which is the site of photosynthesis.

Phosphorus is important for groundnut, being a pulse crop as well as for higher protein and oil yields. Under irrigated condition, P content was found to be higher in the plant compared to lower levels of irrigation. Similarly, the absorption of P was higher at vegetative stage and decreased towards maturity of the crop. This may be due to the fact that the efficiency of applied P may be comparatively low towards crop maturity.

The nutrient concentration in plant varied with age. The stem concentration of P was higher at flowering, but at harvest, the content was more in leaf, which showed the translocation of P from site of absorption to the site of synthesis. The kernel P content was much higher compared to other plant parts. However, the total uptake was higher with increased frequency of irrigation. The major portion of P moves to roots by diffusion through water films around soil particles and under moisture stress these films are thin and hence movement of P to the roots is reduced (Tisdale *et al.*, 1991).

The nutrient levels altered P content in different parts of groundnut and hence also the uptake. The higher leaf and stem concentration of P was noticed with F_3 (10:37.5-75 kg N P_20_5 K_20 ha^{-1}). The translocation of P was also found to be faster in F_3 and highest pod yield was also noticed at this level. This may due to the high utilisation of P by the plant at this level.

Remarkable influence of irrigation on K content and uptake was not seen. However, an increasing trend in K content of leaf and stem was noticed with increasing levels of irrigation. At lower levels of irrigation the plants could not take up adequate amounts of K, which may be the reason for low yield at this level. The total uptake was higher in I_2 (IW/CPE=0.75) at harvest, which may be the sufficient moisture regime for absorption of nutrients.

Regarding the levels of nutrients at flowering, the highest leaf and stem concentration of K was in F_4, which was due to increased K application, and it had reflected in the K content of plant. The uptake was higher in F_3, which is due to the higher dry matter production at this level.

The distribution of K in stem and leaf at the different crop growth stages followed the same pattern of N and P. Higher content in different plant parts and uptake at harvest was noticed with higher level of K. Frequent supply of moisture as well as nutrient might have enabled the plant to absorb higher amount of potassium both from the applied and native K. Unlike N and P, K content of shell and kernel was almost equal. The stem and leaf also maintained higher content of K compared to N and P at harvest .It is well known fact that groundnut is a heavy feeder of K and adequate supply of this nutrient is indispensable to obtain better field.

(Lakshminarayana and Subbiah, 1996). Higher uptake was also due to favourable effect of N and P on availability of K, which was reported by Chevalior (1976) and Soundararajan et al. (1976).

5.3.2 Secondary nutrients

Calcium requirement is very high for groundnut especially for gynophore development and pod filling. Stem and leaf concentration and uptake of calcium were influenced by irrigation after flowering only due to application of lime after flowering. Calcium content was higher at higher frequency of irrigation and uptake was also lowest at lower levels of irrigation (IW/CPE=0.5). Calcium accumulation in plant parts depends on availability of this nutrient as well as soil moisture content because roots intercept more calcium ions in a moist soil than in dry soil (Tisdale *et al.*, 1991).

The concentration and total uptake differed due to levels of nutrients. At flowering the content of calcium did not give a consistent value between levels of nutrients. However the uptake of calcium was high in F_2 (10-0-75 kg N P_2O_5 K_2O ha^{-1}). Calcium was applied, as per recommendation after flowering and that may be the reason that the effect was significant after flowering. Leaf calcium concentration and Ca uptake were higher when no P fertiliser was applied Calcium and P are having antagonistic effect and Ca was found to have a negative relationship with P (Table 42).

Similar to calcium, the effect of irrigation had significant effect on Mg after flowering. Calcium is applied after flowering and it had pronounced effect on magnesium uptake also. The concentration of magnesium was higher in leaf at flowering while it was higher in stem at harvest. This had an implication that the translocation becomes slow after flowering, which may also have impact on yield because magnesium is important for the formation of chlorophyll (Singh and Joshi, 1993).

The levels of nutrients had remarkable effect on magnesium uptake at all stages of crop growth. F_3 (10-37.5-75 kg N P_2O_5 K_2O ha^{-1}) had recorded the highest content in stem and leaf and had the maximum uptake at flowering. At lower levels of K, the cations like calcium and magnesium may be more absorbed by plant to balance the anions and hence magnesium may be more absorbed by the plant. The uptake was highest in F_3 itself at harvest also.

Sulphur is important for groundnut and help in the development of pegs, filling of pods, activation of enzymes and synthesis of protein. Irrigation had its influence on content of S and uptake towards maturity of the crop. At flowering the stem and leaf content of S was higher in IW/CPE ratio of 0.5 though not significant. The stem and leaf concentrations were higher at IW/CPE of 0.75 compared to other two levels of irrigation.

Application of different levels of nutrients altered the S content at flowering. There was wide variation between control and levels of nutrients at flowering. But towards maturity this difference was reduced. The uptake of S was higher in F_3 irrespective of stages of growth. In general, P-S interaction is synergetic at low to medium levels of P and antagonistic only at higher levels at 60 kg P_20_5 ha^{-1} or more in groundnut (Mandal *et al.*, 2002). Hence plants that had received P at the rate of 37.5 kg $P_2 0_5$ ha^{-1}had higher S uptake.

5.3.4 Micro nutrients

Unlike other nutrients, Fe content was higher in leaf at flowering but at harvest the content was higher in stem. The stem as well as leaf concentration and uptake were highest at lowest frequency of irrigation.

Fe become more available under low moisture situations and absorption may be high at IW/CPE ratio of 0.5. Hence at lower moisture content, higher content of Fe was noticed.

Stem and leaf concentrations of Fe were higher in F_2 irrespective of growth stages. The same trend was noticed with respect to uptake also. Fe was more available without applied P, which may be because of relative immobilisation of P due to low availability of P at this level, resulting in less P fixation.

Similar to Fe, Mn content also had the same trend. Stem and leaf concentrations as well as uptake were higher at lower frequency of irrigation. Mn was found to be more available for absorption without applied P (F_2) at all stages of crop growth. Mn was negatively correlated with N, P and K and hence at higher levels of P and K, lower content of Mn was noticed (Table42).

5.4 SOIL PARAMETERS

5.4.1 Soil moisture studies

Consumptive use was always higher in the case of frequent irrigation. With increase in frequency of irrigation favourable condition was created for high evaporation (Veeraputhiran, 1996). Higher growth attributes like plant height, number of leaves increased due to frequent irrigation that made the consumptive use high.

Field water use efficiency was found to be high at I_2 (IW/CPE=0.75)(Fig. 9). FWUE is directly related to yield and yield was highest at that level of irrigation and hence high FWUE. Water above the optimum level may be lost in the form of excessive evaporation, transpiration (or) excess deep percolation (Ajith, 2000). The better water use efficiency at I_2 may be due to the fact that water availability might be optimum at IW/CPE=0.75.

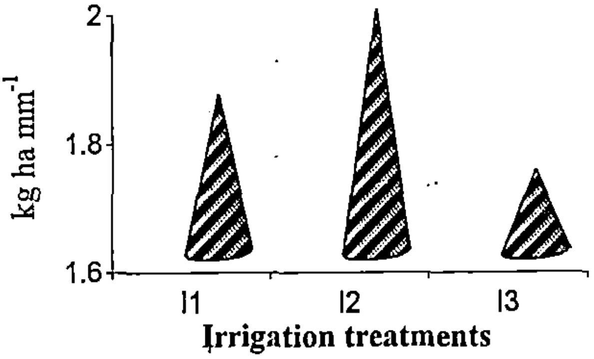


Fig . 9. Field water Use Efficiency as influenced by irrigation treatments

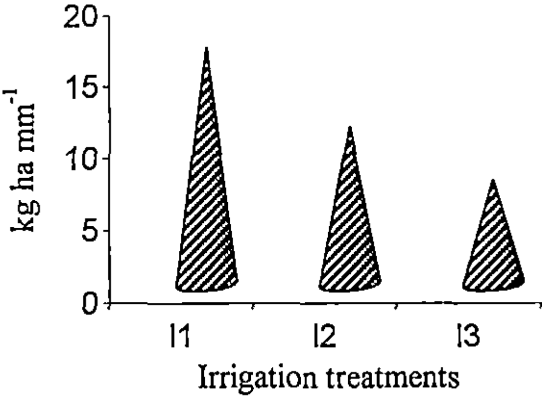


Fig .10. Crop Water Use Efficiency as influenced by irrigation treatments

With respect to CWUE, at lowest level of irrigation had highest CWUE (Fig.10). Cumulative water use efficiency is the efficiency of water for crop production. At higher frequency of irrigation, the consumptive use will be more and consumptive use has indirect relationship with CWUE. This resulted in low CWUE at higher frequency of irrigation.

5.4.2 Soil analysis

The available N content of soil before the experiment was 340.8 kg ha^{-1}. The average depletion of available N from soil was low and observed to be 5 kg due to groundnut cropping(Fig.11). But the content as well as uptake of N was found to be high. This showed that it had utilised soil N as well as symbiotically fixed N resulting in higher plant uptake. The studies conducted indicated that groundnut could fix atmospheric N to the extent of 200 to 260 kg ha^{-1} (Williams, 1979). With starter dose of 10 kg of applied N ha^{-1}, the crop might have fixed good amount of N and hence the available N content of soil was not depleted to large extent.

The application of 10 kg N ha^{-1} did not produce significant variation in available N content of soil at flowering and harvest irrespective of levels of applied nutrients except control. But soil moisture played an important role on N availability in soil and available N was found to be higher at higher level of irrigation and nutrients. The available N content was higher in I_3F_4.

The variation in available P content before and after cropping was less at I_1 (2.86 kg ha^{-1}). At harvest, the available P content was high at low irrigation level of I_1 (IW/CPE=0.5)(Fig.11). P is mainly absorbed by diffusion, which is essentially controlled by soil moisture content of soil. Hence at low moisture content, the P uptake by the plant was reduced and depletion from soil was less. The available P content of soil was higher in

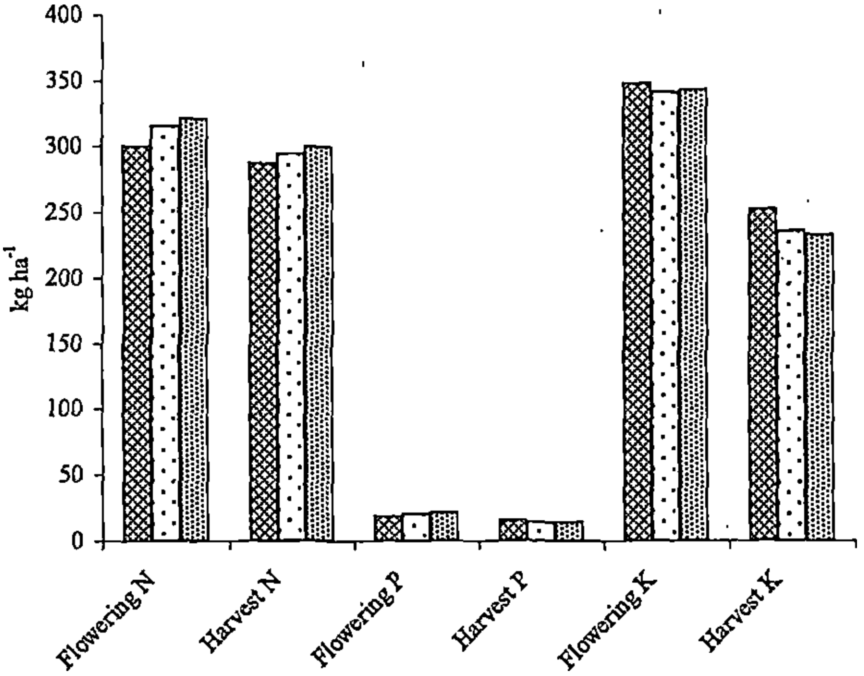


Fig .11. Major nutrient content in the rhizosphere soil as influenced by irrigation treatments

F_1 (10- 75- 75 kg N P_2O_5 K_2O ha^{-1}) and F_4 (10- 75-150 kg N P_2O_5 K_20 ha^{-1}) that was the direct effect of higher quantity of applied P. The depletion of P varied between levels of nutrients. The response of groundnut to P application depends upon the amount of available P in soil rather than applied P. The depletion of P from the soil was in high quantities and hence high content in plant parts and also high uptake of P was noticed.

Groundnut is a heavy feeder of K and absorbs K excessively. The exchangeable K did not show much variation even though there was difference in levels of applied K and it may be due to interaction with other applied and native nutrients and dynamic equilibrium among the different forms of K.

Like available P, exchangeable K of soil was found to be high under less irrigated condition (Fig.11). It may be due to the low moisture content and its impact on nutrient uptake. Frequent supply of moisture enabled the plant to absorb the sufficient amount of K both from applied and native resulting in more depletion of K under frequent irrigation.

Levels of irrigation did not affect exchangeable calcium. Levels of nutrients altered the exchangeable calcium content of soil after flowering due to application of lime during that stage. The F_2 levels in which no P fertiliser was applied showed the lowest calcium content in soil. Calcium content in soil had a positive relationship with P content in soil and also mussouriphos contains appreciable amount of Ca in the form of tri calcium phosphate. So, the calcium content was less when no P fertiliser was applied.

The irrigation or nutrient application had its role on exchangeable Mg content of soil at maturity of the crop only. Highest content of Mg was noticed at lowest level of irrigation and the depletion from other two levels were more. The frequent supply of moisture enabled the plant to absorb more Mg from soil and hence resulted in more depletion.

Regarding the levels of fertiliser, highest content of Mg was noticed at higher levels of P and K (10-75-150 kg N P_2O_5 K_2O ha^{-1}). Mg is found to have positive correlation with P and at higher levels of P, the content of Mg was high which had resulted in higher uptake of plants as evidenced from table 42).

The depletion of sulphur was more under less irrigated condition at flowering. The sulphur content was lower in F_2 where no P fertiliser was applied irrespective of growth stages of crop.

Fe and Mn content of soil were higher at lower levels of irrigation. But the content and uptake of Fe and Mn were also high at low moisture content. Being laterite soil, Fe and Mn content is more and native Fe and Mn may become available and hence uptake may be more.

5.4.3 Soil solution studies

5.5.3.1 pH

Soil solution pH was higher compared to pH of exchangeable phase irrespective of treatments. Irrigation or nutrient application had not contributed to exchangeable pH. However with increase in frequency of irrigation the pH of soil showed a decline.

Soil solution pH was higher at 48 hours after irrigation compared to 24 hours after irrigation in most of the treatments. Like the exchangeable phase, the soil solution pH decreases with increase in frequency of irrigation at 48 and 72 hours after irrigation.

5.4.4 Nutrient content in soil solution

5.4.4.1 Major nutrients

Although absorption of N is definitely reduced on dry soils, it is usually not reduced as much as that of P and K (Tisdale et al., 1991). N did not show the consistent pattern at different levels of soil moisture (Fig.12). However, the highest N content in solution was noticed at the lowest content of moisture at 24 and 48 h after irrigation.

Among the nutrient levels, even though the quantity of applied N was the same at all levels of nutrients, the highest N content was observed at highest levels of P and K (Fig.13). It may be due to the synergetic effect of N and K on N availability and absorption. There was drastic decline in N content when the duration after irrigation increased.

Potassium content increased with increase in frequency of irrigation at 24 h after irrigation (Fig.14). Most of the K passes through the water films and gets K for plants mainly by diffusion. When the water content is lowered, the harder it is for K to move and hence low K at low soil moisture. But K content decreased with increase in frequency of irrigation at 48 hours after irrigation. The K content decreased with increase in duration after irrigation and decline was more pronounced at higher quantity of water. At 48 and 72 hours after irrigation, the K content was highest in plants that receive irrigation at an IW/CPE of 0.75 and decreased at higher level of irrigation, which may be due to leaching loss of K at higher quantity of water.

With respect to levels of nutrients, K content was more in F_3 @ 10-37.5-75 kg N P_2O_5 K_20 ha^{-1} at 24 hours after irrigation (Fig.15). But at 48 hours after irrigation, the content was more in F_4 (10-75-150 kg N P_2O_5 K_2Oha^{-1}) might be due to direct effect of higher dose of applied K.

5.4.4.2 Secondary nutrients

The Ca content was highest at IW/CPE of 0.75 at 24 hours after irrigation. However, at 48 and 72 hours after irrigation, plants that received irrigation at an IW/CPE of 0.5 recorded the highest Ca content. Calcium content increased when the quantity of irrigated water decreased

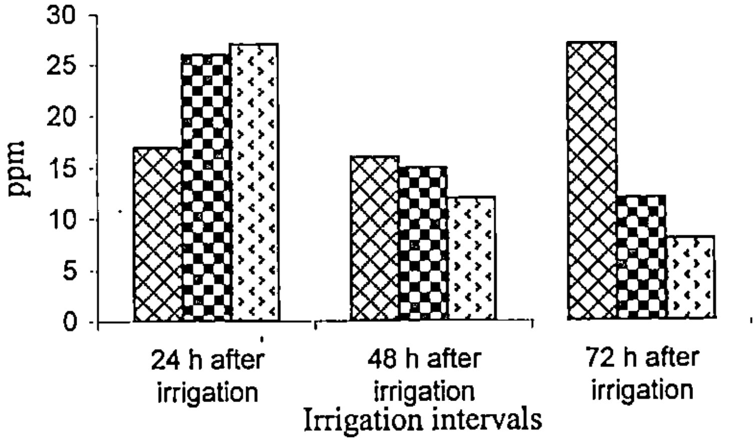


Fig .14 .Soil solution Kas influenced by irrigation treatments at 80 DAS

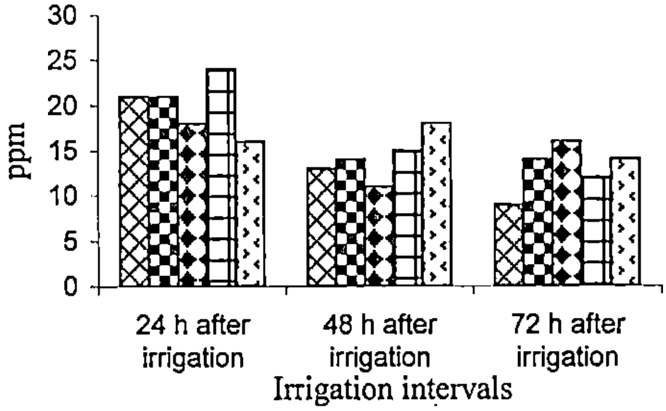


Fig .15. Soil solution K as influenced by fertilizer treatments at 80 DAS

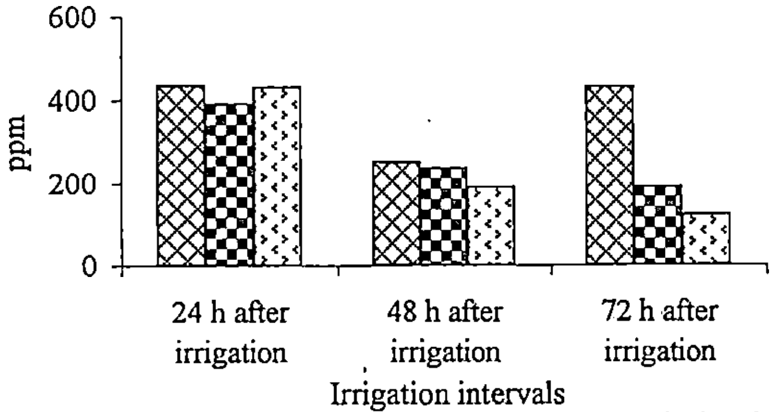


Fig . 12. Soil solution N as influenced by irrigation treatments at 80 DAS

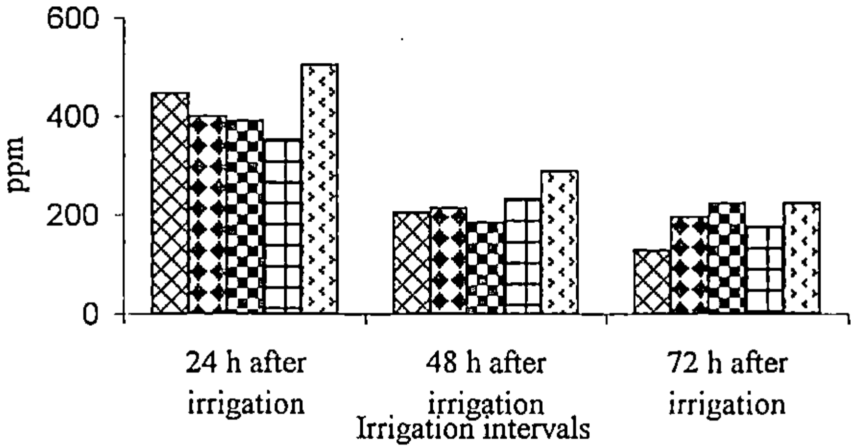


Fig .13. Soil solution N as influenced by fertilizer treatments at 80 DAS after time i.e. 48 hours after irrigation and then decreased. However, the quantity of Ca was more than that at 24 hours after irrigation.

The nutrient level in which P and K applied (F_4) highest dose had the maximum Ca content at 24,48 and 72 hours after irrigation and it may be due to anion effect of K by Ca. The lowest content was noticed by F_0 where no fertilizer was applied. Due to liming after flowering, which is a recommended practice in groundnut, there may be increased Ca availability and it may become unavailable in laterite soil of experimental area.

Magnesium also showed similar pattern of Ca with respect to levels of irrigation. The highest content was noticed in I_3 at highest level of irrigation. Mg content did not show a consistent value with respect to levels of nutrients.

Unlike Ca and Mg, S content decreased when the duration after irrigation was increased. The decline was more prominent between 24 and 48 hours after irrigation.

5.5 WATER- NUTRIENT INTERACTION

Plants absorb nutrients through solution and fertilizer response mainly depends on soil moisture content. Soil moisture plays an important role in the availability and absorption of nutrients. When the available water content is high in soil, that will dilute ionic concentration and the absorption will be more. The quantity of soil solution depletes very fastly and concentration of ions increases due to depletion of water. So, optimum combination of water and nutrients is necessary for maximum availability and absorption of nutrients.

In this present experiment, results indicated that the dry matter production was highest in I_3F_3 (IW/CPE=1.0 and 10-37.5-75 kg N P_2O_5 K_20 ha^{-1}) at 80 DAS and higher dry matter production was noticed in this combination at harvest also. The plants which receive irrigation at an IW/CPE ratio of 1.0 and nutrient level @ 10-37.5-75 kg N P_2O_5 K_2O ha^{-1} had recorded the highest uptake of major nutrients N, P and K (Fig.16,17 and 18) which is mainly attributed to increased pod (Fig.19) and kernel (Fig.20) yield at this particular combination of water and nutrients. The consumptive use of water was found to be higher in I_3F_3 might have contributed to increased availability of water, and plants may absorb higher quantity of nutrients along with water from soil solution. It might have resulted in increased uptake and hence more dry matter production and yield.

At field capacity the availability of nutrients N and K were high in soil solution for absorption by plants due to dilution–concentration effect. Though the available P could not be detected in soil solution, the content and uptake in plant was high at higher level of irrigation. P may become more available due to low activity of P and neutralising effect at high soil moisture content. The cations like Ca and Mg were also in low concentration at high soil moisture content. The interference of Fe and Mn also low when available moisture content in soil was increased.

In agriculture, irrigations had not the mere objective of application of water, but also it favours the availability and absorption of nutrients required for crop growth by reducing the interference of native elements like Fe and Mn. Thus, favourable water nutrient interaction increased the availability and absorption of nutrients and there by enhanced productivity.

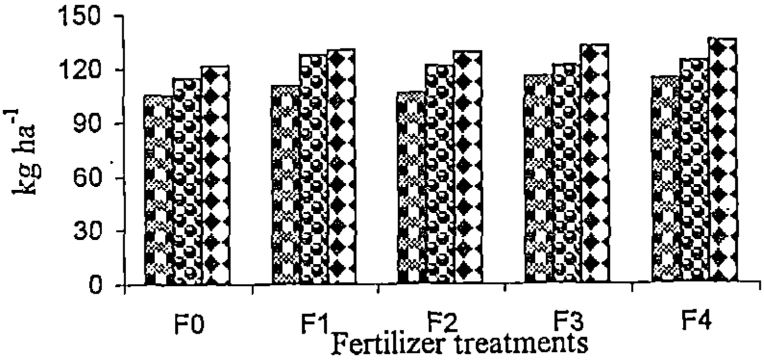


Fig .16. Total N uptake as influenced by interaction effect of irrigation and fertilizers

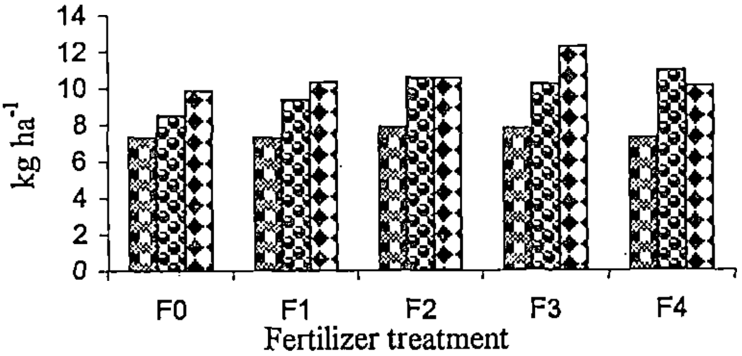


Fig .17. Total P uptake as influenced by interaction effect of irrigation and fertilizers

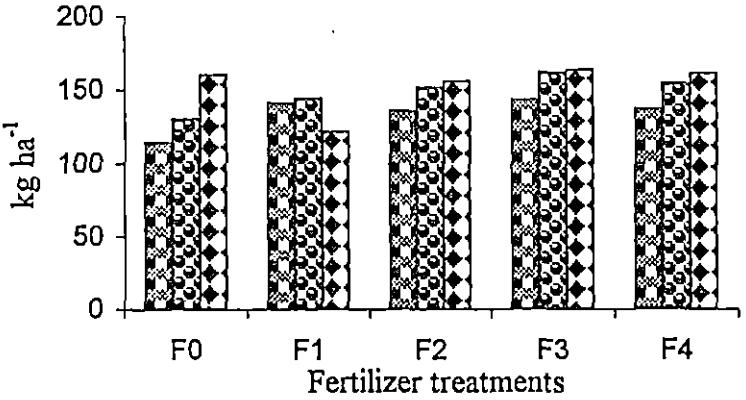


Fig .18. Total K uptake as influenced by interaction effect of irrigation and fertilizers

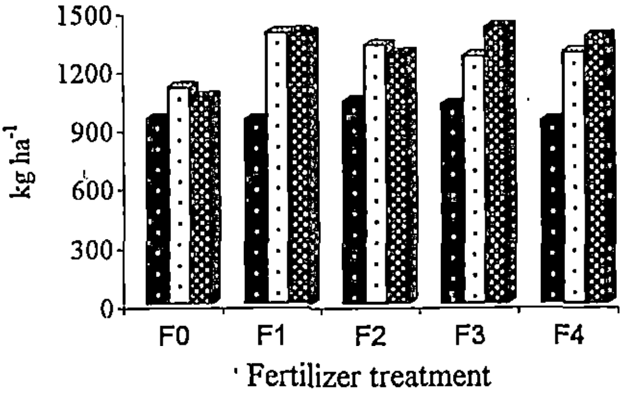


Fig. 19. Pod yield as influenced by interaction effect of irrigation and fertilizers

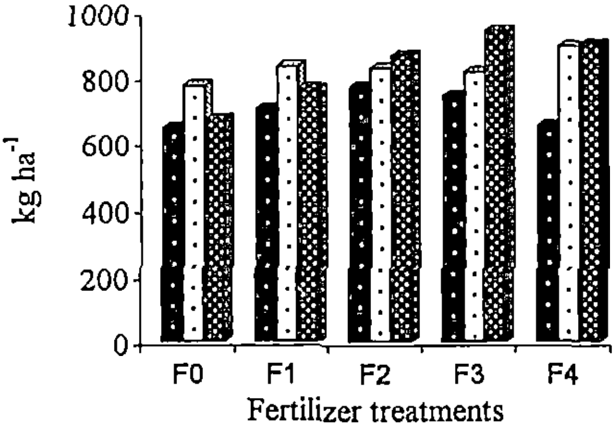


Fig. 20. Kernel yield as influenced by interaction effect of irrigation and fertilizers

Summary

6. SUMMARY

The project entitled "Water–nutrient interaction on productivity of groundnut" was carried out in the Department of Agronomy, College of Horticulture, Kerala Agricultural University, Vellanikkara during October 2001 to January 2002. The main objective was to study the interacting influences of various levels of moisture on the availability, absorption and their functional efficiency of applied and native elements and to develop a comprehensive management technology for high nutrient use efficiency and crop productivity. The experiment was laid out in split plot design with 3 replications. The main plot treatments were three frequencies of irrigations and subplot treatments were five levels of nutrient.

The salient findings of the study are summarized below

Due to frequent rainfall at early stages of crop growth, the irrigation treatment effect was not visible till 42 DAS. Plant height, number of leaves and number of branches were remarkably improved by irrigation from 60 DAS onwards. The plants that were irrigated at IW/CPE of 1.0 were the tallest and they were on par with that irrigated at IW/CPE of 0.75. The nutrient levels did not significantly vary these growth parameters.

The highest dry matter production was noticed at IW/CPE of 0.75 due to improvement in growth at higher irrigation levels. With respect to nutrient levels, the highest dry matter accumulation was recorded in F_3 (10-37.5-75 kg N P_2O_5 K_2O ha^{-1}).

The number of nodules increased upto 80 DAS and declined towards harvest. It increased with increase in frequency of irrigation and highest number was noted in I_3 (IW/CPE=1.0). Similarly the highest levels of nutrients i.e. F_4 (1-75-150 kg N P_2O_5 K_2O ha^{-1}) recorded the highest nodule number. Leaf area index also showed similar pattern with respect to irrigation but F_3 (10-37.5-75 kg N P_2O_5 K_20 ha^{-1}) recorded higher LAI among the nutrient levels.

The effect of irrigation on chlorophyll 'a' and chlorophyll 'b' content was pronounced at 80 DAS. Total chlorophyll content was significantly influenced by irrigation and highest content was observed at IW/CPE of 1.0 (I_3). Among nutrient levels, total chlorophyll content was highest in F_2 at flowering but towards maturity the highest content was recorded in F_4.

The total biomass was remarkably higher in I_3, which received the highest quantity of water. The plant that received irrigation at an interval of 11 days had the highest pod yield as well as kernel yield due to higher number of pegs per plant, 100 kernel weight and high HI. The nutrient levels significantly contributed to increased number of pegs per plant and number of pods per plant. The highest pod as well as kernel yield was recorded in plants that received the nutrient combination of 10-37.5-75 kg N P_2O_5 K_20 ha^{-1} (F_3). The harvest index was also found to be higher in F_3 (10-37.5-75 kg N P_20_5 K_20 ha^{-1}) compared to other levels.

The content of N, P and K was higher in stem at flowering but towards maturity the content was higher in leaves compared to stem. N and P content was remarkably higher in kernel compared to other plant parts. But K content was almost equally distributed in shell and kernel. I_3 recorded the highest content of N and P in different plant parts resulting in highest uptake. K content was highest in I_2 resulting in higher uptake at different stages of crop growth. The effect of irrigation on content and uptake of Ca and Mg was prominent only after flowering due to lime application as a recommended practice in groundnut at flowering. The uptake of Ca and Mg were highest in I_2 at harvest.

Though the content of N was higher in F_4 at flowering as well as harvesting in different plant parts, the total uptake was higher in F_3 due to increased dry matter production. In the case of P, the content and uptake was highest in F_3 irrespective of stages of crop growth. The nutrient combination of 10-75-150 kg N P_2O_5 K_2O ha^{-1} recorded the highest content and uptake of K due to increased rate of K application, which was on par with F_3. Among the levels of nutrients, the content and uptake of Ca were higher in F_2 whereas those of Mg were higher in F_3 at flowering and harvest. The same trend was noticed in sulphur also due to irrigation.

The remarkable influence of irrigation on Fe and Mn content was noticed after flowering only. The content and uptake increased with increase in frequency of irrigation and the highest content and uptake was noted in I_3 (IW/CPE=1.00). F_2 recorded higher content in stem and leaf and uptake of Fe and Mn with respect to different nutrient levels.

The consumptive use was higher in I_3 (IW/CPE=1.0) with respect to irrigation and F_0 and F_3 (control and 10-37.5-75 kg N P K ha^{-1}) with respect to nutrient levels. I_1 was significantly superior in CWUE whereas with respect to FWUE, I_2 was found to be better than other two levels of irrigation.

In the case of soil nutrient content, the decrement in available N and P content in soil between flowering and harvesting was less but the variation was more prominent in exchangeable K content of soil. The content of available N and P and exchangeable K were higher in I_3 at flowering and harvesting stages compare to other levels of irrigation.

Among the levels of nutrients, all levels of nutrients were on par except control with respect to available N. But in the case of available P and exchangeable K, F_1 and F_4 were higher and on par irrespective of stages of crop growth. Maximum depletion of N P and K content from soil was observed to be in F_2 and F_3, which were on par.

Exchangeable Ca and Mg content of soil was significantly influenced by nutrient levels after flowering only. The content of exchangeable Ca was significantly higher in F_4, which was on par with control (F_0). The exchangeable Mg content also followed the same trend and the highest content was noticed in F_4.

Exchangeable phase pH of soil was higher compared to solution phase pH. The content of N and K in soil solution decreased when the duration after irrigation was increased and decrement was more prominent between 48 and 72 hours after irrigation. The N content of soil solution was higher in F_4 whereas K content was higher in F_3 at 24 and 48 hours after irrigation. Ca and Mg content of soil solution increased from 24 to 48 hours after irrigation and then decreased at 72 hours after irrigation. However, the effect of nutrients on Mg content of soil solution was not consistent. S content of soil solution decreased continuously with increase in duration after irrigation. The content was highest at the lowest level of irrigation of IW/CPE=0.5. Even though, F_3 recorded the highest content at 24 hours after irrigation, F_1 had the highest content at 48 and 72 hours after irrigation.

The present investigation indicated effect of irrigation and nutrients on growth and yield of groundnut. Irrigating the groundnut crop at IW/CPE of 0.75 with a nutrient combination of 10-37.5-75 kg N-P_2O_5-K_2O ha^{-1} was found to be best management of water and nutrient for higher yield, nutrient uptake and use efficiency of water.

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* Originals not seen

Appendices

8. APPENDIX

Appendix –1

Average weekly weather data during the crop period

(from 1-10-2001 to 15-1-2002)

Standard week	Temperature		Relative humidity (%)	Wind (km hr^{-1})	Sunshine (hrs day^{-1})	Rainfall (mm)	Evaporation (mm day^{-1})
	Min^{0}c	Max^{0}c					
40	23.1	30.1	82.5	2.9	3.6	47.6	3.3
41	23.0	30.1	82.5	3.1	3.6	94.0	3.3
42	22.8	31.0	80.0	3.2	5.1	56.2	3.1
43	22.3	31.5	80.0	3.4	5.6	61.5	3.6
44	23.5	31.8	76.0	2.8	7.0	11.3	3.8
45	23.6	31.0	78.0	3.2	5.5	74.6	3.2
46	22.8	32.3	77.5	2.5	7.7	30.4	3.3
47	24.5	31.2	79.5	1.8	5.2	74.4	2.2
48	23.7	31.9	75.5	5.9	8.7	1.6	4.4
49	24.0	30.6	73.5	6.2	5.2	23.1	3.3
50	23.9	32.1	74.0	4.0	7.7	43.6	4.0
51	24.1	32.1	74.0	4.7	7.3	0.0	3.5
52	22.7	32.1	67.0	7.8	9.3	0.0	6.1
1	23.7	32.4	57.0	12.7	9.8	0.0	7.4
2	32.5	32.5	62.5	11.0	9.3	0.0	6.8
3	21.3	32.5	59.0	5.0	7.8	0.0	5.3
Average	23.8	31.5	66.5	5.0	6.7	32.3	4.1
Av. (last 4 y)	22.8	31.9	68.9	5.3	7.1	21.5	4.3

Appendix –2

Average weekly weather data for the last four of the cropping period

(from 1997-1998 to 2000-2001)

Standard week	Temperature		Relative humidity (%)	Wind (km hr^{-1})	Sunshine (hrs day^{-1})	Rainfall (mm)	Evaporation (mm day^{-1})
	Min^0 c	Max^{0}c					
40	23.2	29.8	83.0	6.9	5.4	36.1	3.3
41	23.1	28.9	82.1	2.5	4.9	75.4	3.3
42	22.3	30.6	81.7	2.5	5.1	111.4	3.4
43	22.3	29.3	78.6	2.0	6.3	21.3	3.4
44	23.0	31.3	78.6	2.3	6.5	23.7	3.5
45	23.0	31.7	74.0	2.9	4.4	29.8	3.4
46	23.0	31.9	53.5	4.6	7.8	22.8	3.8
47	23.1	31.8	66.6	4.8	7.2	6.8	3.5
48	23.2	31.6	68.4	4.6	8.2	2.6	4.0
49	22.8	31.4	63.3	7.3	7.5	0.35	4.8
50	21.5	30.9	67.6	6.8	7.1	6.75	4.6
51	22.7	31.3	61.6	8.5	8.0	0.0	4.9
52	23.0	31.5	60.5	8.0	8.6	2.0	5.5
1	23.4	31.9	59.5	8.6	9.4	0.0	6.4
2	23.5	31.9	62.9	8.6	8.6	0.0	6.4
3	22.3	33.7	61.2	4.7	9.2	0.0	5.4

Appendix –3

Calendar of operations for groundnut in the experiment

Operations	Date	DBS/DAS
Tractor Ploughing –I	20-9-2002	13 DBS
Tractor Ploughing –II	29-9-2002	4 DBS
Layout and design	1-10-2002	3 DBS
Shelling of seed pods	2-10-2002	2 DBS
Application of fertilizers	4-10-2002	-
Sowing	4-10-2002	-
Gap filling	12-10-2002	8 DAS
1 st hand weeding	22-10-2002	18DAS
1 st biometric observations	24-10-2002	20 DAS
Spraying of pesticide	26-10-2002	22 DAS
2 -nd hand weeding	8-11-2002	35 DAS
Lime application	12-11-2002	39 DAS
2 -rd biometric observations	14-11-2002	40 DAS
3 -rd biometric observations	4-12-2002	60 DAS
4 th biometric observations	24-12-2002	80 DAS
5 th biometric observations	15-1-2002	103 DAS
Harvesting	15-1-2002	103 DAS

WATER-NUTRIENT INTERACTION
ON
PRODUCTIVITY OF GROUNDNUT

By

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ABSTRACT OF THE THESIS

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9. ABSTRACT

A field experiment entitled "Water- nutrient interaction on productivity of groundnut " was carried out in the Department of Agronomy, College of Horticulture, Kerala agricultural University, Vellanikkara during Sep-Oct (2001) to Dec-Jan (2002). The main objective of the experiment was to study the interacting influence of varying levels of moisture on the availability, absorption and their functional efficiency of applied and native elements and also to develop a comprehensive technology for high nutrient use efficiency and crop productivity. The experiment was laid out in split plot design with three replications. The main plot treatments were three frequencies of irrigations viz., irrigation at IW/CPE ratios of 0.5, 0.75 and 1.0. The sub plot treatments were five nutrient levels viz., control, 10-75-75 kg N P_2O_5 K_2O ha^{-1} (Package of Practices Recommendation), 10-0-75 kg N P_2O_5 K_2O ha^{-1}, 10-37.5-75 kg N P_2O_5 K_2O ha^{-1} and 10-75-150 kg N P_2O_5 K_2O ha^{-1}.

Results revealed that irrigation had contributed significantly to growth characters like plant height, leaf production and dry matter production at IW/CPE ratio of 0.75 or 1.0 which were on par. LAI and total chlorophyll content also showed similar pattern. The plants that received irrigation at IW/CPE ratio of 0.75 had recorded the highest pod and kernel yield. The consumptive use increased with increase in frequency of irrigation and highest Field Water Use Efficiency was recorded in I_2(IW/CPE=0.75) but Crop Water Use Efficiency was highest in I_1 (IW/CPE=0.5).

The nutrient levels did not produce considerable variation in growth characters in groundnut. The number of pegs and pods per plant were higher in F_3 (10-37.5-75 kg N P_2O_5 K_2O ha^{-1}), which had resulted in highest pod and kernel yield. Due to haulm: pod ratio, the treatment F_3 recorded the highest harvest index. The oil yield was also highest in F_3.

The content of N and P uptake was in stem and leaf was highest in F_1 (10-37.5-75 kg N P_2O_5 K_2O ha^{-1}), but K content was higher in F_4 (10-75-150 kg N P_2O_5 K_2O ha^{-1}). Irrespective of different stages of growth. N and P content were higher in kernel compared to different plant parts of groundnut. The secondary nutrients Mg and S contents as well as their uptake was also higher in F_3 (10-37.5-75 kg N P_2O_5 K_20 ha^{-1}). Fe and Mn content and uptake were higher in F_2. Maximum depletion of N, P and K content from soil was found to be in F_2 and F_3 which were on par.

The plant which receive combination of irrigation at IW/CPE ratio of 1.0 and nutrient level of 10-37.5-75 kg N P_2O_5 K_20 ha^{-1} recorded the highest pod and kernel yield as well as uptake of major nutrients. The effect of irrigation was more pronounced on nutrient concentration in different parts of groundnut towards maturity of the crop especially with respect to Ca, Mg, S, Fe and Mn. The uptake of N, P, K, Ca and Mg increased with increase in frequency of irrigation. Fe and Mn content was low at higher frequency of irrigation. Available N content of soil increased with increase in frequency of irrigation but available P and exchangeable K of soil showed a decreasing trend with increase in frequency.

Soil solution studies revealed that N and K content of soil solution decreased with increase in duration after the irrigation. N content was highest in lowest frequency of irrigation at field capacity. But K content was high at highest frequency of irrigation. P content could not be detected in soil solution .The content of N and K was not consistent among different duration after irrigation. Ca and Mg content of soil solution increased with increasing duration after irrigation. But S showed decrease in trend. Ca, Mg and S content were highest in. I_1 (IW/CPE=0.5) and decreased with increase in frequency of irrigation.

The result indicated that the combination of irrigation at IW/CPE of 1.0 and nutrient level of 10-37.5-75 kg N P_2O_5 K_2O $ha^{-1}$is found to be optimum for groundnut in terms of growth, yield an uptake of nutrients. The interference of native elements like Fe and Mn was found to be low at this level of water nutrient interaction.