# STRESS INDUCED SOURCE-SINK MODULATION IN YARD LONG BEAN

## (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt)

*by*

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**THESIS**

**Submitted in partial fulfilment of the requirements for the degree of**

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**COLLEGE OF AGRICULTURE**

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# DECLARATION

I, hereby declare that this thesis entitled "**STRESS INDUCED SOURCE-SINK MODULATION IN YARD LONG BEAN (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt)**" 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, associateship, fellowship or other similar title, of any other University or Society.

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## CERTIFICATE

Certified that this thesis entitled "**STRESS INDUCED SOURCE-SINK MODULATION IN YARD LONG BEAN (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt)**" is a record of research work done independently by Ms. Anjana Babu, R.S. 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 her.

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We, the undersigned members of the advisory committee of Ms. Anjana Babu, R.S., a candidate for the degree of **Master of Science in Agriculture** with major in Agronomy, agree that the thesis entitled "**Stress induced source-sink modulation in yard long bean (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt)**" may be submitted by Ms. Anjana Babu, R.S., in partial fulfillment of the requirement for the degree.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| ASM | Available soil moisture |
| B : C | Benefit : Cost |
| BCR | Benefit Cost Ratio |
| cm | centimeter |
| $cm^3$ | cubic centimeter |
| Cu | Consumptive use |
| DAP | Diammonium Phosphate |
| *et al.* | co-workers / co-authors |
| Fig. | Figure |
| FYM | Farmyard manure |
| g | gram |
| ha | hectare |
| *i.e.* | That is |
| K | Potassium |
| KAU | Kerala Agricultural University |
| kg | kilogram |
| kg $ha^{-1}$ | kilogram per hectare |
| kg $ha.mm^{-1}$ | kilogram per hectare millimeter |
| L | Litre |
| LAI | Leaf Area Index |
| m | metre |
| $m^3$ | cubic centimeter |
| MOP | Muriate of Potash |
| N | Nitrogen |
| NS | Non-significant |

| | |
|---|---|
| P | Phosphorus |
| $Plant^{-1}$ | per plant |
| RD N | Recommended Dose of Nitrogen |
| RH | Relative Humidity |
| SEm | Standard Error of mean |
| q $ha^{-1}$ | Quintals per hectare |
| *viz.* | Namely |
| WUE | Water Use Efficiency |
| WP | Water Productivity |
| WR | Water requirement |

## LIST OF SYMBOLS

| | |
|---|---|
| @ | at the rate of |
| °C | degree Celcius |
| % | per cent |
| μ | micro |

# Introduction

# 1. INTRODUCTION

Yard long bean (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt), also known as asparagus bean, long-podded cowpea, pea bean, snake bean, or chinese long bean is an important vegetable crop of Kerala in coverage and preference. Africa is considered as the primary centre of origin of the crop. It is a warm season vegetable and comes up well between 21-35°C. Being a legume vegetable, yard long bean is an integral part of sustainable agriculture.

Yard long bean is extensively cultivated in Kerala both as upland crop throughout the year and in rice fallows in summer season. As an important vegetable crop, it covers an area of 7317 ha (FIB, 2015) in Kerala.

The crop is a vigorous climbing annual which grows up to a height of three to four metres and produces very long, slender and succulent pods which may be white, light green, dark green or brownish red in colour (George, 2008). Pods are 30 to 90 cm long, pendulous, fleshy and tend to shrink when dry. Seeds are elongated and kidney shaped. The pods are highly nutritive containing 23 to 26 per cent of digestible protein and high dietary fibre along with vitamin A, vitamin C, thiamin, riboflavin, calcium, phosphorus, sodium, potassium and magnesium. It is also a good source of micronutrients containing iron (102.69 - 120.02 mg $kg^{-1}$), zinc (32.58 - 36.66 mg $kg^{-1}$), manganese (2.92 - 3.34 mg $kg^{-1}$) and cobalt (0.33 - 0.57 mg $kg^{-1}$) (Ano and Ubochi, 2008). Apart from pods, the young leaves and green seeds are also used as vegetable.

Yard long bean, in general, is sensitive to water logging and requires less moisture compared to other vegetables. However, irrigation is essential to supplement rainfall as severe water stress can lead to drastic reduction in crop yield. Water requirement of vegetable types with protracted and long fruiting phase is more than that of grain cowpea. Farmers usually go for excess irrigation in expectation of getting a bountiful harvest which may result in a prolonged vegetative phase and reduced pod yield. Hardening of plants by restricting irrigation during pre-flowering stage is advantageous for avoiding excess vegetative growth and to induce early flowering. Frequent light irrigations after the onset of flowering is always advantageous. Excess irrigation and frequent rains during fruiting period induces vegetative phase at the expense of fruiting.

Yard long bean responds well to application of fertilizers. At present, there is no separate nutrient recommendation for yard long bean. The Kerala Agricultural University recommendation for grain cowpea (20 t FYM + 20:30:10 kg NPK $ha^{-1}$) is followed for yard long bean. A higher dose of 25:75:60 kg NPK $ha^{-1}$ is also recommended in some other states. Based on the research results conducted in Kerala Agricultural University by Jyothi (1995) and Geetha (1999), the *adhoc* NPK recommendation for yard long bean has been fixed as 30:30:20 kg $ha^{-1}$. Moreover, application of fertilizers in several split doses at fortnightly intervals is advocated to enhance the responsiveness to fertilizers. Several field reports indicated that excess application of nitrogenous fertilizers and organic manures may result in excess vegetative growth. At the same time, though yard long bean is a leguminous crop and has the ability to fix atmospheric nitrogen, it requires a starter dose of nitrogen for early growth and establishment (Russell, 1961).

Foliar application is a viable option to increase the efficiency of fertilizers in vegetable production. Increased yield is possible by utilizing the absorptive capacities of the aerial as well as the subterranean parts of the plant, especially when applying nutrients at critical stages of development such as during the early stages of flowering and fruiting (Wittwer, 1983). Influence of supplemental foliar nutrition on yield and quality improvement of fruits and vegetables was reported from several studies (Swietlik and Faust, 1984 and Kolota and Osinska, 2001).

Compared to grain cowpea, the indeterminate growth habit of yard long bean results in variation in response to irrigation and nitrogen level. Reduction in crop productivity due to enhanced leafiness is a common problem encountered by yard long bean farmers. Inducing a stress in crop management by increasing irrigation interval and controlled nutrient application can reduce the excess foliage growth and will help to prolong the reproductive phase.

With this back ground, the present investigation was carried out with an objective of assessing the influence of moisture-nutrient stress and foliar nutrition on source-sink relationship, productivity and profitability of yard long bean.

# Review of Literature

## 2. REVIEW OF LITERATURE

Irrigation and nutrient management are considered as the key factors for increasing the productivity of any crop. Excess irrigation and nutrient application often lead to over growth of vegetative parts. The review regarding the effect of irrigation, nitrogen and foliar application on performance of yard long bean are presented here. Wherever references on yard long bean are lacking, review on similar crops are also included.

### 2.1 IRRIGATION

Supplying water artificially to permit farming in arid regions or to offset drought in humid regions is an age old art. Irrigation is considered to be a crucial input for production in many nations. The increase in growth and yield characters of crops irrigated at an optimum schedule could be ascribed to the optimum moisture condition in the root zone (Trivedi *et al.*, 1994).

#### 2.1.1 Irrigation on Vegetative Characters

Phogat *et al.* (1984) observed that an increase in the frequency of irrigation resulted in higher dry matter production (DMP) in cowpea. Ramamurthy *et al.* (1990) in cowpea and Pani and Srivastava (1990) in pea opined that the number of branches per plant was not significantly influenced by irrigation. Jyothi (1995) stated that the number of leaves and branches and DMP was appreciably increased in yard long bean by irrigating the crop at 75 per cent field capacity throughout the crop growth in summer season and a reduction in branching was noticed at lower levels of moisture supply. Plant height, leaf area and DMP were favorably influenced by frequent light irrigations at 10 mm depth during summer season (Mini, 1997). Geetha (1999) stated that different levels of irrigation treatments did not have a significant effect on growth characters of yard long bean.

Shubhra *et al.* (2003) reported that soil water deficit decreased the dry weights of leaf, stem and roots in cluster bean. In french bean, irrigation at 0.8

and 1.0 IW/CPE ratio recorded the highest leaf area and maximum dry matter production (Jukte *et al.,* 2007).

**2.1.2 Irrigation on Yield Attributes and Yield**

A field experiment conducted on summer cowpea revealed that the moisture regime of 80 to 100 per cent available soil moisture (ASM) appreciably increased the number and weight of green pods per plant and recorded 12.87 per cent higher yield of green pods as compared to 60 to 100, 40 to 100 and 20 to 100 per cent ASM (Patel, 1979). According to Diputado and del Rosario (1985), moisture stress imposed ten days after emergence until the peak vegetative stage caused considerable reduction in fresh pod yield of yard long bean. Subramanian *et al.* (1993) noted a significant influence of irrigation on pod length and number of seeds per pod in yard long bean and reported that an IW/CPE ratio of 1.0 was superior to 0.6 in terms of vegetable yield.

In a field trial with yard long bean during summer season, an increase in number and length of pods was noted with increase in soil wetness and there was an increasing trend in pod and haulm yields while irrigating at 75 per cent ASM (Jyothi, 1995). Mini (1997) revealed that the minimum number of days to attain 50 per cent flowering, maximum number of pods per plant and the highest yield were obtained with daily light irrigation at 10 mm depth. In yard long bean earliness in flowering and the main yield attributing character *viz*., the number of pods per plant were favorably influenced when irrigation was given at a cumulative pan evaporation (CPE) value of 20 mm with a depth of 10 mm water through micro sprinkler method and it resulted in significantly higher green pod yield as compared to surface irrigation at 20 mm CPE with 40 mm water and daily pot watering at 10 mm depth (Geetha and Varughese, 2001).

Pulekar *et al.* (1993) observed an increase in green pod yield of lablab by narrowing down the irrigation interval. Jadhav *et al.* (1996) reported an increase in the pod yield of lablab when irrigated at 75 mm CPE over 100 and 150 mm CPE. According to Aruna (1999), irrigation at an IW/CPE ratio of 0.6 gave the highest green pod and haulm yields of lablab bean. Greater straw and grain yield were reported in french bean when irrigation was scheduled at an IW/CPE ratio of 0.8 and 1.0 over 0.6 (Jukte *et al.*, 2007).

### 2.1.3 Irrigation on Biochemical Characters

#### *2.1.3.1 Chlorophyll Content*

Diputado and del Rosario (1985) reported a reduction in chlorophyll content in yard long bean during moisture stress conditions. According to Shubhra *et al.* (2003), water stress created by withholding irrigation at vegetative, flowering and pod-filling stages decreased the chlorophyll content of cluster bean.

#### *2.1.3.2 Proline Content*

Geetha (1999) reported that maximum proline content was obtained when crop was irrigated through micro-sprinklers at 20 mm CPE at a depth of 10 mm. Shubhra *et al.* (2003) noted that under water deficit conditions there was accumulation of large amount of proline in the leaf of cluster bean. According to Hamidou *et al.* (2007) there was a significant accumulation of proline during water stress at both vegetative and reproductive stage in different cowpea genotypes. Mohammad (2014) observed an increase in proline and protein in faba bean with increasing water stress.

### 2.1.4 Irrigation on Root Growth

In an experiment conducted by Benjamin and Nielsen (2006) to examine the response of legume root system to water stress using three legumes *viz.*, soybean, chickpea and field pea, it was found that water deficit did not affect the relative root distribution in soybean, but significantly affected the root distribution in chickpea and resulted in greater proportion of chickpea and field pea roots to grow deeper in the soil. Water stress during the vegetative stage resulted in decrease in the root volume of various cowpea genotypes (Hamidou *et al.*, 2007).

### 2.1.5 Irrigation on Moisture Depletion Pattern and Water Use Efficiency

Ahlawat *et al.* (1979) found that in spring cowpea the consumptive use (Cu) and water use efficiency (WUE) increased with increasing levels of irrigation. The maximum values were recorded by irrigating at 75 per cent ASM as compared to 50 and 25 per cent ASM. Another trial conducted on yard long bean revealed that WUE increased with increasing levels of moisture regimes, *i.e.*, from 20 to 100 per cent ASM to 80 to 100 per cent ASM (Patel, 1979). Ziska and Hall (1983) reported that withholding irrigation during the vegetative stage in a rain-free environment following pre-irrigation resulted in lower water use. According to Phogat *et al.* (1984) WUE increased under mild stress conditions compared to moderate and severe stress in cowpea. It was also noticed that an increase in moisture stress increased the soil moisture use from deeper soil layers and among the legumes tried, mung bean extracted more moisture from deeper soil layers under stress conditions than cowpea. Subramanian *et al.* (1993) observed that yard long bean irrigated at an IW/CPE ratio of 1.0 consumed more water than those irrigated at 0.6 and 0.8 ratios. In summer cowpea, scheduling irrigation based on an IW/CPE ratio of 0.8 gave significantly higher Cu of water over the rest of ratios, *i.e.*, 0.4 and 0.6 while different ratios did not exert any significant influence on WUE (Kher *et al.*, 1994). Jyothi (1995) stated that the percentage depletion of moisture from upper layers of soil increased with increase in number of irrigations and that from lower layers increased with moisture stress. Mini (1997) also reported similar results; moisture extraction from the top soil layers increased with wetter regimes and was maximum with daily light irrigation at a depth of 10 mm, while the moisture extraction from deeper layers increased in drier regimes. The highest WUE was obtained by irrigating the crop at 15 mm CPE to a depth of 20 mm. From another experiment it was found that per cent depletion of moisture from the top layer (0 to 15 cm) was higher under micro sprinkler method of irrigation while in the deeper layers, more depletion was noticed with surface method of irrigation (Geetha, 1999). It was also noted that WUE was the highest under micro sprinkler method of irrigation at 10 mm CPE with a depth of 20 mm water.

A study conducted by YihChi *et al.* (2009) indicated that frequent irrigation with higher amount of water could lead to reduced water productivity and yield loss in bottle gourd.

### 2.1.6 Irrigation on Nutrient Composition and Uptake

Subramanian *et al.* (1993) observed no significant difference in P content of cowpea due to varying irrigation but uptake of P was maximum when irrigation was scheduled at an IW/CPE ratio of 0.8 compared to IW/CPE ratios of 0.6 and 1.0. There was a remarkable increase in the uptake of N, P and K when yard long bean was irrigated at 75 per cent field capacity throughout the crop growth (Jyothi, 1995). An experiment by Mini (1997) revealed that the uptake of N, P and K by yard long bean was significantly higher with daily irrigation to a depth of 10 mm. Geetha (1999) reported that light irrigation at 10 mm depth everyday resulted in the highest uptake of P at 90 DAS, however the different levels of irrigation did not influence the nitrogen and potassium uptake.

### 2.1.7 Irrigation on Soil Nutrient Status after the Experiment

From an experiment conducted at College of Agriculture, Vellayani, Jyothi (1995) stated that the maximum contents of N, P and K in soil were observed in treatments with moisture stress (irrigating at 50 per cent field capacity during 34 to 66 days and at 75 per cent field capacity during the remaining period of crop growth). Irrigating the crop at 15 mm CPE to a depth of 20 mm registered the maximum content of N, P and K in soil after the crop (Mini, 1997). According to Geetha (1999) there was no remarkable variation in post experiment soil nutrient status due to different irrigation treatments.

### 2.1.8 Irrigation on Economics

From an experiment conducted on summer cowpea, Patel (1979) reported that maximum net profit was obtained by irrigating at 80 to 100 per cent ASM, while the lowest net profit was obtained by maintaining at 20 to 100 per cent ASM. The highest net income and BCR were registered when yard long bean was irrigated at 75 per cent field capacity throughout the crop growth stage (Jyothi, 1995). Mini (1997) opined that irrigating yard long bean at 10 mm CPE to a depth of 20 mm was most economic. Geetha (1999) reported that the irrigation levels did not have a profound influence on net returns and benefit cost ratio.

Perusal of the review presented above indicated that daily irrigation favours vegetative growth, chlorophyll content and total dry matter production. Regarding yield and WUE, a mild soil moisture stress is always favourable for yard long bean.

## 2.2 NITROGEN

Nitrogen is an essential nutrient for plant growth, development and reproduction. Being a major component of amino acids and nucleic acids, nitrogen management is essential for achieving maximum economic yield. Several reports (Patel, 1979 and Raj and Patel, 1991) are available on the response of yard long bean to moderate applications of nitrogen.

### 2.2.1 Nitrogen on Vegetative Characters

Ramamurthy *et al.* (1990) found that application of 20 kg N $ha^{-1}$ recorded maximum leaf area index (LAI). Jyothi (1995) reported that different nitrogen levels did not influence the production of leaves per plant in yard long bean but maximum LAI was recorded when 20 kg N $ha^{-1}$ was applied. It was also observed that application of nitrogen appreciably influenced the dry matter production at all stages of growth and N @ 30 kg $ha^{-1}$ registered maximum DMP. Akter *et al.* (1998) reported that dry weight of plants increased significantly with increased levels of N up to 40 kg $ha^{-1}$ in yard long bean. Suja (2006) observed that various growth parameters like branches per plant, shoot : root ratio and dry matter content were not influenced by different nitrogen levels, but LAI was significantly superior at 30 kg N $ha^{-1}$ at 30 DAS. Kumawat (2012) reported an increase in LAI in yard long bean under 15 kg N $ha^{-1}$ compared to no nitrogen and 10 kg N $ha^{-1}$.

An increase in nitrogen levels up to 80 kg $ha^{-1}$ increased LAI in french bean (Hegde and Srinivas, 1989). Ramawtar *et al.* (2013) stated that application of N @ 15 kg $ha^{-1}$ significantly enhanced the growth attributes *viz.*, plant height, dry matter accumulation and branches per plant. In cluster bean, significantly higher dry matter production was registered at 40 kg N $ha^{-1}$ as compared to lower levels (Prasanna *et al.*, 2014).

**2.2.2 Nitrogen on Yield Attributes and Yield**

According to Sharma (1977), application of 20 kg N $ha^{-1}$ recorded significantly higher yield of cowpea over no nitrogen. Patel (1979) reported that application of 20 kg N $ha^{-1}$ remarkably influenced the yield attributes like number and weight of green pods per plant and increased the pod yield of cowpea. Ramamurthy *et al.* (1990) and Gandhi *et al.* (1991) found that application of 25 kg N $ha^{-1}$ to cowpea produced maximum number of pods and higher pod weight per plant and significantly higher yield. In a study on summer cowpea, Raj and Patel (1991) reported that application of 20 kg N $ha^{-1}$ significantly improved the pod length, number of grains per pod and yield over no nitrogen.

Jyothi (1995) noticed that N levels (20, 30 and 40 kg N $ha^{-1}$) did not have any influence on the time taken for 50 per cent flowering in yard long bean. However, a trend of earliness in flowering was observed at 30 kg N $ha^{-1}$ and there was a significant increase in the number of pods per plant, length of pods, number of seeds per pod and pod yield for the same treatment. Akter *et al.* (1998) found that the number of pods per plant in yard long bean increased with increasing levels of nitrogen but the optimum level was found with 20 kg N $ha^{-1}$. Earliness in flowering and number of pods per plant were influenced when nitrogen was applied @ 20 kg $ha^{-1}$ as compared to other levels and this level registered higher green pod yield (Geetha, 1999). Suja (2006) reported that nitrogen levels (30, 45 and 60 kg $ha^{-1}$) did not profoundly influence the yield attributing characters like number of pods per plant. Kumawat (2012) reported that the number of pods per plant and pod yield per hectare increased with increase in levels of applied N up to 100 per cent RD (20 kg N $ha^{-1}$).

Singh (1987) reported that there was an increase in pod yield of french bean with increasing levels of N up to 60 kg $ha^{-1}$. Singh (2000) reported that the number of pods per plant improved with rising N levels up to 100 kg $ha^{-1}$ and the green pod yield of french bean was significantly higher at 125 kg N $ha^{-1}$. Higher number of pods per plant in the same crop was recorded in the treatment receiving 120 kg N $ha^{-1}$ (Prajapati *et al.*, 2003 and Behura *et al.*, 2006). Veeresh (2003) stated that increased N application (40, 80 and 120 kg $ha^{-1}$) delayed flowering in french bean (flowering after 29, 32 and 33 days respectively), while the yield was the highest for treatment receiving 120 kg N $ha^{-1}$. The yield attributes like pods per plant, seeds per pod, pod length and pod and seed yield increased significantly in cluster bean with 15 kg N $ha^{-1}$ compared to lower and higher doses of N (Ramawtar *et al.*, 2013). From another study in cluster bean, Prasanna *et al.* (2014) reported that the highest number of clusters per plant, pods per cluster, pods per plant and maximum seed yield were recorded with 30 kg N $ha^{-1}$.

### 2.2.3 Nitrogen on Biochemical Characters

#### *2.2.3.1 Chlorophyll Content*

Kumawat (2012) indicated that application of 20 kg N (100 per cent RD) significantly increased the total chlorophyll content in the leaves of yard long bean over 0 and 50 per cent RD N.

### 2.2.4 Nitrogen on Nutrient Uptake

An increase in the uptake of N, P and K was reported with $N:P_2O_5$ ratio of 30:45 kg $ha^{-1}$ (Jyothi, 1995). Geetha (1999) observed that application of N @ 20 kg $ha^{-1}$ had a remarkable influence on uptake of nitrogen and it was on par with 40 kg N $ha^{-1}$, but different nitrogen levels did not show a remarkable influence on P uptake. In the case of potassium uptake, it was observed that at 30 DAS application of N @ 20 kg $ha^{-1}$ recorded the highest uptake of potassium, but at 90 DAS, 0 kg N $ha^{-1}$ reported the highest uptake. Suja (2006) opined that different nitrogen levels did not markedly influenced the uptake of nutrients.

### 2.2.4 Nitrogen on Soil Nutrient Status after Experiment

According to Jyothi (1995) the N:$P_2O_5$ ratio of 20:30 kg $ha^{-1}$ recorded the maximum content of available N, P and K in the soil compared to higher levels. Geetha (1999) opined that the highest soil N content was obtained with 40 kg N $ha^{-1}$ while P and K contents were unaffected by N levels. Application of 20 kg N $ha^{-1}$ resulted in the maximum N and P content in the soil compared to lower levels (Kumawat, 2012).

### 2.2.5 Nitrogen on Economics

From the trials conducted by Jyothi (1995) it was revealed that the highest net income was obtained with an N:$P_2O_5$ ratio of 30:45 kg $ha^{-1}$ compared to both lower and higher ratios. Geetha (1999) reported that in yard long bean, the nitrogen levels had not favouably influenced the net returns and BCR. Kumawat (2012) reported an increase in net returns and B : C ratio with increasing levels of N up to 100 per cent RD N in yard long bean. From the results of a study conducted by Yadav and Choudhary (2012) in cowpea, it was noticed that application of 100 per cent RD N significantly increased the net returns over 50 and 75 per cent RD N.

In general, N application improved growth characters and nutrient uptake. However, enhancing N level did not have any improvement on total yield.

## 2.3 FOLIAR APPLICATION

Foliar fertilization is fast becoming an essential addition to standard cultivation techniques. Foliar spray although not a substitute for soil application, can be considered as an excellent short term solution for plants experiencing deficiencies.

### 2.3.1 Foliar Application on Vegetative Characters

Results of a field study with three cowpea cultivars showed that sprayings of NPKS and PKS at the onset of flowering or two weeks later increased vegetative development and dry matter accumulation and spraying at flowering was more beneficial than spraying two weeks later (Tayo, 1981). From another study in the same crop it was revealed that spraying 50 to 100 mg N $L^{-1}$ of water twice during the late reproductive stage enhanced leaf retention and resulted in greater accumulation of dry matter in the leaves, stem and roots (Tayo, 1986).

El-Zeiny *et al.* (1990) observed that the leaf, stem and total dry weight of beans at 70 DAS increased with increase in foliar application of urea up to four per cent concentration, but growth was unaffected at 100 DAS. Mohammad (2014) noted that the plant height and leaf area increased with increasing levels of potassium concentration up to 5500 mg $L^{-1}$ in faba bean.

**2.3.2 Foliar Application on Yield Attributes and Yield**

Srinivasan and Ramasamy (1992) reported that spraying two per cent diammonium phosphate (DAP) at 20 and 30 DAS and soil application of N and P @ 125 kg N and 25 kg $P_2O_5$ $ha^{-1}$ produced similar yield of grain cowpea. From an experiment to determine the influence of rates and methods of N application on the yield of vegetable cowpea, the optimum N level for enhanced green and dry pod yield was worked out as 60 kg $ha^{-1}$ as soil application. This treatment performed better than foliar application of N after a common basal dose of manure (20 t $ha^{-1}$), superphosphate (500 kg $ha^{-1}$) and potassium chloride (68 kg $ha^{-1}$) (de Oliveira *et al.*, 2003).

Anez and Tavira (1985) reported that there were no differences in yield and yield attributes between soil and foliar treatments in french beans. Foliar application of urea significantly increased the number of pods per plant and pod yield in french bean and 0.4 per cent urea was the most effective among 0.2, 0.4 and 0.6 per cent (Guvenc, 1996). Foliar spray of two per cent urea recorded the highest yield followed by foliar spray of one per cent KCl with soil application of humic acid in black gram (Sritharan *et al.*, 2007). A field study in Rajasthan revealed that two foliage application of mixed solution of thiourea (0.05 per cent) and zinc sulphate (0.2 per cent) at branching and pod formation stage in chickpea grown under recommended dose of N, P and K had positive influence on seed yield (Dayanand, 2013).

In a study conducted by Mohammad (2014) University of Diyala, it was noted that in faba bean the grain yield increased with increasing levels of potassium concentration up to 5500 mg $L^{-1}$. An experiment conducted in tomato *cv.* Pant C-3 revealed that 87.5 per cent recommended dose of NPK + foliar application of water soluble fertilizers (19:19:19, 13:0:45 and 0:52:34) recorded more fruits per plant, fruits per cluster, fruit weight, fruit diameter and the highest fruit yield per ha (Narayan *et al.*, 2012). Kumawat *et al.* (2015) reported that the application of one per cent urea at 30 and 50 DAS resulted in an increase in grain yield and harvest index by 83 and 13 per cent respectively in guar.

Response to foliar nutrition vary with crops, quantity and time of application. It can serve as an excellent supplement to soil application and the role of foliar nutrition in substituting the soil nutrition needs more investigation.

# Materials and Methods

# 3. MATERIALS AND METHODS

An investigation entitled "Stress induced source-sink modulation in yard long bean (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt)" was undertaken to assess the influence of water and nutrient stress and foliar nutrition on source-sink relationship, productivity and profitability of yard long bean. The field experiment was conducted during the summer season of 2014. The materials used and the methods adopted for the study are briefly described below.

## 3.1 MATERIALS

### 3.1.1 Experimental Site

The experiment was conducted in the D block of Instructional Farm attached to the College of Agriculture, Vellayani, Kerala, located at 8° 25' 46'' N latitude and 76° 59' 24" E longitude and at an altitude of 19 m above the mean sea level.

### 3.1.2 Soil

The soil of the experimental site is red sandy clay loam. The mechanical composition, moisture characteristics and chemical properties of the soil are summarized in Table 1 and 2.

### 3.1.3 Cropping History of the Field

Banana was the previous crop planted in the field.

### 3.1.4 Season

The experiment was conducted during the summer season 2014, the period extending from 24th January 2014 to 16th May 2014.

Table 1. Mechanical composition and moisture characteristics of soil

| Particulars | Value | Method used |
|---|---|---|
| A. Mechanical composition | | |
| Coarse sand (%) | 16.30 | International pipette method (Piper, 1967) |
| Fine sand (%) | 30.50 | |
| Silt (%) | 25.80 | |
| Clay (%) | 26.10 | |
| B. Soil moisture characteristics | | |
| Particle density (g $cc^{-1}$) | 2.30 | Pycnometer method (Black, 1965) |
| Bulk density (g $cc^{-1}$) | 1.40 | Core method (Gupta and Dakshinamoorthi, 1980) |
| Maximum water holding capacity (%) | 23.70 | |
| Field capacity (%) | 21.90 | Pressure plate apparatus (Hillel, 1971) |
| Permanent wilting point (%) | 9.10 | |

Table 2. Chemical characteristics of soil prior to experiment

| Particulars | Value | Rating | Method used |
|---|---|---|---|
| Organic C (%) | 0.9 | High | Walkley and Black rapid titration method (Jackson, 1973) |
| Available N (kg $ha^{-1}$) | 413.95 | Medium | Alkaline $KMnO_4$ method (Subbiah and Asija, 1956) |
| Available P (kg $ha^{-1}$) | 151.4 | High | Bray's colorimetric method (Jackson, 1973) |
| Available K (kg $ha^{-1}$) | 178.98 | Medium | Ammonium acetate method (Jackson, 1973) |
| Soil reaction (pH) | 4.5 | Extremely acidic | pH meter with glass electrode (Jackson, 1973) |
| Electrical conductivity (dS $m^{-1}$) | 0.08 | Safe | Digital conductivity meter |

### 3.1.5 Weather Conditions

The data on weather parameters (rainfall, maximum temperature, minimum temperature, relative humidity and evaporation) during the cropping period are presented in Fig. 1 and Appendix I. The total rainfall received during the cropping period was 324.8 mm.

### 3.1.6 Crop and Variety

Yard long bean (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt) variety *Vellayani Jyothika,* released from the Department of Olericulture, College of Agriculture, Vellayani was selected for the study. The characters of the variety are given in Table 3 and the photo presented in Plate 1.

### 3.1.7 Source of Seed Material

The seed for the experiment was obtained from the Department of Olericulture, College of Agriculture, Vellayani.

Table 3. Characters of yard long bean variety *Vellayani Jyothika*

| **Characters** | **Description** |
|---|---|
| Parentage | Selection from Sreekaryam local |
| Growth habit | Indeterminate, climbing |
| Immature pod colour | Light green |
| Days to 50 per cent flowering | 40 - 45 days |
| Productivity | 24.5 t $ha^{-1}$ |
| Duration | 105 - 120 days |

### 3.1.8 Manures and Fertilizers

Well decomposed FYM analyzing 0.5 per cent nitrogen was used as the organic manure source. Urea (46 per cent N), Mussoriephos (20 per cent $P_2O_5$) and Muriate of Potash (60 per cent $K_2O$) were used as sources of nitrogen, phosphorus and potassium respectively. Potassium nitrate (13-0-45) was used as the source for foliar nutrition.

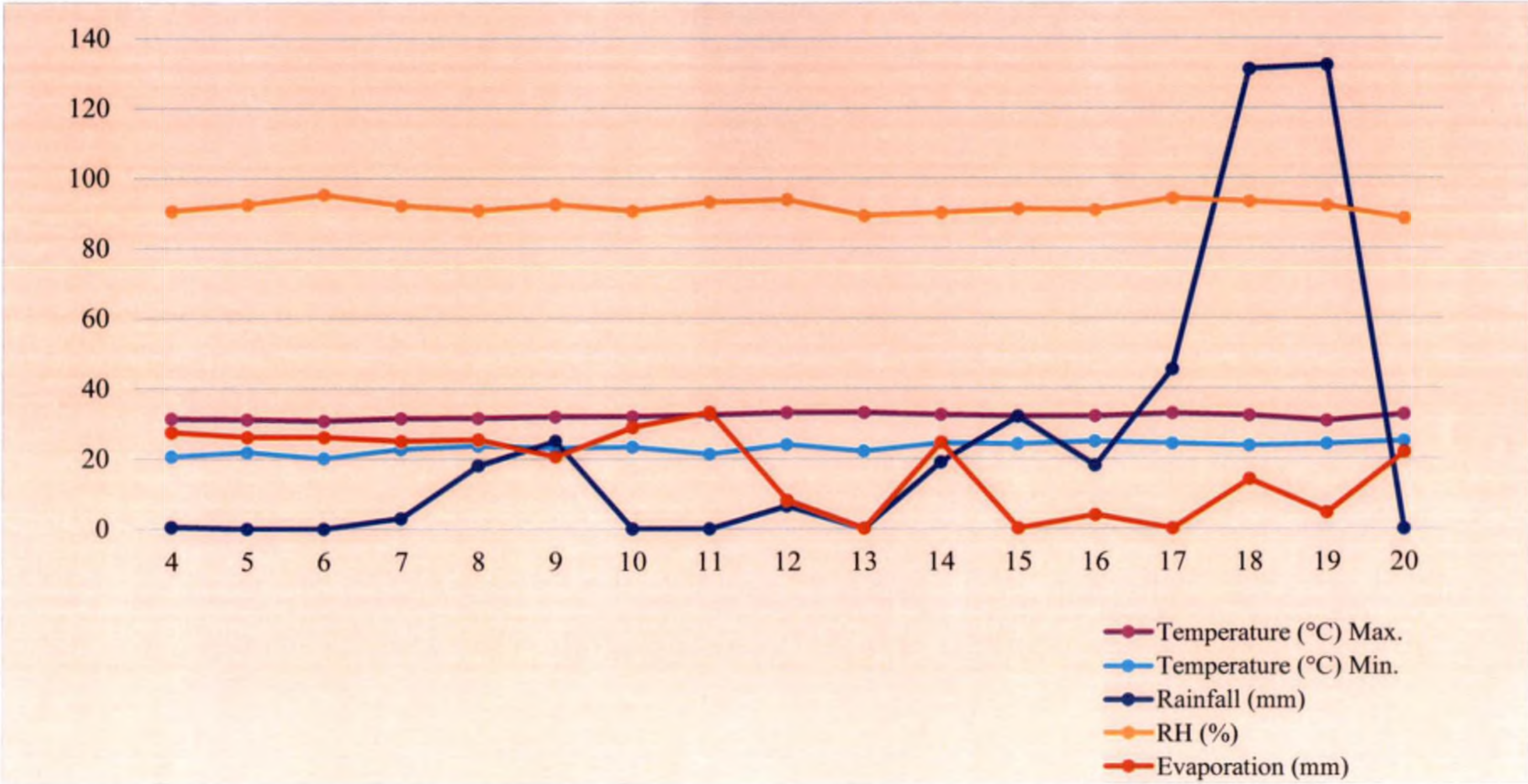


Fig 1. Weather parameters during the cropping period (Feb. 2014 - May 2014)

a. Plant in pod formation stage

b. Pod

Plate 1. Yard long bean variety *Vellayani Jyothika*

## 3.2 METHODS

### 3.2.1 Design and Layout

The field experiment was laid out in split plot design.

### 3.2.2 Treatment Details

Treatments included four levels of irrigation, two levels of nitrogen and two application methods.

**Main plot treatments**: Irrigation intervals (I) - 4

$I_1$ - Daily irrigation at 10 mm depth.

$I_2$ – Irrigation in alternate days at 20 mm depth.

$I_3$ – Irrigation once in 3 days at 20 mm depth.

$I_4$ – Irrigation once in 3 days up to flowering and then in alternate days at 20 mm depth.

**Subplot treatments**: Combinations of N levels and methods of application – 4

Nitrogen stress (N) - 2

$N_0$ : - 0 per cent of recommended N

$N_1$ : - 25 per cent of recommended N

Methods of application (M) - 2

$M_1$ – Soil (N and K in 4 splits as basal, at 20, 30 and 40 DAS)

$M_2$ – Soil + foliar [one-third of N and K as basal followed by foliar application with complex fertilizer 13-0-45 (0.5 per cent) at fortnightly interval]

**Subplot treatment combinations** - 4

$n_0m_1$ $n_0m_2$ $n_1m_1$ $n_1m_2$

**Treatment combinations** – 16

$i_1n_0m_1$ $i_1n_0m_2$ $i_1n_1m_1$ $i_1n_1m_2$

$i_2n_0m_1$ $i_2n_0m_2$ $i_2n_1m_1$ $i_2n_1m_2$

$i_3n_0m_1$ $i_3n_0m_2$ $i_3n_1m_1$ $i_3n_1m_2$

$i_4n_0m_1$ $i_4n_0m_2$ $i_4n_1m_1$ $i_4n_1m_2$

### 3.2.3 Plot Size

| | | |
|---|---|---|
| Gross plot size | – | 3 m x 3.60 m |
| Net plot size | – | 3 m x 2.70 m |
| Spacing | - | 1.5 m x 0.45 m |

### 3.2.4 Field Preparation and Sowing

The experimental field was thoroughly ploughed with a power tiller, stubbles and previous crop residues were removed and levelled properly. The field was then divided into main plots and sub plots. A buffer strip of 50 cm width was provided around each main plot to account seepage loss of water. Within each subplot, two furrows of 20 cm width were taken along the length of the plot at 1.5 m apart. The seeds were dibbled at 45 cm spacing @ two per hole at a depth of 5 cm.

### 3.2.5 Application of Manures and Fertilizers

FYM @ 20 t $ha^{-1}$ was applied uniformly to all plots before sowing and thoroughly incorporated. Based on previous studies the *adhoc* recommendation for yard long bean is fixed as 30:30:20 kg $N:P_2O_5:K_2O$ $ha^{-1}$. Uniform application of phosphorus @ 30 kg $ha^{-1}$ was followed in all treatments. N and K were applied as per the treatments as detailed in Table 4.

### 3.2.6 Aftercultivation

Germination was uniform and gap filling was done in a few plots 5 DAS. The crop was thinned two weeks after emergence and a single plant was maintained at 45 cm spacing. Standards were erected and crop was trailed on trellis by three weeks after emergence. Two weedings were given at 20 and 40 DAS. Five plants were selected randomly from the net plot area and tagged as observational plants.

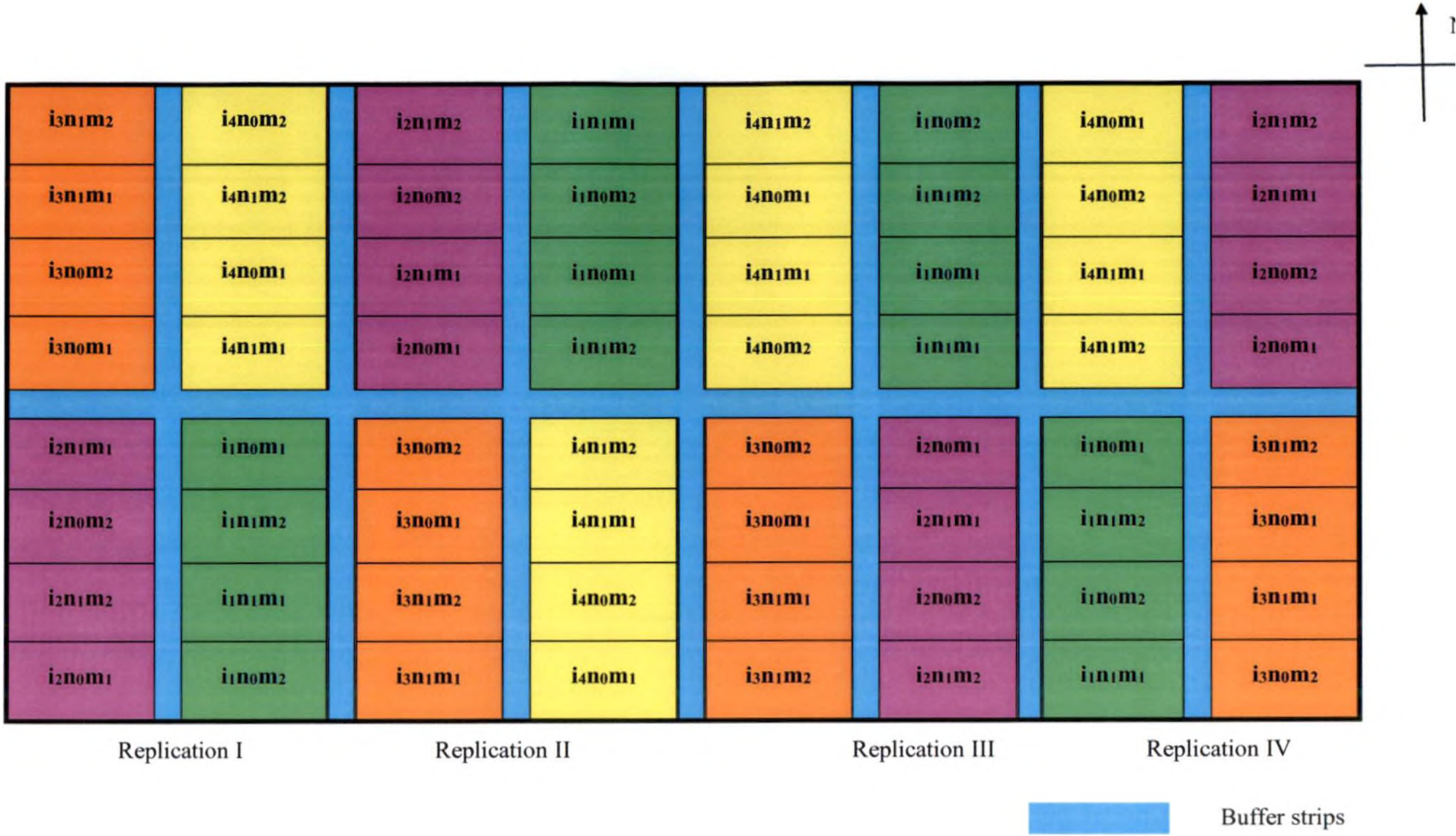


Fig 2. Layout plan of the experiment

Table 4. Details of N and K application as per treatments

| Treatment | N (kg $ha^{-1}$) | K (kg $ha^{-1}$) | Soil | Foliar |
|---|---|---|---|---|
| $n_0 m_1$ | 30 | 20 | N and K in four splits at 10, 20, 30 and 40 DAS | Nil |
| $n_0 m_2$ | 30 | 20 | 1/3 of N and K at 10 DAS (10 kg N and 6.7 kg $K_2O$) | 13-0-45 @ 0.5 % - four times at fortnightly intervals |
| $n_1 m_1$ | 22.5 | 20 | N and K in four splits at 10, 20, 30 and 40 DAS | Nil |
| $n_1 m_2$ | 22.5 | 20 | 1/3 of N and K at 10 DAS (7.5 kg N and 6.7 kg $K_2O$) | 13-0-45 @ 0.5 % - four times at fortnightly intervals |

### 3.2.7 Irrigation

The irrigation schedule started one week after emergence. Measured quantity of water was given to each plot as per the treatment except on rainy days. The details of irrigation schedule are given in Table 5.

Table 5. Irrigation schedule of yard long bean as per treatments

| Irrigation schedule | Depth (mm) | Quantity of water per irrigation* ($m^3$ $ha^{-1}$) |
|---|---|---|
| $I_1$ - Daily irrigation | 10 | 13.3 |
| $I_2$ – Irrigating in alternate days | 20 | 26.7 |
| $I_3$– Irrigating once in 3 days | 20 | 26.7 |
| $I_4$ – Irrigating once in three days up to flowering and in alternate days after flowering | 20 | 26.7 |

* Quantity was worked out considering the wetting area

Plate 2. Water meter for irrigating with measured quantity of water

Plate 3. General view of the experimental field – early stage

Plate 4. General view of the experimental field – pod forming stage

### 3.2.8 Plant Protection

Uniform application of dimethoate @ 0.5 per cent and quinalphos @ 0.3 per cent was done against sucking pests and leaf eating caterpillars respectively at 20 DAS and 35 DAS. At 60 DAS, one spraying of spiromesifen (0.08 per cent) was given against mite attack uniformly in all plots. Two soil drenching with copper oxychloride @ 0.3 per cent was adopted in all plots as a prophylactic measure when *Pythium* stem rot and *Fusarium* wilt were observed in a few patches.

### 3.2.9 Harvesting

Picking of pods commenced from 49 DAS. Subsequent harvests of green pods were done at alternate days uniformly from all the treatments and fresh weight was recorded separately.

## 3.3 OBSERVATIONS TAKEN

### 3.3.1 Biometric observations

Five plants from the net plot area were tagged as observational plants in each plot.

#### *3.3.1.1 Primary Branches Plant$^{-1}$*

The mean number of branches per plant from the observational plants were recorded at 30, 60 and 90 DAS.

#### *3.3.1.2 Functional Leaves Plant$^{-1}$*

The mean number of functional leaves per plant from the observational plants at 30, 60 and 90 days were computed and recorded.

#### *3.3.1.3 Leaf Area Index at Flowering*

The leaf area of observational plants from each plot was measured at flowering stage (45 DAS) by graph paper method and expressed in $cm^2$.

Leaf area index was then computed using the equation:

$$LAI = \frac{\text{Total leaf area}}{\text{Land area}}$$

### *3.3.1.4 Dry Matter Partitioning and Source : Sink Ratio*

Dry matter production was recorded during the final harvest. The observational plants were uprooted from each plot carefully without damaging the roots and separated into leaves, stem and roots. They were dried under shade separately and then oven dried at 80 ± 5° C for about 10 hours until two consecutive weights were the same. The final weight of individual parts were recorded and totaled to get the total dry matter production and expressed in q $ha^{-1}$. Similarly the dry matter production of pods was recorded and expressed as dry matter production of the sink and the ratio of source and sink worked out.

### *3.3.1.5 Crop Duration*

The duration of the crop from sowing up to the end of the cropping period *i.e.*, till vegetable yield came below economic level was recorded and expressed in days.

## 3.3.2 Yield and Yield Attributes

### *3.3.2.1 Days for 50 Percentage Flowering*

The date for flowering of 50 per cent of the net population per plot was recorded and the period taken was expressed as number of days.

### *3.3.2.2 Peduncle Length*

Length of the peduncle was measured from five randomly selected inflorescence in each observational plant, the average worked out and expressed in cm.

### *3.3.2.3 Flowers Inflorescence$^{-1}$*

Number of flowers opened in each of the three tagged inflorescence per observational plant was counted, the average worked out and recorded.

### *3.3.2.4 Setting Percentage*

Number of pods set per each of the tagged inflorescence was counted and setting percentage was calculated as follows:

$$\text{Setting percentage} = \frac{\text{No. of pods per inflorescence} \times 100}{\text{No. of flowers per inflorescence}}$$

### *3.3.2.5 Pod Length*

Length of three randomly selected pods from each observational plant at each harvest were measured using an ordinary scale, the average worked out and presented in cm.

### *3.3.2.6 Pod Girth*

Girth of the pods were recorded from the same pods used for measurement of length and expressed in cm.

### *3.3.2.7 Pod Weight*

Individual pods which were used for measurement of length and girth were weighed and weight expressed in g.

### *3.3.2.8 Number of Pods Plant$^{-1}$*

The pods obtained from each of the observational plant was counted and the average worked out.

### *3.3.2.9 Pod Yield Plant$^{-1}$*

The pods obtained from the observational plants were weighed separately and averages were recorded.

*3.3.2.10 Pod Yield Harvest[1]*

The pod yield obtained from the net area of each treatment plot was recorded separately and tabulated harvest wise and expressed in g.

*3.3.2.11 Total Pod Yield*

Yield of green pods obtained from each harvest was recorded separately according to the treatment and totaled up at the end of the cropping period and expressed in q $ha^{-1}$.

*3.3.2.12 Number of Pickings*

Number of pickings of immature pods from each treatment during the total crop period was recorded.

*3.3.2.13 Harvest Index*

Harvest index was calculated using the formula:

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Biological yield}} \quad \text{(Donald, 1962)}$$

**3.3.3 Biochemical and Quality Studies**

*3.3.3.1 Proline Content of Leaves at Flowering*

The free proline content was estimated by the method of Bates *et al*, (1973) and expressed in μ moles $g^{-1}$ fresh weight.

*3.3.3.2 Chlorophyll Content at Flowering*

The chlorophyll content of the leaves at flowering was analysed by using the dimethyl sulphoxide (DMSO) method (Yoshida *et al.*, 1976). Chlorophyll content was measured from the leaf extract by a spectrophotometer and expressed in mg $g^{-1}$.

*3.3.3.3 Crude Protein*

Crude protein content of pods was calculated by multiplying the nitrogen content of pod by the factor 6.25 (Simpson *et al.*, 1965).

*3.3.3.4. Crude Fibre*

Crude fibre content of pods was determined by A.O.A.C method (A.O.A.C, 1975)

**3.3.4 Root Studies at Final Harvest**

*3.3.4.1 Root Volume*

After the final harvest, the observational plants were uprooted and the root volume was measured by water displacement method in a graduated cylinder and the volume expressed as $cm^3$.

*3.3.4.2 Root Weight*

The fresh weight and the dry weight of the roots taken for volume measurement were recorded and expressed in g.

**3.3.5 Pest and Disease Incidence**

The incidence of pests and diseases during the crop period was recorded treatment wise. The following major pests and diseases were observed during the crop period.

Table 6. Major pests and diseases observed during the cropping period

| **Pests** | **Diseases** |
|---|---|
| Leaf eating caterpillar – *Spodoptura litura* | Fusarium wilt – *Fusarium oxysporum* |
| Mite – *Tetranichus sp* | Stem rot – *Pythium debarianum* |

Per cent intensity of damage was calculated for mite attack while, per cent disease incidence was calculated for *Pythium* stem rot (Appendix II and III). Adequate control measures were adopted in the initial stages of incidence.

**3.3.6 Chemical Analysis**

***3.3.6.1 Nutrient Uptake Studies***

After the final harvest, the plant parts (leaf, stem, root and pod) were analyzed for major nutrients. Nutrient uptake was calculated by multiplying the percentage nutrient content with total dry matter production and expressed in kg $ha^{-1}$. Nutrient uptake by the source and sink were calculated separately.

***3.3.6.2 Soil Analysis after the Experiment***

Soil samples were collected from individual plots of the experimental area after final harvest of the crop. The composite samples drawn from the individual plots were air dried, powdered, sieved through 2 mm sieve and analysed for N, P and K. Available N content was determined by Alkaline potassium permanganate method (Subbiah and Asija, 1956), available $P_2O_5$ content by Bray's colorimetric method (Jackson, 1973) and available $K_2O$ by Ammonium acetate method (Jackson, 1973).

**3.3.7 Moisture Studies**

***3.3.7.1 Water Requirement and Water Use Efficiency***

Total water requirement (WR) in each treatment was estimated directly by adding up the quantity of water required for irrigation with effective rainfall and moisture contribution from soil profile. Moisture contribution from soil profile was insignificant and the total water requirement was calculated using the following relationship.

WR = Irrigation requirement + Effective rainfall

[Effective rainfall = 70 per cent of total seasonal rainfall (Dastane, 1974)]

Field water use efficiency was calculated by dividing the economic crop yield by the total water requirement and expressed in kg $ha.mm^{-1}$.

*3.3.7.2 Water Productivity*

Water productivity was estimated using the formula proposed by Kijne *et al.* (2003) and expressed as kg $ha.mm^{-1}$.

$$\text{Water Productivity (WP)} = \frac{\text{Total biomass}}{\text{Total water utilized}}$$

*3.3.7.3 Moisture Depletion Pattern*

The average relative soil moisture depletion from each soil layer in the root zone at 0 to 15 cm and 15 to 30 cm were worked out for an interval of 15 days for each treatment and the total loss from each layer was determined at the end of the cropping period and expressed in per cent.

**3.3.8 Economic Analysis**

The economics of cultivation of the crop was worked out and the net income and benefit cost ratio (BCR) were calculated as follows.

*3.3.8.1 Net Income*

The net income was calculated by subtracting cost of cultivation from gross income and expressed in ₹ $ha^{-1}$.

*3.3.8.2 Benefit : Cost Ratio*

BCR was worked out as the ratio of gross income to cost of cultivation.

$$\text{B:C ratio} = \frac{\text{Gross income (₹ ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}}$$

**3.3.9 Statistical Analysis**

The data was analysed statistically by applying the techniques of analysis of variance (Panse and Sukhatme, 1985). Wherever the effects were found to be significant, CD values were calculated by using standard technique. Correlation of yield with other major parameters were also worked out.

# Results

# 4. RESULTS

The present study was conducted in the Instructional Farm attached to the College of Agriculture, Vellayani during February 2014 to May 2014 to assess the influence of water and nutrient stress and foliar nutrition on source-sink relationship, productivity and profitability of yard long bean. The experimental data were analyzed statistically and the results are presented below.

## 4.1 GROWTH ATTRIBUTES

### 4.1.1 Number of Primary Branches per Plant

The data on number of primary branches per plant as influenced by treatments are presented in Table 7.

The different levels of irrigation, nitrogen and method of application and their interactions did not have any significant influence on number of branches plant per plant at 30 DAS.

At 60 DAS, number of branches plant per plant was influenced by irrigation levels. Irrigating once in 3 days up to flowering and then in alternate days at 20 mm depth ($I_4$) registered the highest number of branches (10.62) and it was on par with irrigation in alternate days at 20 mm depth ($I_2$). At 90 DAS $I_4$ was observed to be significantly superior to all other treatments.

The nitrogen levels did not influence the number of branches at 60 and 90 DAS.

The influence of method of application was evident only at 90 DAS and soil + foliar application ($M_2$) was significantly superior compared to soil application ($M_1$).

The interaction effect was significant only at 60 DAS where I x N and I x M combinations differed with treatments. Among I x N interactions, $i_4n_0$ registered the highest number of branches (11.50) and was on par with $i_2n_1$.

Regarding I x M combinations, $i_4m_2$ registered the highest number of branches (11.37) and was on par with $i_2m_2$.

**4.1.2 Number of Functional Leaves per Plant**

Observations on number of functional leaves recorded at 30, 60 and 90 DAS are given in Table 8.

Irrigation levels favorably affected the number of functional leaves per plant at 60 and 90 DAS, whereas, the influence was not insignificant at 30 DAS. At 60 DAS and at 90 DAS, daily irrigation at 10 mm depth ($I_1$) was significantly superior to other treatments.

Effect of nitrogen levels was evident only at 90 DAS when recommended dose of N ($N_0$) registered the highest value of 79.16.

In the case of method of application, number of leaves recorded at 60 and 90 DAS was significantly superior in soil + foliar application ($M_2$) over soil application alone ($M_1$).

I x N interaction was significant at 60 DAS and 90 DAS. At 60 DAS, $i_1n_0$ recorded the highest value (83.25) and it was on par with $i_4n_1$ and $i_1n_1$. At 90 DAS also $i_1n_0$ recorded the highest number of functional leaves and was on par with $i_2n_0$.

Number of functional leaves was favorably influenced by I x M interaction at 60 and 90 DAS and N x M interaction at 30 and 90 DAS (Table 10). Among I x M interactions, $i_1m_2$ was superior to other treatments and was on par with $i_4m_2$ at 60 DAS. At 90 DAS also $i_1m_2$ recorded the highest number of functional leaves (89.0) and it was on par with $i_1m_1$, $i_2m_1$ and $i_2m_2$.

In the case of N x M interaction, $n_1m_1$ recorded the highest number of leaves (20.39) and it was on par with $n_0m_2$ at 30 DAS. At 90 DAS, the highest number of leaves was recorded in $n_0m_1$ which was on par with $n_0m_2$ and $n_1m_2$.

Table 7. Effect of irrigation, nitrogen levels and method of application on number of primary branches $plant^{-1}$

| Treatments | 30 DAS | 60 DAS | 90 DAS |
|---|---|---|---|
| Irrigation Levels | | | |
| $I_1$ - Daily at 10 mm depth | 4.0 | 6.75 | 10.69 |
| $I_2$ – Alternate days at 20 mm depth | 4.0 | 10.37 | 11.19 |
| $I_3$ - Once in three days, 20 mm depth | 3.56 | 9.31 | 10.62 |
| $I_4$ - $I_3$ up to flowering followed by $I_2$ | 4.0 | 10.62 | 12.44 |
| SEm (±) | 0.191 | 0.295 | 0.437 |
| CD (0.05) | NS | 0.667 | 0.989 |
| Nitrogen Levels | | | |
| $N_0$ - RD N | 3.78 | 9.44 | 11.28 |
| $N_1$ - 25 % less of RD N | 4.0 | 9.09 | 11.19 |
| SEm (±) | 0.211 | 0.238 | 0.224 |
| CD (0.05) | NS | NS | NS |
| Method of application | | | |
| $M_1$ - Soil application | 3.94 | 9.03 | 11.00 |
| $M_2$ – Soil + foliar application | 3.84 | 9.50 | 11.47 |
| SEm (±) | 0.211 | 0.238 | 0.224 |
| CD (0.05) | NS | NS | 0.454 |

Table 8. Effect of irrigation, nitrogen levels and method of application on number of functional leaves $plant^{-1}$

| Treatments | 30 DAS | 60 DAS | 90 DAS |
|---|---|---|---|
| Irrigation Levels | | | |
| $I_1$ - Daily at 10 mm depth | 20.03 | 81.94 | 87.94 |
| $I_2$ – Alternate days at 20 mm depth | 19.99 | 70.62 | 84.12 |
| $I_3$ - Once in three days, 20 mm depth | 18.37 | 74.25 | 64.81 |
| $I_4$ - $I_3$ up to flowering followed by $I_2$ | 18.97 | 77.56 | 68.75 |
| SEm (±) | 0.681 | 1.800 | 1.571 |
| CD (0.05) | NS | 4.072 | 3.555 |
| Nitrogen Levels | | | |
| $N_0$ - RD N | 19.12 | 75.47 | 79.16 |
| $N_1$ - 25 % less of RD N | 19.56 | 76.72 | 73.66 |
| SEm (±) | 0.438 | 1.083 | 1.291 |
| CD (0.05) | NS | NS | 2.619 |
| Method of application | | | |
| $M_1$ - Soil application | 19.63 | 73.94 | 74.62 |
| $M_2$ – Soil + foliar application | 19.05 | 78.25 | 78.19 |
| SEm (±) | 0.438 | 1.083 | 1.291 |
| CD (0.05) | NS | 2.196 | 2.619 |

Table 9. Interaction effect of irrigation, nitrogen and method of application on number of primary branches plant$^{-1}$

| Treatments | 30 DAS | 60 DAS | 90 DAS |
|---|---|---|---|
| I x N | | | |
| $i_1$ $n_0$ | 3.75 | 6.87 | 11.00 |
| $i_1$ $n_1$ | 4.25 | 6.62 | 10.37 |
| $i_2$ $n_0$ | 3.87 | 9.87 | 11.00 |
| $i_2$ $n_1$ | 4.12 | 10.85 | 11.37 |
| $i_3 n_0$ | 3.37 | 9.50 | 10.62 |
| $i_3$ $n_1$ | 3.75 | 9.12 | 10.62 |
| $i_4$ $n_0$ | 4.12 | 11.50 | 12.50 |
| $i_4$ $n_1$ | 3.87 | 9.75 | 12.37 |
| SEm (±) | 0.421 | 0.475 | 0.448 |
| CD (0.05) | NS | 0.964 | NS |
| I x M | | | |
| $i_1$ $m_1$ | 4.12 | 6.87 | 10.75 |
| $i_1$ $m_2$ | 3.87 | 6.62 | 10.62 |
| $i_2$ $m_1$ | 4.00 | 9.87 | 10.75 |
| $i_2$ $m_2$ | 4.00 | 10.80 | 11.62 |
| $i_3$ $m_1$ | 3.62 | 9.50 | 10.62 |
| $i_3$ $m_2$ | 3.50 | 9.12 | 10.62 |
| $i_4$ $m_1$ | 4.00 | 9.87 | 11.87 |
| $i_4$ $m_2$ | 4.00 | 11.37 | 13.00 |
| SEm (±) | 0.421 | 0.475 | 0.448 |
| CD (0.05) | NS | 0.964 | NS |
| N x M | | | |
| $n_0$ $m_1$ | 3.75 | 9.25 | 11.00 |
| $n_0$ $m_2$ | 3.81 | 9.62 | 11.56 |
| $n_1$ $m_1$ | 4.12 | 8.81 | 11.00 |
| $n_1$ $m_2$ | 3.87 | 9.37 | 11.37 |
| SEm (±) | 0.298 | 0.336 | 0.317 |
| CD (0.05) | NS | NS | NS |
| I x N x M | | | |
| $i_1$ $n_0$ $m_1$ | 3.75 | 7.00 | 11.00 |
| $i_1$ $n_0$ $m_2$ | 3.75 | 6.75 | 11.00 |
| $i_1$ $n_1$ $m_1$ | 4.50 | 6.75 | 10.50 |
| $i_1$ $n_1$ $m_2$ | 4.00 | 6.50 | 10.25 |
| $i_2$ $n_0$ $m_1$ | 3.75 | 9.75 | 11.00 |
| $i_2$ $n_0$ $m_2$ | 4.00 | 10.00 | 11.00 |
| $i_2$ $n_1$ $m_1$ | 4.25 | 10.00 | 10.50 |
| $i_2$ $n_1$ $m_2$ | 4.00 | 11.75 | 12.25 |
| $i_3$ $n_0$ $m_1$ | 3.25 | 10.00 | 10.50 |
| $i_3$ $n_0$ $m_2$ | 3.50 | 9.00 | 10.75 |
| $i_3$ $n_1$ $m_1$ | 4.00 | 9.00 | 10.75 |
| $i_3$ $n_1$ $m_2$ | 3.50 | 9.25 | 10.50 |
| $i_4$ $n_0$ $m_1$ | 4.25 | 10.25 | 11.50 |
| $i_4$ $n_0$ $m_2$ | 4.00 | 12.75 | 13.50 |
| $i_4$ $n_1$ $m_1$ | 3.75 | 9.50 | 12.25 |
| $i_4$ $n_1$ $m_2$ | 4.00 | 10.00 | 12.50 |
| SEm (±) | 0.596 | 0.672 | 0.634 |
| CD (0.05) | NS | NS | NS |

Table 10. Interaction effect of irrigation, nitrogen and method of application on number of functional leaves plant$^{-1}$

| Treatments | 30 DAS | 60 DAS | 90 DAS |
|---|---|---|---|
| I x N | | | |
| $i_1$ $n_0$ | 20.19 | 83.25 | 92.62 |
| $i_1$ $n_1$ | 19.87 | 80.62 | 83.25 |
| $i_2$ $n_0$ | 19.37 | 67.62 | 88.75 |
| $i_2$ $n_1$ | 20.60 | 73.62 | 79.50 |
| $i_3$$n_0$ | 18.94 | 77.87 | 67.37 |
| $i_3$ $n_1$ | 17.81 | 70.62 | 62.25 |
| $i_4$ $n_0$ | 18.00 | 73.12 | 67.87 |
| $i_4$ $n_1$ | 19.94 | 82.00 | 69.62 |
| SEm (±) | 0.875 | 2.166 | 2.583 |
| CD (0.05) | NS | 4.392 | 5.239 |
| I x M | | | |
| $i_1$ $m_1$ | 20.31 | 77.50 | 86.87 |
| $i_1$ $m_2$ | 19.75 | 86.37 | 89.00 |
| $i_2$ $m_1$ | 19.35 | 69.75 | 84.12 |
| $i_2$ $m_2$ | 20.62 | 71.5 | 84.12 |
| $i_3$ $m_1$ | 19.12 | 79.12 | 66.87 |
| $i_3$ $m_2$ | 17.62 | 69.37 | 62.75 |
| $i_4$ $m_1$ | 19.75 | 69.37 | 60.62 |
| $i_4$ $m_2$ | 18.19 | 85.75 | 76.87 |
| SEm (±) | 0.875 | 2.166 | 2.583 |
| CD (0.05) | NS | 4.392 | 5.239 |
| N x M | | | |
| $n_0$ $m_1$ | 18.87 | 72.75 | 79.31 |
| $n_0$ $m_2$ | 19.37 | 78.19 | 79.00 |
| $n_1$ $m_1$ | 20.39 | 75.12 | 69.94 |
| $n_1$ $m_2$ | 18.72 | 78.31 | 77.37 |
| SEm (±) | 0.619 | 1.531 | 1.826 |
| CD (0.05) | 1.255 | NS | 2.359 |
| I x N x M | | | |
| $i_1$ $n_0$ $m_1$ | 19.87 | 78.25 | 98.25 |
| $i_1$ $n_0$ $m_2$ | 20.50 | 88.25 | 87.00 |
| $i_1$ $n_1$ $m_1$ | 20.75 | 76.75 | 75.50 |
| $i_1$ $n_1$ $m_2$ | 19.00 | 84.50 | 91.00 |
| $i_2$ $n_0$ $m_1$ | 18.37 | 72.75 | 90.50 |
| $i_2$ $n_0$ $m_2$ | 20.37 | 62.50 | 87.00 |
| $i_2$ $n_1$ $m_1$ | 20.32 | 66.75 | 77.75 |
| $i_2$ $n_1$ $m_2$ | 20.87 | 80.50 | 81.25 |
| $i_3$ $n_0$ $m_1$ | 19.00 | 80.75 | 71.25 |
| $i_3$ $n_0$ $m_2$ | 18.87 | 75.00 | 63.50 |
| $i_3$ $n_1$ $m_1$ | 19.25 | 77.50 | 62.50 |
| $i_3$ $n_1$ $m_2$ | 16.37 | 63.75 | 62.00 |
| $i_4$ $n_0$ $m_1$ | 18.25 | 59.25 | 57.25 |
| $i_4$ $n_0$ $m_2$ | 17.75 | 87.00 | 78.50 |
| $i_4$ $n_1$ $m_1$ | 21.25 | 79.50 | 64.00 |
| $i_4$ $n_1$ $m_2$ | 18.62 | 84.50 | 75.25 |
| SEm (±) | 1.238 | 3.063 | 3.653 |
| CD (0.05) | NS | 6.211 | 7.409 |

The I x N x M interaction exerted a favorable influence on functional leaves at 60 and 90 DAS. At 60 DAS $i_1n_0m_2$ had the highest number of functional leaves (88.25) and it was on par with $i_4n_0m_2$, $i_1n_1m_2$ and $i_4n_1m_2$. At 90 DAS, $i_1n_0m_1$ recorded the highest value (98.25) and was on par with $i_2n_0m_1$.

**4.1.3 Leaf Area Index at Flowering (LAI)**

Table 11 depicts the values of LAI at flowering.

The main plot treatments exerted a significant influence on LAI of yard long bean at flowering stage. Daily irrigation at 10 mm depth ($I_1$) was significantly superior to all other treatments and recorded the highest LAI of 1.56.

Both the sub plot treatments had a favorable influence on LAI at flowering. Recommended dose of N ($N_0$) was significantly superior to 25 per cent less of RD N ($N_1$). Among the methods of application, soil + foliar application of N and K ($M_2$) registered superior LAI (1.28) over soil application ($M_1$).

Among the interactions, I x N, I x M and N x M combinations had significant influence on this character. Considering I x N interactions, daily irrigation with RD N ($i_1n_0$) was significantly superior over other combinations. In the case of I x M interaction, $i_1m_2$ recorded maximum LAI and was on par with $i_1m_1$. Regarding N x M combinations, the highest LAI was registered in $n_0m_2$ and was significantly superior to other combinations.

The LAI at flowering was not influenced by I x N x M interaction.

**4.1.4 Days to 50 Percentage Flowering**

Observations on effect of different treatments on number of days for 50 per cent flowering are presented in Table 11.

Irrigation levels had a favorable influence on the number of days to 50 per cent flowering. Irrigating once in three days @ 20mm depth ($I_3$) recorded the lowest number of days to attain 50 per cent flowering, (39.19) and all other treatments were on par and required more duration for 50 per cent flowering.

Nitrogen levels also influenced the duration for 50 per cent flowering of the crop. Application of N @ 25 per cent less of RD ($N_1$) resulted in early flowering compared to RD N ($N_0$).

Methods of application had no influence on the number of day for 50 per cent flowering.

Among the combinations, only N x M interaction exerted a favorable influence on days for 50 per cent flowering. The treatment $n_1m_1$ recorded the shortest duration to attain 50 per cent flowering (39.37).

**4.1.5 Crop Duration**

The results in Table 11 revealed that the main plot treatments and the sub plot treatments imparted a significant influence on crop duration.

Among the main plot treatments, daily irrigation ($I_1$) resulted in the longest crop duration (104.87 days) and this was followed by irrigation in alternate days ($I_2$). In the case of nitrogen levels, crop duration was significantly higher under recommended N level ($N_0$). The method of application also influenced the duration of the crop. Crop duration was more (99.44 days) in soil + foliar application ($M_2$) which was significantly superior over soil application alone ($M_1$).

Among the interactions, I x N, I x M and I x N x M interactions were significant. In the case of I x N combinations, $i_1n_0$, recorded the longest duration (106.12 days) whereas, $i_4n_1$ recorded the shortest (94.62 days). Among I x M interactions, $i_1m_2$ recorded the longest duration and the shortest duration was noted in $i_4m_1$. In the case of I x N x M combinations, the longest duration was recorded by $i_1n_0m_2$ which was significantly superior to all other combinations.

#### 4.1.6 Number of Pickings

The data in Table 11 indicated that though irrigation and nitrogen levels had significant effect on number of pod picking, methods of application and its interaction with nitrogen levels did not exert any significant influence.

The highest number of picking (20.97) was noted in daily irrigation at 10 mm depth ($I_1$) which was significantly higher than other treatments. The lowest picking number was observed in irrigating once in three days @ 20 mm depth ($I_3$)

Providing N at the recommended dose ($N_0$) recorded more number of picking over N application @ 25 per cent less of RD ($N_1$).

Combination of irrigation with nitrogen levels and irrigation with methods of application had a favorable impact on number of picking.

Among I x N, $i_1n_0$ recorded the highest number of pickings (21.90) and $i_3n_1$ registered the lowest (17.95). Considering I x M combinations $i_1m_1$ recorded the highest number of picking and was on par with $i_1m_2$. The lowest picking was observed in $i_3m_1$ which was on par with $i_3m_2$.

#### 4.1.7 Dry Matter Partitioning

The influence of treatments on dry matter partitioning is presented in Table 12.

Daily irrigation at 10 mm depth ($I_1$) was significantly superior to other treatments on leaf, stem and total dry matter production. This was on par with irrigating in alternate days ($I_2$) in stem dry matter production. Root and pod dry matter production were not influenced by irrigation levels.

Nitrogen levels significantly influenced the leaf and total dry matter production where RD N ($N_0$) was significantly superior to 25 per cent less of RD N ($N_1$).

Dry matter accumulation in pods and total dry matter production were influenced by method of nutrient application, where soil application ($M_1$) was observed to be superior to soil + foliar application ($M_2$).

Table 11. Effect of irrigation, nitrogen levels and method of application on LAI, days to 50 per cent flowering, crop duration and number of pickings

| Treatments | LAI | Days to 50 % flowering | Crop duration | No. of pickings |
|---|---|---|---|---|
| Irrigation Levels | | | | |
| $I_1$ - Daily at 10 mm depth | 1.56 | 40.62 | 104.87 | 20.97 |
| $I_2$ – Alternate days at 20 mm depth | 1.18 | 40.75 | 98.25 | 20.07 |
| $I_3$ - Once in three days, 20 mm depth | 1.07 | 39.19 | 97.00 | 18.49 |
| $I_4$ - $I_3$ up to flowering followed by $I_2$ | 1.06 | 40.19 | 95.25 | 19.49 |
| SEm (±) | 0.026 | 0.273 | 0.153 | 0.201 |
| CD (0.05) | 0.060 | 0.618 | 0.346 | 0.455 |
| Nitrogen Levels | | | | |
| $N_0$ – Recommended N dose | 1.40 | 40.44 | 100.06 | 20.02 |
| $N_1$ - - 25 % Recommended dose | 1.03 | 39.94 | 97.62 | 19.49 |
| SEm (±) | 0.016 | 0.233 | 0.175 | 0.139 |
| CD (0.05) | 0.033 | 0.473 | 0.356 | 0.282 |
| Method of application | | | | |
| $M_1$ - Soil application | 1.15 | 39.97 | 98.25 | 19.67 |
| $M_2$ – Soil + foliar application | 1.28 | 40.41 | 99.44 | 19.84 |
| SEm (±) | 0.016 | 0.233 | 0.175 | 0.139 |
| CD (0.05) | 0.033 | NS | 0.356 | NS |

Table 12. Effect of irrigation, nitrogen levels and method of application on dry matter partitioning, q ha$^{-1}$

| Treatments | Leaf | Stem | Root | Pod | Total |
|---|---|---|---|---|---|
| Irrigation Levels | | | | | |
| $I_1$ - Daily at 10 mm depth | 11.74 | 22.93 | 1.38 | 13.71 | 49.76 |
| $I_2$ – Alternate days at 20 mm depth | 10.97 | 22.53 | 1.51 | 13.29 | 48.29 |
| $I_3$ - Once in three days, 20 mm depth | 10.11 | 20.15 | 1.41 | 13.60 | 45.28 |
| $I_4$ - $I_3$ up to flowering followed by $I_2$ | 11.23 | 21.39 | 1.44 | 13.46 | 47.51 |
| SEm (±) | 0.128 | 0.387 | 0.392 | 0.251 | 0.273 |
| CD (0.05) | 0.290 | 0.876 | NS | NS | 0.619 |
| Nitrogen Levels | | | | | |
| $N_0$ - RD N | 11.49 | 21.87 | 1.47 | 13.49 | 48.33 |
| $N_1$ - 25 % less of RD N | 10.53 | 21.63 | 1.40 | 13.53 | 47.10 |
| SEm (±) | 0.109 | 0.196 | 0.500 | 0.149 | 0.335 |
| CD (0.05) | 0.221 | NS | NS | NS | 0.679 |
| Method of application | | | | | |
| $M_1$ - Soil application | 11.03 | 21.85 | 1.42 | 14.26 | 48.57 |
| $M_2$ – Soil + foliar application | 10.99 | 21.64 | 1.45 | 12.77 | 46.85 |
| SEm (±) | 0.109 | 0.196 | 0.500 | 0.149 | 0.335 |
| CD (0.05) | NS | NS | NS | 0.302 | 0.679 |

Table 13. Interaction effect of irrigation, nitrogen and method of application on LAI, days to 50 per cent flowering, crop duration and number of pickings

| Treatments | LAI | Days to 50 % flowering | Crop duration | No. of pickings |
|---|---|---|---|---|
| I x N | | | | |
| $i_1 n_0$ | 1.71 | 40.87 | 106.12 | 21.90 |
| $i_1 n_1$ | 1.40 | 40.37 | 103.62 | 20.05 |
| $i_2 n_0$ | 1.33 | 41.25 | 100.25 | 20.10 |
| $i_2 n_1$ | 1.02 | 40.25 | 96.25 | 20.05 |
| $i_3 n_0$ | 1.28 | 39.50 | 98.00 | 19.02 |
| $i_3 n_1$ | 0.85 | 38.87 | 96.00 | 17.95 |
| $i_4 n_0$ | 1.26 | 40.12 | 95.87 | 19.05 |
| $i_4 n_1$ | 0.85 | 40.25 | 94.62 | 19.92 |
| SEm (±) | 0.032 | 0.467 | 0.351 | 0.278 |
| CD (0.05) | 0.066 | NS | 0.712 | 0.565 |
| I x M | | | | |
| $i_1 m_1$ | 1.53 | 40.62 | 104.12 | 21.21 |
| $i_1 m_2$ | 1.58 | 40.62 | 105.62 | 20.74 |
| $i_2 m_1$ | 1.14 | 40.50 | 98.00 | 19.70 |
| $i_2 m_2$ | 1.22 | 41.00 | 98.50 | 20.45 |
| $i_3 m_1$ | 0.98 | 38.75 | 96.00 | 18.47 |
| $i_3 m_2$ | 1.16 | 39.62 | 98.00 | 18.50 |
| $i_4 m_1$ | 0.94 | 40.00 | 94.87 | 19.30 |
| $i_4 m_2$ | 1.17 | 40.37 | 95.62 | 19.67 |
| SEm (±) | 0.032 | 0.467 | 0.351 | 0.278 |
| CD (0.05) | 0.066 | NS | 0.712 | 0.565 |
| N x M | | | | |
| $n_0 m_1$ | 1.35 | 40.56 | 99.37 | 19.91 |
| $n_0 m_2$ | 1.44 | 40.31 | 100.75 | 20.13 |
| $n_1 m_1$ | 0.94 | 39.37 | 97.12 | 19.44 |
| $n_1 m_2$ | 1.12 | 40.50 | 98.12 | 19.55 |
| SEm (±) | 0.023 | 0.330 | 0.248 | 0.197 |
| CD (0.05) | 0.046 | 0.669 | NS | NS |
| I x N x M | | | | |
| $i_1 n_0 m_1$ | 1.70 | 41.25 | 105.50 | 21.92 |
| $i_1 n_0 m_2$ | 1.72 | 40.50 | 106.75 | 21.87 |
| $i_1 n_1 m_1$ | 1.37 | 40.00 | 102.75 | 20.50 |
| $i_1 n_1 m_2$ | 1.43 | 40.75 | 104.50 | 19.60 |
| $i_2 n_0 m_1$ | 1.30 | 41.50 | 98.75 | 19.70 |
| $i_2 n_0 m_2$ | 1.36 | 41.00 | 101.75 | 20.50 |
| $i_2 n_1 m_1$ | 0.97 | 39.50 | 97.25 | 19.70 |
| $i_2 n_1 m_2$ | 1.07 | 41.00 | 95.25 | 20.40 |
| $i_3 n_0 m_1$ | 1.22 | 39.00 | 97.75 | 18.90 |
| $i_3 n_0 m_2$ | 1.34 | 40.00 | 98.25 | 19.15 |
| $i_3 n_1 m_1$ | 0.73 | 38.50 | 94.25 | 18.05 |
| $i_3 n_1 m_2$ | 0.97 | 39.25 | 97.75 | 17.85 |
| $i_4 n_0 m_1$ | 1.18 | 40.50 | 95.50 | 19.10 |
| $i_4 n_0 m_2$ | 1.33 | 39.75 | 96.25 | 19.00 |
| $i_4 n_1 m_1$ | 0.70 | 39.50 | 94.25 | 19.50 |
| $i_4 n_1 m_2$ | 1.01 | 41.00 | 95.00 | 20.35 |
| SEm (±) | 0.046 | 0.660 | 0.496 | 0.394 |
| CD (0.05) | NS | NS | 1.007 | NS |

Table 14. Interaction effect of irrigation, nitrogen and method of application on dry matter partitioning, q ha$^{-1}$

| Treatments | Leaf | Stem | Root | Pod | Total |
|---|---|---|---|---|---|
| I x N | | | | | |
| $i_1 n_0$ | 12.35 | 22.52 | 1.47 | 14.07 | 50.41 |
| $i_1 n_1$ | 11.14 | 23.33 | 1.29 | 13.35 | 49.11 |
| $i_2 n_0$ | 11.57 | 22.85 | 1.48 | 12.67 | 48.58 |
| $i_2 n_1$ | 10.37 | 22.20 | 1.53 | 13.90 | 48.00 |
| $i_3 n_0$ | 10.55 | 20.29 | 1.39 | 13.18 | 45.42 |
| $i_3 n_1$ | 9.67 | 20.01 | 1.44 | 14.03 | 45.15 |
| $i_4 n_0$ | 11.52 | 21.80 | 1.53 | 14.05 | 48.90 |
| $i_4 n_1$ | 10.94 | 20.97 | 1.35 | 12.86 | 46.13 |
| SEm (±) | 0.218 | 0.393 | 0.100 | 0.298 | 0.669 |
| CD (0.05) | NS | 0.796 | NS | 0.604 | NS |
| I x M | | | | | |
| $i_1 m_1$ | 11.90 | 23.55 | 1.35 | 14.08 | 50.88 |
| $i_1 m_2$ | 11.59 | 22.30 | 1.40 | 13.34 | 48.64 |
| $i_2 m_1$ | 10.89 | 22.59 | 1.56 | 13.99 | 49.02 |
| $i_2 m_2$ | 11.05 | 22.47 | 1.46 | 12.58 | 47.56 |
| $i_3 m_1$ | 10.01 | 20.21 | 1.39 | 14.74 | 46.37 |
| $i_3 m_2$ | 10.21 | 20.09 | 1.43 | 12.47 | 44.20 |
| $i_4 m_1$ | 11.34 | 21.07 | 1.37 | 14.23 | 48.00 |
| $i_4 m_2$ | 11.12 | 21.71 | 1.50 | 12.69 | 47.03 |
| SEm (±) | 0.218 | 0.393 | 0.100 | 0.298 | 0.669 |
| CD (0.05) | NS | 0.796 | NS | 0.604 | NS |
| N x M | | | | | |
| $n_0 m_1$ | 11.71 | 22.31 | 1.47 | 13.92 | 49.41 |
| $n_0 m_2$ | 11.28 | 21.42 | 1.47 | 13.07 | 47.24 |
| $n_1 m_1$ | 10.35 | 21.40 | 1.37 | 14.60 | 47.73 |
| $n_1 m_2$ | 10.71 | 21.86 | 1.44 | 12.47 | 46.47 |
| SEm (±) | 0.154 | 0.278 | 0.071 | 0.21 | 0.473 |
| CD (0.05) | 0.313 | 0.563 | NS | 0.427 | NS |
| I x N x M | | | | | |
| $i_1 n_0 m_1$ | 12.57 | 23.40 | 1.54 | 14.43 | 51.95 |
| $i_1 n_0 m_2$ | 12.12 | 21.64 | 1.40 | 13.71 | 48.87 |
| $i_1 n_1 m_1$ | 11.22 | 23.69 | 1.17 | 13.73 | 49.82 |
| $i_1 n_1 m_2$ | 11.06 | 22.97 | 1.41 | 12.96 | 48.4 |
| $i_2 n_0 m_1$ | 11.98 | 23.70 | 1.48 | 12.86 | 50.02 |
| $i_2 n_0 m_2$ | 11.16 | 22.01 | 1.49 | 12.49 | 47.15 |
| $i_2 n_1 m_1$ | 9.79 | 21.47 | 1.64 | 15.12 | 48.03 |
| $i_2 n_1 m_2$ | 10.95 | 22.93 | 1.42 | 12.68 | 47.98 |
| $i_3 n_0 m_1$ | 10.73 | 20.72 | 1.38 | 13.96 | 46.80 |
| $i_3 n_0 m_2$ | 10.37 | 19.87 | 1.40 | 12.40 | 44.04 |
| $i_3 n_1 m_1$ | 9.30 | 19.71 | 1.40 | 15.52 | 45.94 |
| $i_3 n_1 m_2$ | 10.04 | 20.31 | 1.47 | 12.53 | 44.35 |
| $i_4 n_0 m_1$ | 11.57 | 21.41 | 1.48 | 14.42 | 48.89 |
| $i_4 n_0 m_2$ | 11.46 | 22.19 | 1.57 | 13.69 | 48.91 |
| $i_4 n_1 m_1$ | 11.10 | 20.72 | 1.26 | 14.04 | 47.12 |
| $i_4 n_1 m_2$ | 10.78 | 21.23 | 1.45 | 11.69 | 45.15 |
| SEm (±) | 0.309 | 0.555 | 0.141 | 0.421 | 0.947 |
| CD (0.05) | 0.627 | 1.126 | NS | NS | NS |

I x N interaction showed significant influence on dry matter production by stem and pod. In the case of stem, $i_1n_1$ was significantly superior, which was on par with $i_2n_0$. In the case of pod $i_1n_0$ was superior and was on par with $i_4n_0$, $i_3n_1$ and $i_2n_1$.

I x M interaction was significant for dry matter production by stem and pod. In the case of stem, $i_1m_1$ was significantly superior whereas in pod, $i_3m_1$ was superior and was on par with $i_4m_1$.

N x M combination was significant for dry matter accumulation in leaf, stem and pod. $n_0m_1$ recorded the highest dry matter production by leaf and stem and it was on par with $n_1m_2$ in the case of stem dry matter production. The combination $n_1m_1$ recorded the highest dry matter accumulation by pod.

I x N x M interaction was found to be significant for dry matter accumulation in leaf and stem. The combinations $i_1n_0m_1$, $i_1n_0m_2$ and $i_2n_0m_1$ were on par and recorded higher leaf dry matter production. In stem dry matter production $i_2n_0m_1$ registered the highest and was on par with $i_1n_1m_1$, $i_1n_0m_1$, $i_1n_1m_2$ and $i_2n_1m_2$.

## 4.2 YIELD ATTRIBUTES AND YIELD

### 4.2.1 Flowers per Inflorescence and Setting Percentage

The data presented in Table 15 revealed that irrigation levels had no influence on both flower number per inflorescence and setting percentage.

Nitrogen levels influenced the flower number per inflorescence but had no effect on setting percentage. Application of RD N ($N_0$) registered higher number of flowers per inflorescence than 25 per cent less of RD N ($N_1$). The method of application significantly influenced both these characters. Though soil + foliar application of N and K ($M_2$) recorded more flowers per inflorescence (7.32), the setting percentage was significantly superior (74.21 per cent) for soil application of N and K ($M_1$).

Among the interactions, only N x M interaction influenced the number of flowers per inflorescence where $n_0m_2$ was superior and was on par with $n_0m_1$ and $n_1m_2$. In the case of setting percentage, only I x N interaction was significant; $i_2n_1$ registered the highest setting percentage and it was on par with $i_1n_0$ and $i_3n_1$.

### 4.2.2 Peduncle Length

Among the treatments only N levels had a significant influence on peduncle length. Application of RD N ($N_0$) resulted in longer peduncle (17.44 cm) than 25 per cent less of RD N ($N_1$).

Among the combinations, I x M, N x M and I x N x M were significant. Irrigating once in three days at 20 mm depth with soil + foliar application of N and K fertilizers ($i_3m_2$) recorded the longest peduncle, which was on par with $i_4m_1$, $i_2m_2$, $i_2m_1$ and $i_1m_1$. In the case of N x M, $n_0m_1$ was significantly superior to other treatments. In the case of I x N x M interactions, $i_2n_0m_1$ recorded the highest value for peduncle length (19.54 cm) which was on par with $i_4n_0m_1$.

### 4.2.3. Pod Characteristics

Data on pod characteristics of yard long bean are given in Table 16 .

Pod length and pod girth were significantly influenced by irrigation levels, but pod weight did not show any influence. Irrigating once in three days up to flowering and then in alternate days at 20 mm depth ($I_4$) recorded the longest pods (47.62 cm) and it was significantly superior. Girth of the pod was significantly increased (2.63 cm) by daily irrigation at 10 mm depth ($I_1$) which was on par with irrigating once in three days at 20 mm depth ($I_3$).

Though varying N levels influenced the pod length, pod girth and pod weight were unaffected. Recommended dose of N ($N_0$) produced longer pods than 25 per cent less of RD N ($N_1$).

Table 15. Effect of irrigation, nitrogen levels and method of application on flowers inflorescence$^{-1}$, setting percentage and peduncle length

| Treatments | Flowers inflorescence$^{-1}$ | Setting % | Peduncle length (cm) |
|---|---|---|---|
| Irrigation Levels | | | |
| $I_1$ - Daily at 10 mm depth | 7.27 | 71.46 | 16.51 |
| $I_2$ – Alternate days at 20 mm depth | 7.33 | 72.13 | 16.89 |
| $I_3$ - Once in three days, 20 mm depth | 6.81 | 70.72 | 16.65 |
| $I_4$ - $I_3$ up to flowering followed by $I_2$ | 7.24 | 69.12 | 16.52 |
| SEm (±) | 0.209 | 1.174 | 0.452 |
| CD (0.05) | NS | NS | NS |
| Nitrogen Levels | | | |
| $N_0$ - RD N | 7.32 | 70.71 | 17.44 |
| $N_1$ - 25 % less of RD N | 7.01 | 71.00 | 15.84 |
| SEm (±) | 0.132 | 1.083 | 0.193 |
| CD (0.05) | 0.267 | NS | 0.392 |
| Method of application | | | |
| $M_1$ - Soil application | 7.01 | 74.21 | 16.60 |
| $M_2$ – Soil + foliar application | 7.32 | 67.51 | 16.68 |
| SEm (±) | 0.132 | 1.083 | 0.193 |
| CD (0.05) | 0.267 | 2.196 | NS |

Table 16. Effect of irrigation, nitrogen levels and method of application on pod characteristics

| Treatments | Pod length (cm) | Pod girth (cm) | Pod weight (g) |
|---|---|---|---|
| Irrigation Levels | | | |
| $I_1$ - Daily at 10 mm depth | 45.75 | 2.63 | 18.53 |
| $I_2$ – Alternate days at 20 mm depth | 46.11 | 2.48 | 18.51 |
| $I_3$ - Once in three days, 20 mm depth | 45.42 | 2.58 | 18.53 |
| $I_4$ - $I_3$ up to flowering followed by $I_2$ | 47.62 | 2.54 | 18.46 |
| SEm (±) | 0.522 | 0.034 | 0.055 |
| CD (0.05) | 1.182 | 0.077 | NS |
| Nitrogen Levels | | | |
| $N_0$ - RD N | 46.91 | 2.542 | 18.51 |
| $N_1$ - 25 % less of RD N | 45.53 | 2.570 | 18.50 |
| SEm (±) | 0.397 | 0.020 | 0.038 |
| CD (0.05) | 0.805 | NS | NS |
| Method of application | | | |
| $M_1$ - Soil application | 46.17 | 2.566 | 18.55 |
| $M_2$ – Soil + foliar application | 46.27 | 2.546 | 18.46 |
| SEm (±) | 0.397 | 0.020 | 0.038 |
| CD (0.05) | NS | NS | 0.078 |

Table 17. Interaction effect of irrigation, nitrogen and method of application on flowers inflorescence$^{-1}$, setting percentage and peduncle length

| Treatments | Flowers inflorescence$^{-1}$ | Setting % | Peduncle length (cm) |
|---|---|---|---|
| I x N | | | |
| $i_1$ $n_0$ | 7.48 | 74.02 | 17.51 |
| $i_1$ $n_1$ | 7.06 | 68.89 | 15.51 |
| $i_2$ $n_0$ | 7.39 | 68.21 | 17.68 |
| $i_2$ $n_1$ | 7.28 | 76.05 | 16.10 |
| $i_3n_0$ | 7.03 | 69.01 | 17.26 |
| $i_3$ $n_1$ | 6.60 | 72.42 | 16.04 |
| $i_4$ $n_0$ | 7.39 | 71.60 | 17.31 |
| $i_4$ $n_1$ | 7.10 | 66.64 | 15.74 |
| SEm (±) | 0.264 | 2.166 | 0.387 |
| CD (0.05) | NS | 4.392 | NS |
| I x M | | | |
| $i_1$ $m_1$ | 7.10 | 72.54 | 16.61 |
| $i_1$ $m_2$ | 7.44 | 70.38 | 16.41 |
| $i_2$ $m_1$ | 7.19 | 75.29 | 16.86 |
| $i_2$ $m_2$ | 7.48 | 68.97 | 16.92 |
| $i_3$ $m_1$ | 6.60 | 74.96 | 15.90 |
| $i_3$ $m_2$ | 7.03 | 66.47 | 17.39 |
| $i_4$ $m_1$ | 7.14 | 74.04 | 17.06 |
| $i_4$ $m_2$ | 7.35 | 64.20 | 15.99 |
| SEm (±) | 0.264 | 2.166 | 0.387 |
| CD (0.05) | NS | NS | 0.784 |
| N x M | | | |
| $n_0$ $m_1$ | 7.31 | 72.99 | 18.37 |
| $n_0$ $m_2$ | 7.33 | 68.43 | 16.52 |
| $n_1$ $m_1$ | 6.71 | 66.58 | 14.84 |
| $n_1$ $m_2$ | 7.31 | 66.58 | 16.84 |
| SEm (±) | 0.186 | 1.531 | 0.273 |
| CD (0.05) | 0.378 | NS | 0.555 |
| I x N x M | | | |
| $i_1$ $n_0$ $m_1$ | 7.48 | 75.00 | 18.13 |
| $i_1$ $n_0$ $m_2$ | 7.48 | 73.05 | 16.90 |
| $i_1$ $n_1$ $m_1$ | 6.73 | 70.09 | 15.09 |
| $i_1$ $n_1$ $m_2$ | 7.4 | 67.71 | 15.92 |
| $i_2$ $n_0$ $m_1$ | 7.48 | 69.28 | 19.54 |
| $i_2$ $n_0$ $m_2$ | 7.3 | 67.14 | 15.82 |
| $i_2$ $n_1$ $m_1$ | 6.9 | 81.30 | 14.17 |
| $i_2$ $n_1$ $m_2$ | 7.65 | 70.80 | 18.02 |
| $i_3$ $n_0$ $m_1$ | 6.73 | 71.42 | 17.01 |
| $i_3$ $n_0$ $m_2$ | 7.33 | 66.60 | 17.50 |
| $i_3$ $n_1$ $m_1$ | 6.48 | 78.50 | 14.79 |
| $i_3$ $n_1$ $m_2$ | 6.73 | 66.35 | 17.29 |
| $i_4$ $n_0$ $m_1$ | 7.55 | 76.25 | 18.79 |
| $i_4$ $n_0$ $m_2$ | 7.23 | 66.95 | 15.84 |
| $i_4$ $n_1$ $m_1$ | 6.73 | 71.83 | 15.32 |
| $i_4$ $n_1$ $m_2$ | 7.48 | 61.46 | 16.15 |
| SEm (±) | 0.373 | 3.063 | 0.547 |
| CD (0.05) | NS | NS | 1.109 |

Table 18. Interaction effect of irrigation, nitrogen and method of application on pod characteristics

| Treatments | Pod length (cm) | Pod girth (cm) | Pod weight (g) |
|---|---|---|---|
| I x N | | | |
| $i_1$ $n_0$ | 47.11 | 2.62 | 18.49 |
| $i_1$ $n_1$ | 44.38 | 2.63 | 18.57 |
| $i_2$ $n_0$ | 47.29 | 2.49 | 18.53 |
| $i_2$ $n_1$ | 44.93 | 2.48 | 18.48 |
| $i_3n_0$ | 45.16 | 2.56 | 18.56 |
| $i_3$ $n_1$ | 45.67 | 2.59 | 18.51 |
| $i_4$ $n_0$ | 48.08 | 2.50 | 18.46 |
| $i_4$ $n_1$ | 47.16 | 2.57 | 18.46 |
| SEm (±) | 0.794 | 0.041 | 0.077 |
| CD (0.05) | 1.610 | NS | NS |
| I x M | | | |
| $i_1$ $m_1$ | 45.51 | 2.67 | 18.57 |
| $i_1$ $m_2$ | 45.98 | 2.58 | 18.49 |
| $i_2$ $m_1$ | 45.51 | 2.48 | 18.53 |
| $i_2$ $m_2$ | 46.71 | 2.49 | 18.48 |
| $i_3$ $m_1$ | 45.92 | 2.65 | 18.58 |
| $i_3$ $m_2$ | 44.92 | 2.50 | 18.49 |
| $i_4$ $m_1$ | 47.75 | 2.47 | 18.54 |
| $i_4$ $m_2$ | 47.49 | 2.61 | 18.38 |
| SEm (±) | 0.794 | 0.04105 | 0.077 |
| CD (0.05) | NS | 0.083 | NS |
| N x M | | | |
| $n_0$ $m_1$ | 46.08 | 2.52 | 18.57 |
| $n_0$ $m_2$ | 47.74 | 2.56 | 18.45 |
| $n_1$ $m_1$ | 46.26 | 2.61 | 18.54 |
| $n_1$ $m_2$ | 44.81 | 2.53 | 18.46 |
| SEm (±) | 0.561 | 0.029 | 0.054 |
| CD (0.05) | 1.138 | 0.059 | NS |
| I x N x M | | | |
| $i_1$ $n_0$ $m_1$ | 45.57 | 2.60 | 18.57 |
| $i_1$ $n_0$ $m_2$ | 48.65 | 2.63 | 18.41 |
| $i_1$ $n_1$ $m_1$ | 45.45 | 2.74 | 18.57 |
| $i_1$ $n_1$ $m_2$ | 43.30 | 2.53 | 18.56 |
| $i_2$ $n_0$ $m_1$ | 45.29 | 2.42 | 18.53 |
| $i_2$ $n_0$ $m_2$ | 49.29 | 2.56 | 18.53 |
| $i_2$ $n_1$ $m_1$ | 45.72 | 2.54 | 18.53 |
| $i_2$ $n_1$ $m_2$ | 44.13 | 2.42 | 18.44 |
| $i_3$ $n_0$ $m_1$ | 46.39 | 2.64 | 18.64 |
| $i_3$ $n_0$ $m_2$ | 43.93 | 2.48 | 18.47 |
| $i_3$ $n_1$ $m_1$ | 45.44 | 2.66 | 18.51 |
| $i_3$ $n_1$ $m_2$ | 45.91 | 2.53 | 18.50 |
| $i_4$ $n_0$ $m_1$ | 47.07 | 2.42 | 18.52 |
| $i_4$ $n_0$ $m_2$ | 49.09 | 2.58 | 18.40 |
| $i_4$ $n_1$ $m_1$ | 48.42 | 2.51 | 18.56 |
| $i_4$ $n_1$ $m_2$ | 45.90 | 2.64 | 18.36 |
| SEm (±) | 1.122 | 0.058 | 0.109 |
| CD (0.05) | 2.277 | 0.118 | NS |

Pod length and pod girth were unaffected by method of application, while it had a significant influence on pod weight. Applying N and K fertilizers through soil alone ($M_1$) recorded higher weight of pods than soil + foliar application ($M_2$).

Among the pod characters, I x N interaction significantly influenced the pod length only. The combination $i_4n_0$ recorded the highest pod length which was on par with $i_2n_0$, $i_4n_1$ and $i_1n_0$.

I x M combinations influenced only the pod girth. $i_1m_1$ recorded the highest girth which was on par with $i_3m_1$ and $i_4m_2$. N x M interaction influenced both pod length and pod girth. In the case of pod length, $n_0m_2$ recorded the longest pods (47.74 cm) which was significantly superior, whereas in case of pod girth, $n_1m_1$ recorded the highest value and was on par with $n_0m_2$.

I x N x M combinations influenced pod length and pod girth favorably, but not pod weight. $i_2n_0m_2$ recorded the highest pod length which was on par with $i_4n_0m_2$, $i_1n_0m_2$, $i_4n_1m_1$ and $i_4n_0m_1$. In the case of pod girth, $i_1n_1m_1$ recorded the highest value which was on par with $i_3n_1m_1$, $i_3n_0m_1$, $i_4n_1m_2$ and $i_1n_0m_2$.

### 4.2.4 Pod yield per harvest

The data on pod yield per plot per harvest (Table 19) revealed that there was variation in the yield during the initial and final harvests. In $I_3$ (irrigation once in three days) and $I_4$ (irrigation once in three days up to flowering followed by irrigation in alternate days) the yield in the initial harvests were higher, while in daily irrigation ($I_1$) and irrigation in alternate days ($I_2$), the yield in the later harvests were higher.

### 4.2.5 Pods per Plant

The data presented in Table 20 revealed that only the method of application and various combinations of I, N and M had a favorable influence on pod number $plant^{-1}$.

Soil application of N and K recorded significantly higher pod number (47.68) over soil + foliar application.

Combinations of I x N, I x M and N x M were found to be significant. $i_2n_1$ was superior among I x N interactions, which was on par with $i_3n_1$, $i_1n_0$ and $i_4n_0$. In the case I x M interactions, $i_3m_1$, $i_4m_1$ and $i_1m_1$ recorded higher pod number and were on par.

The combination $n_1m_1$ recorded higher values of both the characters in the case of N x M interaction. I x N x M interaction was not significant for the character.

### 4.2.6 Pod Yield per Plant

The trend observed in pod number per plant was followed in pod yield per plant also. Only the method of application and various combinations of I, N and M had a favorable influence on pod yield plant per plant.

Soil application of N and K recorded significantly higher pod yield per plant (618.96 g) over soil + foliar application.

Combinations of I x N, I x M and N x M were found to be significant. $i_2n_1$ was superior among I x N interactions, which was on par with $i_3n_1$, $i_1n_0$ and $i_4n_0$. Regarding I x M interactions, $i_3m_1$, $i_4m_1$ and $i_1m_1$ recorded higher pod yield and were on par.

The combination $n_1m_1$ recorded higher values of both the characters in the case of N x M interaction. The I x N x M interaction was non-significant

### 4.2.7 Total Pod Yield

The yield data in Table 20 revealed that different levels of irrigation and nitrogen did not have any significant influence on pod yield. However, the method of application had a favorable influence on pod yield. Soil application of N and K was found superior and registered a yield of 100.03 q $ha^{-1}$.

Among the interactions, I x N, I x M and N x M had significant influence on pod yield. $i_2n_1$ was superior among i x n combinations which was on par with $i_3n_1$, $i_1n_0$ and $i_4n_0$. Among I x M interactions, $i_3m_1$ was found significantly superior and among N x M interactions $n_1m_1$ was found superior. Pod yield was not influenced by I x N x M interaction.

**4.2.8 Source : Sink Ratio**

Results given in Table 21 revealed that both the main effects and their interactions significantly influenced the source : sink ratio.

Irrigating at 20 mm depth once in three days ($I_3$) recorded ideal source : sink ratio (0.75) while daily irrigation at 10 mm depth ($I_1$) recorded the highest ratio which was on par with irrigating in alternate days ($I_2$) and irrigating once in three days up to flowering followed by irrigating in alternate days ($I_4$).

Among the N levels, application of N @ 25 per cent less of RD ($N_1$) recorded a better (lower) source : sink ratio over RD N ($N_0$).

Soil + foliar application of N and K ($M_2$) significantly increased the source : sink ratio over soil application alone.

In the case of I x N interactions, $i_3n_1$ registered the lowest source : sink ratio (0.70) while $i_2n_0$ recorded the highest ratio which was on par with $i_1n_0$ and $i_4n_1$.

For I x M interactions $i_3m_1$ was found to produce better source : sink ratio (0.68). The combinations $i_2m_2$, $i_4m_2$, $i_1m_2$ and $i_1m_1$ were on par and registered higher ratios. Among N x M interactions, $n_1m_1$ resulted in the lowest source : sink ratio.

Regarding I x N x M interaction, $i_3n_1m_1$ was found to produce the lowest source : sink ratio which was on par with $i_2n_1m_1$. The highest source : sink ratio was registered by $i_4n_1m_2$ which was on par with $i_2n_0m_1$, $i_2n_0m_2$ and $i_1n_0m_1$.

### 4.2.8 Harvest Index

The data presented in Table 21 revealed that all the different treatments had significant influence on harvest index of yard long bean. Among the different levels of irrigation, scheduling irrigation once in three days up to flowering followed by alternate days ($I_4$) and irrigating once in three days ($i_3$) were on par and registered superior harvest indices (0.396 and 0.391 respectively).

Providing N @ 25 per cent less of RD ($N_1$) was superior to application of RD N ($N_0$).

Regarding the method of application of N and K, soil application ($M_1$) recorded significantly superior harvest index over soil + foliar application ($M_2$).

Combination effects of I x N, I x M and N x M were found to be significant (Table 22). Among I x M combinations, both $i_2n_1$ and $i_4n_0$ resulted in the highest harvest index (0.399) and were on par with $i_3n_1$, $i_4n_1$ and $i_1n_0$.

In the case of I x M interactions, $i_3m_1$ registered the maximum harvest index which was on par with $i_4m_1$. Among N x M combinations, $n_1m_1$ had the highest harvest index which was significantly superior over other combinations.

## 4.3 BIOCHEMICAL AND QUALITY CHARACTERS

### 4.3.1 Chlorophyll Content of Leaves at Flowering

The data on chlorophyll content at flowering (Table 24) revealed that irrigation levels and combination of irrigation with nitrogen imparted significant influence on the content of chlorophyll *a*, *b* and total chlorophyll. Among the irrigation treatments, irrigating once in two days at 20 mm depth ($I_2$) and irrigating once in three days up to flowering followed by irrigating in alternate days at 20 mm depth ($I_4$) recorded the highest values of chlorophyll *a* (0.64 mg $g^{-1}$) and they were on par with irrigating once in three days ($I_3$). Daily irrigation ($I_1$) registered the lowest content of chlorophyll *a*. The nitrogen levels and methods of application had no significant influence on chlorophyll *a* content.

Table 19. Effect of irrigation, nitrogen levels and method of application on pod yield harvest$^{-1}$ *

| Treatments | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $i_1 n_0 m_1$ | 155.2 | 84.0 | 183.2 | 202.5 | 181.2 | 516.0 | 313.5 | 600.0 | 834.0 | 863.0 | 900.7 |
| $i_1 n_0 m_2$ | 151.2 | 73.0 | 40.6 | 159.5 | 272.7 | 527.2 | 650.0 | 722.0 | 494.0 | 520.0 | 534.0 |
| $i_1 n_1 m_1$ | 106.5 | 12.0 | 70.4 | 325.0 | 319 | 559.0 | 723.7 | 639.2 | 1010.3 | 299.7 | 573.8 |
| $i_1 n_1 m_2$ | 51.75 | 74.0 | 222.5 | 108.4 | 131.5 | 312.6 | 497.5 | 565.3 | 560.0 | 527.3 | 808.7 |
| $i_2 n_0 m_1$ | 54.75 | 0 | 110.0 | 168.9 | 133.5 | 329.0 | 577.6 | 748.0 | 642.8 | 403.8 | 627.9 |
| $i_2 n_0 m_2$ | 218.7 | 52.2 | 112.6 | 214.8 | 162.7 | 466.2 | 372.5 | 485.4 | 875.0 | 763.5 | 613.5 |
| $i_2 n_1 m_1$ | 163.7 | 0 | 307.6 | 170.4 | 243.6 | 466.4 | 702.2 | 1001.7 | 1215.5 | 741.5 | 871.2 |
| $i_2 n_1 m_2$ | 238.0 | 0 | 273.0 | 191.2 | 462.0 | 805.0 | 979.0 | 758.5 | 845.2 | 659.3 | 568.4 |
| $i_3 n_0 m_1$ | 314.0 | 66.3 | 330.6 | 202.2 | 374.1 | 762.2 | 740.0 | 1300.0 | 820.2 | 761.0 | 700.2 |
| $i_3 n_0 m_2$ | 130.0 | 82.7 | 254.5 | 137.4 | 333.5 | 634.0 | 740.7 | 782.5 | 705.3 | 446.8 | 472.0 |
| $i_3 n_1 m_1$ | 372.0 | 0 | 417.9 | 0 | 588.5 | 1067.6 | 778.5 | 1016.7 | 612.5 | 1027.7 | 802.0 |
| $i_3 n_1 m_2$ | 167.7 | 80.4 | 245.0 | 23.5 | 394.0 | 716.6 | 685.0 | 753.6 | 883.3 | 659.0 | 560.3 |
| $i_4 n_0 m_1$ | 107.5 | 63.5 | 381.8 | 281.8 | 383.7 | 680.7 | 887.2 | 591.5 | 967.0 | 910.0 | 736.0 |
| $i_4 n_0 m_2$ | 192.2 | 154.8 | 205.0 | 193.8 | 552.8 | 667.3 | 769.2 | 830.2 | 769.0 | 621.2 | 817.5 |
| $i_4 n_1 m_1$ | 316.7 | 73.7 | 167.5 | 337.2 | 296.7 | 701.7 | 927.2 | 765.8 | 737.4 | 885.0 | 809.0 |
| $i_4 n_1 m_2$ | 160.2 | 69.4 | 128.9 | 61.3 | 216.8 | 610.8 | 670.0 | 901.1 | 611.5 | 1098.6 | 559.1 |

* Data not statistically analysed

Table 19 continued. Effect of irrigation, nitrogen levels and method of application on pod yield harvest$^{-1}$ *

| Treatments | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $i_1 n_0 m_1$ | 585.2 | 746.0 | 1153.0 | 589.5 | 750.5 | 483.5 | 503.7 | 272.7 | 280.7 | 270.0 | 227.5 |
| $i_1 n_0 m_2$ | 466.0 | 660.2 | 456.0 | 1012.0 | 293.5 | 288.5 | 636.2 | 277.0 | 495.5 | 316.7 | 237.0 |
| $i_1 n_1 m_1$ | 330.2 | 614.1 | 608.8 | 380.5 | 532.5 | 849.0 | 529.5 | 523.5 | 415.4 | 298.7 | 240.9 |
| $i_1 n_1 m_2$ | 807.8 | 618.0 | 598.0 | 837.0 | 543.2 | 484.3 | 417.7 | 247.5 | 405.0 | 305.0 | 185.0 |
| $i_2 n_0 m_1$ | 661.8 | 512.6 | 841.5 | 713.7 | 826.5 | 585.5 | 476.2 | 286.5 | 258.2 | 95.0 | 58.5 |
| $i_2 n_0 m_2$ | 638.0 | 854.5 | 518.0 | 474.25 | 587.2 | 467.7 | 444.5 | 475.4 | 231.5 | 159.1 | 137 |
| $i_2 n_1 m_1$ | 900.7 | 807.2 | 807.7 | 590.7 | 567.3 | 496.9 | 396.5 | 404.5 | 338.5 | 169.0 | 83.7 |
| $i_2 n_1 m_2$ | 610.0 | 536.7 | 425.0 | 495.6 | 326.3 | 498.5 | 267.7 | 302.0 | 168.5 | 211.0 | 0 |
| $i_3 n_0 m_1$ | 684.2 | 705.5 | 522.3 | 438.5 | 482.0 | 334.5 | 249.5 | 247.9 | 155.0 | 0 | 0 |
| $i_3 n_0 m_2$ | 550.0 | 434.2 | 323.5 | 258.5 | 381.7 | 302.2 | 271.0 | 207.5 | 223.8 | 78.0 | 0 |
| $i_3 n_1 m_1$ | 715.8 | 722.8 | 641.8 | 553.3 | 515.3 | 502.5 | 386.8 | 258.7 | 250.5 | 112.5 | 0 |
| $i_3 n_1 m_2$ | 415.5 | 683.3 | 669.0 | 463.5 | 502.3 | 316.7 | 423.5 | 224.5 | 243.0 | 234.5 | 118.7 |
| $i_4 n_0 m_1$ | 819.6 | 720.0 | 592.0 | 652.8 | 563.0 | 299.5 | 358.7 | 306.0 | 243.5 | 130.0 | 0 |
| $i_4 n_0 m_2$ | 827.0 | 487.5 | 822.0 | 680.0 | 536.7 | 350.0 | 365.0 | 324.2 | 319.0 | 87.5 | 0 |
| $i_4 n_1 m_1$ | 563.5 | 742.6 | 531.0 | 548.6 | 495.0 | 378.8 | 347.5 | 324.7 | 315.0 | 124.0 | 0 |
| $i_4 n_1 m_2$ | 681.5 | 571.9 | 744.3 | 555.5 | 530.6 | 301.0 | 328.7 | 248.5 | 179.8 | 99.0 | 0 |

* Data not statistically analysed

Table 20. Effect of irrigation, nitrogen levels and method of application on pod number plant$^{-1}$, pod yield plant$^{-1}$ and pod yield ha$^{-1}$

| Treatments | Pod number plant$^{-1}$ | Pod yield plant$^{-1}$ (g) | Pod yield (q ha$^{-1}$) |
|---|---|---|---|
| Irrigation Levels | | | |
| $I_1$ - Daily at 10 mm depth | 45.93 | 590.85 | 95.86 |
| $I_2$ – Alternate days at 20 mm depth | 45.56 | 584.92 | 94.98 |
| $I_3$ - Once in three days, 20 mm depth | 45.89 | 590.19 | 95.76 |
| $I_4$ - $I_3$ up to flowering followed by $I_2$ | 45.18 | 578.83 | 95.39 |
| SEm (±) | 0.954 | 15.259 | 2.074 |
| CD (0.05) | NS | NS | NS |
| Nitrogen Levels | | | |
| $N_0$ - RD N | 45.30 | 580.74 | 94.36 |
| $N_1$ - 25 % less of RD N | 45.98 | 591.66 | 96.64 |
| SEm (±) | 0.467 | 7.467 | 1.146 |
| CD (0.05) | NS | NS | NS |
| Method of application | | | |
| $M_1$ - Soil application | 47.68 | 618.96 | 100.03 |
| $M_2$ – Soil + foliar application | 43.59 | 553.43 | 90.97 |
| SEm (±) | 0.467 | 7.467 | 1.146 |
| CD (0.05) | 0.946 | 15.144 | 2.324 |

Table 21.Effect of irrigation, nitrogen levels and method of application on source : sink ratio and harvest index

| Treatments | Source:sink ratio | Harvest index |
|---|---|---|
| Irrigation Levels | | |
| $I_1$ - Daily at 10 mm depth | 0.86 | 0.382 |
| $I_2$ – Alternate days at 20 mm depth | 0.84 | 0.384 |
| $I_3$ - Once in three days, 20 mm depth | 0.75 | 0.391 |
| $I_4$ - $I_3$ up to flowering followed by $I_2$ | 0.84 | 0.396 |
| SEm (±) | 0.018 | 0.0044 |
| CD (0.05) | 0.042 | 0.0100 |
| Nitrogen Levels | | |
| $N_0$ - RD N | 0.85 | 0.386 |
| $N_1$ - 25 % less of RD N | 0.79 | 0.391 |
| SEm (±) | 0.013 | 0.0027 |
| CD (0.05) | 0.026 | 0.0056 |
| Method of application | | |
| $M_1$ - Soil application | 0.78 | 0.402 |
| $M_2$ – Soil + foliar application | 0.86 | 0.375 |
| SEm (±) | 0.013 | 0.0027 |
| CD (0.05) | 0.026 | 0.0056 |

Table 22. Interaction effect of irrigation, nitrogen and method of application on pod number plant$^{-1}$, pod yield plant$^{-1}$ and pod yield ha$^{-1}$

| Treatments | Pod number plant$^{-1}$ | Pod yield plant$^{-1}$ (g) | Pod yield (q ha$^{-1}$) |
|---|---|---|---|
| I x N | | | |
| $i_1 n_0$ | 46.99 | 607.88 | 98.38 |
| $i_1 n_1$ | 44.86 | 573.82 | 93.34 |
| $i_2 n_0$ | 42.87 | 541.90 | 88.61 |
| $i_2 n_1$ | 48.25 | 627.93 | 101.36 |
| $i_3 n_0$ | 44.38 | 566.09 | 92.19 |
| $i_3 n_1$ | 47.39 | 614.30 | 99.34 |
| $i_4 n_0$ | 46.94 | 607.08 | 98.27 |
| $i_4 n_1$ | 43.41 | 550.58 | 92.52 |
| SEm (±) | 0.933 | 14.934 | 2.292 |
| CD (0.05) | 1.893 | 30.288 | 4.647 |
| I x M | | | |
| $i_1 m_1$ | 47.02 | 608.38 | 98.46 |
| $i_1 m_2$ | 44.83 | 573.31 | 93.26 |
| $i_2 m_1$ | 46.76 | 604.06 | 97.82 |
| $i_2 m_2$ | 44.36 | 565.78 | 92.15 |
| $i_3 m_1$ | 49.51 | 648.10 | 104.34 |
| $i_3 m_2$ | 42.27 | 532.29 | 87.19 |
| $i_4 m_1$ | 47.46 | 615.30 | 99.48 |
| $i_4 m_2$ | 42.90 | 542.35 | 91.30 |
| SEm (±) | 0.933 | 14.934 | 2.292 |
| CD (0.05) | 1.893 | 30.288 | 4.647 |
| N x M | | | |
| $n_0 m_1$ | 46.54 | 600.64 | 97.31 |
| $n_0 m_2$ | 44.05 | 560.83 | 91.42 |
| $n_1 m_1$ | 48.83 | 637.28 | 102.74 |
| $n_1 m_2$ | 43.13 | 546.03 | 90.54 |
| SEm (±) | 0.660 | 10.560 | 1.620 |
| CD (0.05) | 1.339 | 21.417 | 3.286 |
| I x N x M | | | |
| $i_1 n_0 m_1$ | 48.05 | 624.81 | 100.89 |
| $i_1 n_0 m_2$ | 45.93 | 590.95 | 95.88 |
| $i_1 n_1 m_1$ | 46.00 | 591.96 | 96.03 |
| $i_1 n_1 m_2$ | 43.73 | 555.68 | 90.65 |
| $i_2 n_0 m_1$ | 43.41 | 550.48 | 89.88 |
| $i_2 n_0 m_2$ | 42.34 | 533.32 | 87.34 |
| $i_2 n_1 m_1$ | 50.10 | 657.63 | 105.75 |
| $i_2 n_1 m_2$ | 46.39 | 598.24 | 96.96 |
| $i_3 n_0 m_1$ | 46.69 | 602.96 | 97.66 |
| $i_3 n_0 m_2$ | 42.08 | 529.21 | 86.73 |
| $i_3 n_1 m_1$ | 52.33 | 693.25 | 111.03 |
| $i_3 n_1 m_2$ | 42.46 | 535.36 | 87.64 |
| $i_4 n_0 m_1$ | 48.02 | 624.30 | 100.82 |
| $i_4 n_0 m_2$ | 45.87 | 589.85 | 95.71 |
| $i_4 n_1 m_1$ | 46.90 | 606.30 | 98.15 |
| $i_4 n_1 m_2$ | 39.93 | 494.85 | 86.89 |
| SEm (±) | 1.320 | 21.120 | 3.241 |
| CD (0.05) | NS | NS | NS |

Table 23. Interaction effect of irrigation, nitrogen and method of application on source : sink ratio and harvest index

| Treatments | Source : sink ratio | Harvest index |
|---|---|---|
| I x N | | |
| $i_1$ $n_0$ | 0.88 | 0.389 |
| $i_1$ $n_1$ | 0.84 | 0.375 |
| $i_2$ $n_0$ | 0.91 | 0.370 |
| $i_2$ $n_1$ | 0.76 | 0.399 |
| $i_3 n_0$ | 0.80 | 0.385 |
| $i_3$ $n_1$ | 0.70 | 0.397 |
| $i_4$ $n_0$ | 0.82 | 0.399 |
| $i_4$ $n_1$ | 0.86 | 0.394 |
| SEm (±) | 0.025 | 0.0055 |
| CD (0.05) | 0.052 | 0.0112 |
| I x M | | |
| $i_1$ $m_1$ | 0.85 | 0.390 |
| $i_1$ $m_2$ | 0.87 | 0.374 |
| $i_2$ $m_1$ | 0.79 | 0.391 |
| $i_2$ $m_2$ | 0.88 | 0.377 |
| $i_3$ $m_1$ | 0.68 | 0.416 |
| $i_3$ $m_2$ | 0.82 | 0.366 |
| $i_4$ $m_1$ | 0.80 | 0.410 |
| $i_4$ $m_2$ | 0.88 | 0.382 |
| SEm (±) | 0.025 | 0.0055 |
| CD (0.05) | 0.052 | 0.0112 |
| N x M | | |
| $n_0$ $m_1$ | 0.84 | 0.396 |
| $n_0$ $m_2$ | 0.87 | 0.376 |
| $n_1$ $m_1$ | 0.71 | 0.408 |
| $n_1$ $m_2$ | 0.86 | 0.374 |
| SEm (±) | 0.018 | 0.0039 |
| CD (0.05) | 0.037 | 0.0079 |
| I x N x M | | |
| $i_1$ $n_0$ $m_1$ | 0.87 | 0.395 |
| $i_1$ $n_0$ $m_2$ | 0.89 | 0.382 |
| $i_1$ $n_1$ $m_1$ | 0.82 | 0.385 |
| $i_1$ $n_1$ $m_2$ | 0.85 | 0.365 |
| $i_2$ $n_0$ $m_1$ | 0.93 | 0.370 |
| $i_2$ $n_0$ $m_2$ | 0.90 | 0.370 |
| $i_2$ $n_1$ $m_1$ | 0.65 | 0.412 |
| $i_2$ $n_1$ $m_2$ | 0.87 | 0.385 |
| $i_3$ $n_0$ $m_1$ | 0.77 | 0.405 |
| $i_3$ $n_0$ $m_2$ | 0.84 | 0.365 |
| $i_3$ $n_1$ $m_1$ | 0.60 | 0.427 |
| $i_3$ $n_1$ $m_2$ | 0.80 | 0.367 |
| $i_4$ $n_0$ $m_1$ | 0.80 | 0.412 |
| $i_4$ $n_0$ $m_2$ | 0.84 | 0.385 |
| $i_4$ $n_1$ $m_1$ | 0.79 | 0.407 |
| $i_4$ $n_1$ $m_2$ | 0.93 | 0.380 |
| SEm (±) | 0.036 | 0.0078 |
| CD (0.05) | 0.073 | NS |

In the case of chlorophyll *b* and total chlorophyll content, daily irrigation at 10 mm depth ($I_1$) recorded the highest values (0.85 mg $g^{-1}$ and 1.47 mg $g^{-1}$ respectively) which were significantly superior to other treatments.

The levels of N also significantly influenced the chlorophyll *b* and total chlorophyll content of leaves. Application of RD N ($N_0$) recorded higher values of chlorophyll *b* and total chlorophyll. In the case of methods of application, soil + foliar application of N and K fertilizers ($M_2$) recorded significantly higher values of chlorophyll *b* and total chlorophyll content (0.74 mg $g^{-1}$ and 1.37 mg $g^{-1}$ respectively).

Among I x N interactions, $i_2n_1$ and $i_4n_0$ recorded the highest values of chlorophyll *a* content while $i_1n_0$ had the highest values of chlorophyll *b* and total chlorophyll.

In the case of I x M interactions, $i_1m_1$ recorded the highest chlorophyll *b* and total chlorophyll contents and was on par with $i_1m_2$.

The I x N x M combination, $i_1n_0m_1$ had the highest chlorophyll *b* and total chlorophyll and it was on par with $i_2n_0m_2$ in the case of total chlorophyll content.

**4.3.2 Proline Content of Leaves at Flowering**

The data on proline content of leaves at flowering is presented in Table 25.

Among irrigation levels, irrigating once in three days at 20 mm depth ($I_3$) recorded the highest proline content of 3.04 μ mols $g^{-1}$ fresh weight and daily irrigation at 10 mm depth ($I_1$) recorded the lowest content.

N application @ 25 per cent less of RD recorded significantly higher proline content (2.57 μ mols $g^{-1}$ fresh weight) than RD of N ($N_0$). Regarding method of application, soil + foliar application of N and K ($M_2$) registered higher proline content than soil application alone ($M_1$).

Among the interactions, N x M combinations were non-significant while all others (I x N, I x M and I x N x M) were significant. $i_3n_1$ was significantly superior among I x N interactions and $i_3m_2$ was significantly superior among I x M interaction. In the case of I x N x M interaction, $i_3n_1m_2$ was superior to other combinations.

### 4.3.3 Crude Protein Content

The data presented in Table 25 revealed that daily irrigation at 10 mm depth ($I_1$) and irrigation in alternate days ($I_2$) were on par and recorded higher protein content at final harvest (30.45 per cent and 30.19 per cent).

Among the nitrogen levels, RD N ($N_0$) registered superior crude protein content over 25 per cent less of RD N ($N_1$) and among method of application, soil application of N and K was found to be superior.

Regarding the combinations, I x N, I x M and I x N x M were found to be significant. In the case of I x N, $i_1n_0$ was superior and was on par with $i_2n_0$.

Among I x M interaction, $i_2m_1$ was found to have significantly superior crude protein content, while in the case of I x N x M interaction, $i_2n_0m_1$ and $i_1n_0m_1$ were on par and recorded superior crude protein content.

### 4.3.4 Crude Fibre Content

The crude fibre content at final harvest (Table 25) was influenced only by irrigation levels and method of application.

Daily irrigation at 10 mm depth ($I_1$) registered significantly lower crude fibre content (12.39 per cent) while the highest crude fibre content (21.24 per cent) was recorded in irrigation once in three days at 20 mm depth ($I_3$).

Among the application methods, soil + foliar application of N and K ($M_2$) registered lower fibre content (16.70 per cent).

None of the interaction was found to be significant.

## 4.4 ROOT CHARACTERS AT FINAL HARVEST

Data on root parameters presented in Table 28 indicated that root volume was significantly influenced by all the three main effects whereas the root fresh weight was affected by irrigation levels and method of application. The main effects and their interactions were found to be insignificant for root dry weight.

Daily irrigation registered maximum root volume and root fresh weight (80.94 $cm^3$ and 60.06 g) which were significantly higher than other levels of irrigation.

Recommended dose of N ($N_0$) recorded higher values of root volume over 25 per cent less of RD N ($N_1$).

Application of N and K through soil alone ($M_1$) recorded higher values of root volume and root weight over soil + foliar application ($M_2$).

Combinations of I x N and I x M imparted significant influence on root volume and root weight. $i_1n_1$ registered the highest root volume and root weight and was on par with $i_1n_0$ for root volume. In the case of I x M interactions, $i_1m_1$ was significantly superior over other combinations for both root volume and root weight.

N x M interaction exerted a favorable influence on root volume, $n_1m_1$ recording the highest volume (52.44 $cm^3$) which was on par with $n_0m_1$.

## 4.5 INCIDENCE OF PEST AND DISEASES

The major pest observed in the field was spider mite (*Tetranichus sp*). As per the data presented in Table 29, the percentage intensity of damage due to mite ranged from 21.25 to 25 per cent. No significant visible variation on mite incidence was observed due to treatment effects. Incidence of *Spodoptera litura* was also noticed during the initial crop growth stages.

Table 24. Effect of irrigation, nitrogen levels and method of application on chlorophyll content at flowering, mg $g^{-1}$

| Treatments | Chlorophyll *a* | Chlorophyll *b* | Total chlorophyll |
|---|---|---|---|
| Irrigation Levels | | | |
| $I_1$ - Daily at 10 mm depth | 0.62 | 0.85 | 1.47 |
| $I_2$ – Alternate days at 20 mm depth | 0.64 | 0.67 | 1.32 |
| $I_3$ - Once in three days, 20 mm depth | 0.63 | 0.69 | 1.32 |
| $I_4$ - $I_3$ up to flowering followed by $I_2$ | 0.64 | 0.57 | 1.22 |
| SEm (±) | 0.004 | 0.020 | 0.019 |
| CD (0.05) | 0.010 | 0.046 | 0.043 |
| Nitrogen Levels | | | |
| $N_0$ - RD N | 0.63 | 0.76 | 1.39 |
| $N_1$ - 25 % less of RD N | 0.63 | 0.63 | 1.27 |
| SEm (±) | 0.004 | 0.011 | 0.011 |
| CD (0.05) | NS | 0.023 | 0.022 |
| Method of application | | | |
| $M_1$ - Soil application | 0.63 | 0.65 | 1.29 |
| $M_2$ – Soil + foliar application | 0.63 | 0.74 | 1.37 |
| SEm (±) | 0.004 | 0.011 | 0.011 |
| CD (0.05) | NS | 0.023 | 0.022 |

Table 25. Effect of irrigation, nitrogen levels and method of application on proline content of leaves at flowering, crude protein and crude fibre content of pods

| Treatments | Proline content (μ mols $g^{-1}$) | Crude protein (%) | Crude fibre (%) |
|---|---|---|---|
| Irrigation Levels | | | |
| $I_1$ - Daily at 10 mm depth | 1.09 | 30.45 | 12.39 |
| $I_2$ – Alternate days at 20 mm depth | 2.01 | 30.19 | 14.92 |
| $I_3$ - Once in three days, 20 mm depth | 3.04 | 26.34 | 21.24 |
| $I_4$ - $I_3$ up to flowering followed by $I_2$ | 2.83 | 25.62 | 19.73 |
| SEm (±) | 0.077 | 0.267 | 0.540 |
| CD (0.05) | 0.175 | 0.603 | 1.221 |
| Nitrogen Levels | | | |
| $N_0$ - RD N | 1.92 | 29.53 | 17.03 |
| $N_1$ - 25 % less of RD N | 2.57 | 26.76 | 17.11 |
| SEm (±) | 0.061 | 0.273 | 0.345 |
| CD (0.05) | 0.124 | 0.555 | NS |
| Method of application | | | |
| $M_1$ - Soil application | 2.10 | 29.59 | 17.44 |
| $M_2$ – Soil + foliar application | 2.39 | 26.71 | 16.70 |
| SEm (±) | 0.061 | 0.273 | 0.345 |
| CD (0.05) | 0.124 | 0.555 | 0.701 |

Tables 26. Interaction effect of irrigation, nitrogen and method of application on chlorophyll content at flowering, mg $g^{-1}$

| Treatments | Chlorophyll *a* | Chlorophyll *b* | Total chlorophyll |
|---|---|---|---|
| I x N | | | |
| $i_1 n_0$ | 0.61 | 0.97 | 1.58 |
| $i_1 n_1$ | 0.63 | 0.72 | 1.36 |
| $i_2 n_0$ | 0.62 | 0.87 | 1.50 |
| $i_2 n_1$ | 0.66 | 0.47 | 1.13 |
| $i_3 n_0$ | 0.63 | 0.66 | 1.29 |
| $i_3 n_1$ | 0.62 | 0.72 | 1.35 |
| $i_4 n_0$ | 0.66 | 0.54 | 1.20 |
| $i_4 n_1$ | 0.63 | 0.61 | 1.23 |
| SEm (±) | 0.008 | 0.022 | 0.022 |
| CD (0.05) | 0.017 | 0.045 | 0.045 |
| I x M | | | |
| $i_1 m_1$ | 0.62 | 0.86 | 1.48 |
| $i_1 m_2$ | 0.62 | 0.84 | 1.46 |
| $i_2 m_1$ | 0.64 | 0.64 | 1.28 |
| $i_2 m_2$ | 0.64 | 0.71 | 1.35 |
| $i_3 m_1$ | 0.63 | 0.64 | 1.27 |
| $i_3 m_2$ | 0.63 | 0.75 | 1.37 |
| $i_4 m_1$ | 0.65 | 0.48 | 1.13 |
| $i_4 m_2$ | 0.64 | 0.67 | 1.30 |
| SEm (±) | 0.008 | 0.022 | 0.022 |
| CD (0.05) | NS | 0.045 | 0.045 |
| N x M | | | |
| $n_0 m_1$ | 0.63 | 0.73 | 1.36 |
| $n_0 m_2$ | 0.63 | 0.80 | 1.43 |
| $n_1 m_1$ | 0.63 | 0.58 | 1.22 |
| $n_1 m_2$ | 0.63 | 0.68 | 1.32 |
| SEm (±) | 0.006 | 0.016 | 0.016 |
| CD (0.05) | NS | NS | NS |
| I x N x M | | | |
| $i_1 n_0 m_1$ | 0.61 | 1.01 | 1.62 |
| $i_1 n_0 m_2$ | 0.61 | 0.92 | 1.53 |
| $i_1 n_1 m_1$ | 0.62 | 0.70 | 1.34 |
| $i_1 n_1 m_2$ | 0.63 | 0.76 | 1.39 |
| $i_2 n_0 m_1$ | 0.63 | 0.81 | 1.45 |
| $i_2 n_0 m_2$ | 0.62 | 0.94 | 1.56 |
| $i_2 n_1 m_1$ | 0.66 | 0.46 | 1.12 |
| $i_2 n_1 m_2$ | 0.66 | 0.48 | 1.15 |
| $i_3 n_0 m_1$ | 0.63 | 0.59 | 1.22 |
| $i_3 n_0 m_2$ | 0.62 | 0.74 | 1.37 |
| $i_3 n_1 m_1$ | 0.62 | 0.69 | 1.32 |
| $i_3 n_1 m_2$ | 0.63 | 0.75 | 1.38 |
| $i_4 n_0 m_1$ | 0.66 | 0.49 | 1.15 |
| $i_4 n_0 m_2$ | 0.65 | 0.60 | 1.25 |
| $i_4 n_1 m_1$ | 0.64 | 0.48 | 1.12 |
| $i_4 n_1 m_2$ | 0.62 | 0.73 | 1.35 |
| SEm (±) | 0.011 | 0.032 | 0.031 |
| CD (0.05) | NS | 0.064 | 0.064 |

Table 27. Interaction effect of irrigation, nitrogen and method of application on proline content of leaves at flowering, crude protein and crude fibre content of pods

| Treatments | Proline (μ mols g[-1]) | Crude protein (%) | Crude fibre (%) |
|---|---|---|---|
| I x N | | | |
| $i_1 n_0$ | 0.96 | 32.82 | 11.84 |
| $i_1 n_1$ | 1.22 | 28.07 | 12.95 |
| $i_2 n_0$ | 1.73 | 31.72 | 15.27 |
| $i_2 n_1$ | 2.30 | 28.66 | 14.58 |
| $i_3 n_0$ | 2.35 | 27.04 | 20.87 |
| $i_3 n_1$ | 3.73 | 25.63 | 21.60 |
| $i_4 n_0$ | 2.63 | 26.54 | 20.15 |
| $i_4 n_1$ | 3.04 | 24.70 | 19.32 |
| SEm (±) | 0.122 | 0.547 | 0.691 |
| CD (0.05) | 0.248 | 1.109 | NS |
| I x M | | | |
| $i_1 m_1$ | 0.97 | 31.96 | 13.22 |
| $i_1 m_2$ | 1.21 | 28.93 | 11.56 |
| $i_2 m_1$ | 1.72 | 33.39 | 15.13 |
| $i_2 m_2$ | 2.30 | 26.99 | 14.71 |
| $i_3 m_1$ | 2.87 | 26.63 | 21.55 |
| $i_3 m_2$ | 3.20 | 26.05 | 20.92 |
| $i_4 m_1$ | 2.84 | 26.38 | 19.85 |
| $i_4 m_2$ | 2.83 | 24.86 | 19.61 |
| SEm (±) | 0.122 | 0.547 | 0.691 |
| CD (0.05) | 0.248 | 1.109 | NS |
| N x M | | | |
| $n_0 m_1$ | 1.81 | 30.98 | 17.59 |
| $n_0 m_2$ | 2.02 | 28.08 | 16.47 |
| $n_1 m_1$ | 2.39 | 28.20 | 17.29 |
| $n_1 m_2$ | 2.75 | 25.33 | 16.93 |
| SEm (±) | 0.086 | 0.387 | 0.489 |
| CD (0.05) | NS | NS | NS |
| I x N x M | | | |
| $i_1 n_0 m_1$ | 0.70 | 33.63 | 13.48 |
| $i_1 n_0 m_2$ | 1.23 | 32.02 | 10.20 |
| $i_1 n_1 m_1$ | 1.24 | 30.3 | 12.96 |
| $i_1 n_1 m_2$ | 1.19 | 25.84 | 12.93 |
| $i_2 n_0 m_1$ | 1.62 | 34.38 | 15.64 |
| $i_2 n_0 m_2$ | 1.83 | 29.07 | 14.89 |
| $i_2 n_1 m_1$ | 1.82 | 32.41 | 14.62 |
| $i_2 n_1 m_2$ | 2.78 | 24.91 | 14.53 |
| $i_3 n_0 m_1$ | 2.28 | 27.69 | 21.13 |
| $i_3 n_0 m_2$ | 2.43 | 26.39 | 20.61 |
| $i_3 n_1 m_1$ | 3.47 | 25.56 | 21.97 |
| $i_3 n_1 m_2$ | 3.98 | 25.71 | 21.23 |
| $i_4 n_0 m_1$ | 2.65 | 28.24 | 20.10 |
| $i_4 n_0 m_2$ | 2.60 | 24.85 | 20.19 |
| $i_4 n_1 m_1$ | 3.02 | 24.52 | 19.60 |
| $i_4 n_1 m_2$ | 3.07 | 24.88 | 19.03 |
| SEm (±) | 0.173 | 0.774 | 0.977 |
| CD (0.05) | 0.350 | 1.569 | NS |

Table 28. Effect of irrigation, nitrogen levels and method of application on root volume and root weight

| Treatments | Root volume ($cm^3$) | Root fresh weight (g) | Root dry weight (g) |
|---|---|---|---|
| Irrigation Levels | | | |
| $I_1$ - Daily at 10 mm depth | 80.94 | 60.06 | 9.33 |
| $I_2$ – Alternate days at 20 mm depth | 47.06 | 46.62 | 10.18 |
| $I_3$ - Once in three days, 20 mm depth | 32.50 | 34.09 | 9.54 |
| $I_4$ - $I_3$ up to flowering followed by $I_2$ | 33.19 | 31.41 | 9.72 |
| SEm (±) | 0.927 | 0.906 | 0.265 |
| CD (0.05) | 2.097 | 2.049 | NS |
| Nitrogen Levels | | | |
| $N_0$ - RD N | 49.69 | 43.16 | 9.91 |
| $N_1$ - 25 % less of RD N | 47.16 | 42.94 | 9.47 |
| SEm (±) | 0.926 | 0.724 | 0.337 |
| CD (0.05) | 1.878 | NS | NS |
| Method of application | | | |
| $M_1$ - Soil application | 52.25 | 44.16 | 9.57 |
| $M_2$ – Soil + foliar application | 44.59 | 41.94 | 9.80 |
| SEm (±) | 0.926 | 0.724 | 0.337 |
| CD (0.05) | 1.878 | 1.467 | NS |

Table 29. Effect of irrigation, nitrogen levels and method of application on the intensity of damage by mite and *Pythium* stem rot, per cent *

| Treatments | Intensity of damage by mite (%) | Incidence of stem rot (%) | |
|---|---|---|---|
| | | | Mean |
| $i_1 n_0 m_1$ | 25.00 | 4.69 | 2.73 |
| $i_1 n_0 m_2$ | 23.75 | 4.69 | |
| $i_1 n_1 m_1$ | 23.75 | 1.56 | |
| $i_1 n_1 m_2$ | 21.25 | 0 | |
| $i_2 n_0 m_1$ | 23.75 | 3.12 | 1.56 |
| $i_2 n_0 m_2$ | 21.25 | 0 | |
| $i_2 n_1 m_1$ | 21.25 | 1.56 | |
| $i_2 n_1 m_2$ | 23.75 | 1.56 | |
| $i_3 n_0 m_1$ | 25.00 | 1.56 | 0.78 |
| $i_3 n_0 m_2$ | 25.00 | 0 | |
| $i_3 n_1 m_1$ | 25.00 | 1.56 | |
| $i_3 n_1 m_2$ | 21.25 | 0 | |
| $i_4 n_0 m_1$ | 25.00 | 3.12 | 1.17 |
| $i_4 n_0 m_2$ | 23.75 | 0 | |
| $i_4 n_1 m_1$ | 23.75 | 0 | |
| $i_4 n_1 m_2$ | 26.25 | 1.56 | |

*Data not statistically analysed

Table 30. Interaction effect of irrigation, nitrogen and method of application on root volume and root weight

| Treatments | Root volume ($cm^3$) | Root fresh weight (g) | Root dry weight (g) |
|---|---|---|---|
| I x N | | | |
| $i_1$ $n_0$ | 79.75 | 57.25 | 9.94 |
| $i_1$ $n_1$ | 82.12 | 62.87 | 8.71 |
| $i_2$ $n_0$ | 56.75 | 51.06 | 10.03 |
| $i_2$ $n_1$ | 37.37 | 42.19 | 10.33 |
| $i_3n_0$ | 29.87 | 34.25 | 9.38 |
| $i_3$ $n_1$ | 35.12 | 33.94 | 9.70 |
| $i_4$ $n_0$ | 32.37 | 30.06 | 10.30 |
| $i_4$ $n_1$ | 34.00 | 32.75 | 9.13 |
| SEm (±) | 1.851 | 1.447 | 0.675 |
| CD (0.05) | 3.755 | 2.935 | NS |
| I x M | | | |
| $i_1$ $m_1$ | 90.62 | 64.25 | 9.14 |
| $i_1$ $m_2$ | 71.25 | 55.87 | 9.51 |
| $i_2$ $m_1$ | 49.87 | 46.50 | 10.52 |
| $i_2$ $m_2$ | 44.25 | 46.75 | 9.83 |
| $i_3$ $m_1$ | 33.25 | 34.56 | 9.39 |
| $i_3$ $m_2$ | 31.75 | 33.62 | 9.68 |
| $i_4$ $m_1$ | 35.25 | 31.31 | 9.26 |
| $i_4$ $m_2$ | 31.12 | 31.50 | 10.18 |
| SEm (±) | 1.851 | 1.447 | 0.675 |
| CD (0.05) | 3.755 | 2.935 | NS |
| N x M | | | |
| $n_0$ $m_1$ | 52.06 | 44.25 | 9.92 |
| $n_0$ $m_2$ | 47.31 | 42.06 | 9.90 |
| $n_1$ $m_1$ | 52.44 | 44.06 | 9.23 |
| $n_1$ $m_2$ | 41.87 | 41.81 | 9.71 |
| SEm (±) | 1.309 | 1.023 | 0.477 |
| CD (0.05) | 2.655 | NS | NS |
| I x N x M | | | |
| $i_1$ $n_0$ $m_1$ | 88.00 | 44.25 | 10.40 |
| $i_1$ $n_0$ $m_2$ | 71.50 | 42.06 | 9.49 |
| $i_1$ $n_1$ $m_1$ | 93.25 | 44.06 | 7.89 |
| $i_1$ $n_1$ $m_2$ | 71.00 | 41.81 | 9.54 |
| $i_2$ $n_0$ $m_1$ | 59.50 | 44.25 | 9.99 |
| $i_2$ $n_0$ $m_2$ | 54.00 | 42.06 | 10.07 |
| $i_2$ $n_1$ $m_1$ | 40.25 | 44.06 | 11.05 |
| $i_2$ $n_1$ $m_2$ | 34.50 | 41.81 | 9.60 |
| $i_3$ $n_0$ $m_1$ | 29.00 | 44.25 | 9.30 |
| $i_3$ $n_0$ $m_2$ | 30.75 | 42.06 | 9.45 |
| $i_3$ $n_1$ $m_1$ | 37.50 | 44.06 | 9.48 |
| $i_3$ $n_1$ $m_2$ | 32.75 | 41.81 | 9.92 |
| $i_4$ $n_0$ $m_1$ | 31.75 | 44.25 | 10.02 |
| $i_4$ $n_0$ $m_2$ | 33.00 | 42.06 | 10.59 |
| $i_4$ $n_1$ $m_1$ | 38.75 | 44.06 | 8.49 |
| $i_4$ $n_1$ $m_2$ | 29.25 | 41.81 | 9.77 |
| SEm (±) | 2.618 | 2.047 | 0.955 |
| CD (0.05) | NS | NS | NS |

Stem rot caused by *Pythium debarianum* was observed to be the major disease. Treatment wise variation was noted in the percentage disease incidence. The disease incidence was higher (2.73 per cent) in daily irrigation ($I_1$) while, the lowest incidence was noted in $I_3$ (irrigation once in three days at 20 mm depth) (0.78 per cent). Wilt caused by *Fusarium oxysporum* was also observed in patches in the field and it was not influenced by different treatments.

## 4.6 NUTRIENT UPTAKE

### 4.6.1 Uptake of Nitrogen

Data in Table 31 revealed that the different treatments had significant influence on total N uptake and uptake by various plant parts at harvest. It was noticed that the N uptake by different plant parts were significantly higher in daily irrigation at 10 mm depth ($I_1$). The total N uptake was also higher in daily irrigation ($I_1$), (169.82 kg $ha^{-1}$) which was followed by irrigating in alternate days at 20 mm depth ($I_2$).

Regarding N levels, RD N ($N_0$) recorded higher N uptake by all plant parts. Among the two application methods, soil application ($M_1$) resulted in higher N uptake by leaf, root and pod while N uptake by stem was higher for soil + foliar application ($M_2$). The total N uptake (161.02 kg $ha^{-1}$) in soil application of N and K ($M_1$) was superior to soil + foliar application ($M_2$).

Among the combinations of I x N, $i_1n_0$ recorded superior N uptake by leaf, root and pod which was on par with $i_1n_1$, $i_3n_1$ and $i_4n_0$ in the case of root. The combination $i_1n_1$ recorded the highest N uptake by stem. The total N uptake was significantly superior for $i_1n_0$.

In I x M interactions, $i_1m_2$ recorded superior N uptake by leaf and stem, while $i_2m_1$ registered the highest uptake by pod and it was on par with $i_1m_1$. $i_1m_1$ recorded higher N uptake by root. The highest total N uptake was registered by $i_2m_1$ which was on par with $i_1m_2$ and $i_1m_1$.

N x M interaction also favorably influenced the N uptake by different plant parts. The highest uptake by leaf was recorded by $n_0m_1$. N uptake by stem was superior for $n_0m_2$ and was on par with $n_1m_2$ and $n_0m_1$. For N uptake by root $n_1m_1$, $n_0m_2$ and $n_0m_1$ were found to be on par and superior to $n_1m_2$. In the case of pod, $n_1m_1$ was found to be superior and was on par with $n_0m_1$. N x M interaction was insignificant for total N uptake by all plant parts.

Among I x N x M interactions, leaf N uptake was superior for $i_1n_0m_1$ which was on par with $i_2n_0m_1$ and $i_4n_0m_1$. In the case of N uptake by stem $i_1n_1m_2$ was found to be superior to all other combinations, while in the case pod uptake, $i_2n_1m_1$ was significantly superior. I x N x M combination was insignificant for N uptake by root. The total N uptake was the highest in $i_1n_0m_1$ (176.70 kg $ha^{-1}$).

**4.6.2 Uptake of Phosphorus**

Uptake of phosphorus by different plant parts (Table 32) were influenced by the treatments. Among the irrigation levels, irrigating once in three days at 20 mm depth ($I_3$) recorded significantly superior P uptake by leaf, pod and root, whereas daily irrigation at 10 mm depth ($I_1$) recorded the highest uptake by stem. The total P uptake by all plant parts was also higher for daily irrigation at 10 mm depth ($I_1$) which was on par with irrigating once in three days at 10 mm depth.

Application of N @ 25 per cent less of RD N ($N_1$) recorded superior P uptake by leaf, stem and pod while RD N ($N_0$) recorded higher P uptake by root. The total P uptake was higher for $N_1$.

Soil application of N and K ($M_1$) registered more P uptake over soil + foliar application ($M_2$) for leaf, pod and root whereas, P uptake by stem was higher in soil + foliar application. The total uptake of P was found to be superior for soil application of N and K ($M_1$).

Combinations of main plot and sub plot factors also influenced the uptake by various plant parts. Among I x N interaction, $i_3n_1$ registered the highest P uptake by both leaf and pod. $i_1n_1$ recorded superior P uptake by stem, while $i_1n_0$

recorded the highest P uptake by root which was on par with $i_3n_1$ and $i_3n_0$. The total P uptake was the highest for $i_3n_1$.

Regarding I x M interaction, $i_3m_1$ was superior to all other combinations for P uptake by leaf, root, pod and total uptake. For P uptake by stem, $i_1m_2$ registered the highest value.

Among N x M interactions, $n_1m_1$ was significantly superior to other combinations in leaf and pod P uptake, while $n_1m_2$ was superior to others in stem uptake. The interactions, $n_0m_2$ and $n_1m_1$ were superior with regard to P uptake by root and were on par with $n_0m_1$. Regarding total uptake, $n_1m_1$ and $n_1m_2$ were on par and superior to other combinations.

In the case of I x N x M interaction, $i_3n_1m_1$ registered the highest P uptake by leaf, root, pod and total uptake of P and it was on par with $i_1n_0m_1$ and $i_2n_0m_2$ for P uptake by root. P uptake by stem was the highest in $i_2n_1m_2$ and was on par with $i_1n_1m_2$.

**4.6.3 Uptake of Potassium**

Data on potassium uptake by different plant parts are presented in Table 35.

Daily irrigation at 10 mm depth ($I_1$) registered the highest K uptake by leaf and root and was on par with irrigating once in three days ($I_3$) in case of root K uptake. K uptake by stem was significantly superior in irrigating once in three days at 20 mm depth ($I_3$) while, irrigating once in three days at 20 mm depth followed by irrigating in alternate days ($I_4$) recorded the highest K uptake by pod (41.68 kg $ha^{-1}$) which was on par with irrigating once in three days ($I_3$) and irrigating in alternate days ($I_2$). The total K uptake by all plant parts was superior for $I_3$ and was on par with $I_1$.

Among the N levels, RD N registered higher K uptake by leaf, root, pod and total uptake while N levels were insignificant in K uptake by stem.

Table 31. Effect of irrigation, nitrogen levels and method of application on uptake of nitrogen, kg $ha^{-1}$

| Treatments | Leaf (source) | Stem | Root | Pod (sink) | Total |
|---|---|---|---|---|---|
| Irrigation Levels | | | | | |
| $I_1$ - Daily at 10 mm depth | 45.12 | 53.15 | 3.41 | 68.13 | 169.82 |
| $I_2$ – Alternate days at 20 mm depth | 38.33 | 46.29 | 2.78 | 65.11 | 152.52 |
| $I_3$ - Once in three days, 20 mm depth | 33.08 | 48.10 | 3.15 | 57.71 | 142.04 |
| $I_4$ - $I_3$ up to flowering followed by $I_2$ | 40.26 | 46.75 | 2.91 | 57.26 | 147.18 |
| SEm (±) | 0.534 | 0.986 | 0.068 | 1.169 | 1.024 |
| CD (0.05) | 1.209 | 2.231 | 0.155 | 2.646 | 2.317 |
| Nitrogen Levels | | | | | |
| $N_0$ – Recommended N dose | 44.10 | 49.53 | 3.19 | 64.20 | 161.02 |
| $N_1$ - - 25 % Recommended dose | 34.30 | 47.62 | 2.94 | 59.90 | 144.75 |
| SEm (±) | 0.436 | 0.442 | 0.081 | 0.703 | 1.123 |
| CD (0.05) | 0.884 | 0.897 | 0.165 | 1.425 | 2.277 |
| Method of application | | | | | |
| $M_1$ - Soil application | 41.11 | 47.31 | 3.22 | 68.80 | 160.44 |
| $M_2$ – Soil + foliar application | 37.29 | 49.84 | 2.90 | 55.31 | 145.33 |
| SEm (±) | 0.436 | 0.442 | 0.081 | 0.703 | 1.123 |
| CD (0.05) | 0.884 | 0.897 | 0.165 | 1.425 | 2.277 |

Table 32. Effect of irrigation, nitrogen levels and method of application on uptake of phosphorus, kg $ha^{-1}$

| Treatments | Leaf (source) | Stem | Root | Pod (sink) | Total |
|---|---|---|---|---|---|
| Irrigation Levels | | | | | |
| $I_1$ - Daily at 10 mm depth | 3.10 | 7.98 | 0.35 | 6.23 | 17.66 |
| $I_2$ – Alternate days at 20 mm depth | 3.17 | 6.42 | 0.31 | 5.80 | 15.71 |
| $I_3$ - Once in three days, 20 mm depth | 3.92 | 5.74 | 0.38 | 7.41 | 17.46 |
| $I_4$ - $I_3$ up to flowering followed by $I_2$ | 3.38 | 5.91 | 0.25 | 5.89 | 15.44 |
| SEm (±) | 0.048 | 0.123 | 0.009 | 0.114 | 0.093 |
| CD (0.05) | 0.109 | 0.277 | 0.020 | 0.257 | 0.211 |
| Nitrogen Levels | | | | | |
| $N_0$ – Recommended N dose | 3.11 | 5.65 | 0.34 | 6.01 | 15.11 |
| $N_1$ - - 25 % Recommended dose | 3.68 | 7.38 | 0.30 | 6.65 | 18.02 |
| SEm (±) | 0.037 | 0.065 | 0.012 | 0.067 | 0.113 |
| CD (0.05) | 0.075 | 0.132 | 0.024 | 0.136 | 0.228 |
| Method of application | | | | | |
| $M_1$ - Soil application | 3.89 | 6.05 | 0.34 | 6.77 | 17.05 |
| $M_2$ – Soil + foliar application | 2.90 | 6.98 | 0.30 | 5.89 | 16.08 |
| SEm (±) | 0.037 | 0.065 | 0.012 | 0.067 | 0.113 |
| CD (0.05) | 0.075 | 0.132 | 0.024 | 0.136 | 0.228 |

Table 33. Interaction effect of irrigation, nitrogen and method of application on uptake of nitrogen, kg ha$^{-1}$

| Treatments | Leaf (source) | Stem | Root | Pod (sink) | Total |
|---|---|---|---|---|---|
| I x N | | | | | |
| $i_1$ $n_0$ | 50.36 | 51.87 | 3.54 | 74.27 | 180.04 |
| $i_1$ $n_1$ | 39.88 | 54.44 | 3.28 | 61.99 | 159.60 |
| $i_2$ $n_0$ | 42.33 | 46.05 | 2.96 | 60.92 | 152.26 |
| $i_2$ $n_1$ | 34.33 | 46.53 | 2.61 | 69.31 | 152.78 |
| $i_3$$n_0$ | 36.42 | 51.15 | 3.04 | 57.86 | 148.47 |
| $i_3$ $n_1$ | 29.75 | 45.05 | 3.25 | 57.56 | 135.62 |
| $i_4$ $n_0$ | 47.29 | 49.05 | 3.21 | 63.78 | 163.33 |
| $i_4$ $n_1$ | 33.22 | 44.45 | 2.6 | 50.74 | 131.02 |
| SEm (±) | 0.871 | 0.885 | 0.163 | 1.405 | 2.246 |
| CD (0.05) | 1.767 | 1.795 | 0.331 | 2.850 | 4.555 |
| I x M | | | | | |
| $i_1$ $m_1$ | 42.71 | 48.76 | 3.91 | 74.39 | 169.77 |
| $i_1$ $m_2$ | 47.54 | 57.55 | 2.91 | 61.87 | 169.87 |
| $i_2$ $m_1$ | 43.24 | 47.97 | 2.95 | 76.47 | 170.62 |
| $i_2$ $m_2$ | 33.42 | 44.61 | 2.62 | 53.76 | 134.41 |
| $i_3$ $m_1$ | 33.68 | 45.63 | 3.18 | 63.37 | 145.85 |
| $i_3$ $m_2$ | 32.49 | 50.57 | 3.12 | 52.05 | 138.23 |
| $i_4$ $m_1$ | 44.81 | 46.88 | 2.86 | 60.96 | 155.52 |
| $i_4$ $m_2$ | 35.70 | 46.61 | 2.96 | 53.56 | 138.83 |
| SEm (±) | 0.871 | 0.885 | 0.163 | 1.405 | 2.246 |
| CD (0.05) | 1.767 | 1.795 | 0.331 | 2.850 | 4.555 |
| N x M | | | | | |
| $n_0$ $m_1$ | 47.89 | 49.09 | 3.17 | 68.23 | 168.39 |
| $n_0$ $m_2$ | 40.31 | 49.96 | 3.20 | 60.18 | 153.66 |
| $n_1$ $m_1$ | 34.33 | 45.53 | 3.27 | 69.36 | 152.49 |
| $n_1$ $m_2$ | 34.26 | 49.71 | 2.60 | 50.44 | 137.01 |
| SEm (±) | 0.616 | 0.626 | 0.115 | 0.994 | 1.588 |
| CD (0.05) | 1.250 | 1.269 | 0.234 | 2.015 | NS |
| I x N x M | | | | | |
| $i_1$ $n_0$ $m_1$ | 52.10 | 55.05 | 3.71 | 78.34 | 189.21 |
| $i_1$ $n_0$ $m_2$ | 48.62 | 48.68 | 3.37 | 70.20 | 170.87 |
| $i_1$ $n_1$ $m_1$ | 33.31 | 42.46 | 4.12 | 70.45 | 150.34 |
| $i_1$ $n_1$ $m_2$ | 46.45 | 66.42 | 2.45 | 53.54 | 168.86 |
| $i_2$ $n_0$ $m_1$ | 50.93 | 45.26 | 2.98 | 64.01 | 163.18 |
| $i_2$ $n_0$ $m_2$ | 33.73 | 46.84 | 2.94 | 57.83 | 141.34 |
| $i_2$ $n_1$ $m_1$ | 35.55 | 50.68 | 2.91 | 88.92 | 178.07 |
| $i_2$ $n_1$ $m_2$ | 33.11 | 42.38 | 2.31 | 49.69 | 127.49 |
| $i_3$ $n_0$ $m_1$ | 38.19 | 47.66 | 2.92 | 63.26 | 152.04 |
| $i_3$ $n_0$ $m_2$ | 34.64 | 54.63 | 3.16 | 52.46 | 144.90 |
| $i_3$ $n_1$ $m_1$ | 29.16 | 43.60 | 3.44 | 63.48 | 139.67 |
| $i_3$ $n_1$ $m_2$ | 30.34 | 46.51 | 3.07 | 51.64 | 131.56 |
| $i_4$ $n_0$ $m_1$ | 50.33 | 48.39 | 3.09 | 67.33 | 169.14 |
| $i_4$ $n_0$ $m_2$ | 44.25 | 49.70 | 3.34 | 60.23 | 157.52 |
| $i_4$ $n_1$ $m_1$ | 39.30 | 45.37 | 2.63 | 54.60 | 141.90 |
| $i_4$ $n_1$ $m_2$ | 27.15 | 43.53 | 2.58 | 46.89 | 120.14 |
| SEm (±) | 1.232 | 1.252 | 0.231 | 1.987 | 3.176 |
| CD (0.05) | 2.50 | 2.538 | NS | 4.030 | 6.442 |

Table 34. Interaction effect of irrigation, nitrogen and method of application on uptake of phosphorus, kg ha$^{-1}$

| Treatments | Leaf (source) | Stem | Root | Pod (sink) | Total |
|---|---|---|---|---|---|
| I x N | | | | | |
| $i_1 n_0$ | 2.41 | 7.57 | 0.41 | 5.88 | 16.27 |
| $i_1 n_1$ | 3.79 | 8.39 | 0.28 | 6.57 | 19.04 |
| $i_2 n_0$ | 3.79 | 5.45 | 0.34 | 5.10 | 14.69 |
| $i_2 n_1$ | 2.55 | 7.40 | 0.29 | 6.50 | 16.73 |
| $i_3 n_0$ | 3.34 | 4.91 | 0.37 | 6.51 | 15.13 |
| $i_3 n_1$ | 4.51 | 6.58 | 0.38 | 8.30 | 19.78 |
| $i_4 n_0$ | 2.92 | 4.68 | 0.24 | 6.53 | 14.37 |
| $i_4 n_1$ | 3.85 | 7.14 | 0.26 | 5.25 | 16.52 |
| SEm (±) | 0.074 | 0.130 | 0.024 | 0.134 | 0.225 |
| CD (0.05) | 0.151 | 0.264 | 0.049 | 0.273 | 0.457 |
| I x M | | | | | |
| $i_1 m_1$ | 2.87 | 7.64 | 0.38 | 6.30 | 17.20 |
| $i_1 m_2$ | 3.33 | 8.37 | 0.31 | 6.16 | 18.11 |
| $i_2 m_1$ | 4.34 | 5.55 | 0.29 | 6.28 | 16.46 |
| $i_2 m_2$ | 2.00 | 7.29 | 0.34 | 5.32 | 14.96 |
| $i_3 m_1$ | 5.07 | 7.10 | 0.44 | 8.67 | 21.29 |
| $i_3 m_2$ | 2.78 | 4.38 | 0.31 | 6.14 | 13.62 |
| $i_4 m_1$ | 3.28 | 3.89 | 0.26 | 5.83 | 13.25 |
| $i_4 m_2$ | 3.49 | 7.94 | 0.25 | 5.96 | 17.64 |
| SEm (±) | 0.074 | 0.130 | 0.024 | 0.134 | 0.225 |
| CD (0.05) | 0.151 | 0.264 | 0.049 | 0.273 | 0.457 |
| N x M | | | | | |
| $n_0 m_1$ | 3.74 | 6.09 | 0.33 | 5.86 | 16.02 |
| $n_0 m_2$ | 2.49 | 5.22 | 0.35 | 6.16 | 14.21 |
| $n_1 m_1$ | 4.04 | 6.01 | 0.35 | 7.68 | 18.08 |
| $n_1 m_2$ | 3.31 | 8.75 | 0.26 | 5.63 | 17.95 |
| SEm (±) | 0.052 | 0.092 | 0.017 | 0.095 | 0.159 |
| CD (0.05) | 0.106 | 0.187 | 0.034 | 0.193 | 0.323 |
| I x N x M | | | | | |
| $i_1 n_0 m_1$ | 2.43 | 8.89 | 0.50 | 5.95 | 17.76 |
| $i_1 n_0 m_2$ | 2.39 | 6.25 | 0.33 | 5.82 | 14.78 |
| $i_1 n_1 m_1$ | 3.32 | 6.40 | 0.27 | 6.65 | 16.64 |
| $i_1 n_1 m_2$ | 4.27 | 10.38 | 0.30 | 6.50 | 21.44 |
| $i_2 n_0 m_1$ | 5.65 | 6.96 | 0.21 | 4.96 | 17.8 |
| $i_2 n_0 m_2$ | 1.93 | 3.93 | 0.48 | 5.24 | 11.58 |
| $i_2 n_1 m_1$ | 3.03 | 4.14 | 0.36 | 7.59 | 15.12 |
| $i_2 n_1 m_2$ | 2.07 | 10.66 | 0.21 | 5.40 | 18.34 |
| $i_3 n_0 m_1$ | 3.34 | 5.14 | 0.36 | 6.45 | 15.29 |
| $i_3 n_0 m_2$ | 3.34 | 4.69 | 0.38 | 6.58 | 14.98 |
| $i_3 n_1 m_1$ | 6.80 | 9.07 | 0.52 | 10.90 | 27.29 |
| $i_3 n_1 m_2$ | 2.23 | 4.08 | 0.25 | 5.71 | 12.27 |
| $i_4 n_0 m_1$ | 3.53 | 3.3 | 0.28 | 6.07 | 13.23 |
| $i_4 n_0 m_2$ | 2.30 | 6.00 | 0.21 | 7.00 | 15.51 |
| $i_4 n_1 m_1$ | 3.03 | 4.41 | 0.24 | 5.59 | 13.27 |
| $i_4 n_1 m_2$ | 4.68 | 9.87 | 0.29 | 4.92 | 19.76 |
| SEm (±) | 0.105 | 0.184 | 0.034 | 0.190 | 0.319 |
| CD (0.05) | 0.213 | 0.374 | 0.069 | 0.386 | 0.646 |

In the case of method of application, soil application recorded higher K uptake by leaf, stem and root, while it was insignificant in K uptake by pod. Total uptake of potassium was also more in soil application of N and K ($M_1$).

Regarding I x N combinations, $i_1n_1$ was superior in K uptake by leaf, which was on par with $i_1n_0$. K uptake by stem was more in $i_3n_1$ and was on par with $i_3n_0$. $i_1n_0$ was significantly superior for K uptake by pod and total uptake.

Among I x M interactions, $i_1m_1$ recorded the highest uptake of K by leaf and root. In the case of stem, $i_3m_2$ recorded the highest uptake and was on par with $i_1m_1$. The combination, $i_4m_1$ registered the highest K uptake by pod and was on par with $i_3m_2$. The total uptake of K by the crop was found to be superior for $i_1m_1$ and was on par with $i_3m_2$.

Among N x M interaction, $n_0m_2$ had the highest uptake of K by both leaf and pod and it was on par with $n_0m_1$ in the case of K uptake by leaf. $n_1m_1$ recorded significantly superior K uptake by stem while, N x M interaction was insignificant in K uptake by root. Regarding the total K uptake, $n_0m_2$ and $n_1m_1$ were on par and superior.

Among I x N x M interaction, $i_1n_1m_1$ registered the highest uptake of K by leaf and stem, while uptake by pod was significantly superior for $i_1n_0m_1$. The total uptake of K was found to be superior for $i_3n_0m_2$ (176.9 kg $ha^{-1}$) and was on par with $i_1n_0m_1$.

4.7 SOIL NUTRIENT STATUS AFTER THE EXPERIMENT

The data presented in Table 36 revealed that irrigation levels significantly influenced both soil P and K while it was non-significant for soil N. Soil P was the highest for daily irrigation at 10 mm depth ($I_1$). Irrigating once in three days at 20 mm depth ($I_3$) registered superior K content which was on par with irrigating in alternate days ($I_2$).

N levels influenced N, P and K status in the soil. RD N ($N_0$) recorded superior N (352.86 kg $ha^{-1}$) and P (169.29 kg $ha^{-1}$) over 25 per cent less of RD N ($N_1$), while K was found to be higher for $N_1$.

Method of application significantly influenced P where soil application ($M_1$) recorded higher P (166.33 kg $ha^{-1}$) content.

Among the interactions, I x N was found to be significant for all three nutrients. The highest N content was registered by $i_4n_0$ which was on par with $i_3n_0$ and $i_1n_0$. The combination, $i_3n_0$ recorded the highest soil P which was on par with $i_1n_1$, while $i_2n_1$ recorded significantly superior K content in soil and was on par with $i_3n_1$ and $i_1n_1$.

Soil P and K were significantly influenced by I x M interactions. The combinations $i_1m_1$ and $i_2m_1$ were on par and registered superior P content, while $i_2m_1$ registered the maximum K content.

N x M interaction influenced only soil K where $n_1m_2$ was superior to other combinations.

In the case of I x N x M interaction soil P and K were favorably influenced. The combination, $i_1n_1m_2$ recorded the highest P content and was on par with $i_3n_0m_2$, $i_3n_0m_1$, $i_2n_0m_1$ and $i_1n_1m_1$. The maximum K content was recorded by $i_1n_1m_2$ which was on par with $i_3n_1m_2$, $i_2n_1m_2$, $i_2n_1m_1$ and $i_2n_0m_1$.

## 4.8 MOISTURE STUDIES

### 4.8.1 Water Requirement, Water Use Efficiency and Water Productivity

Data on total water requirement, WUE and water productivity as influenced by irrigation and nitrogen levels and method of application are given in Tables 39 and 40.

The water requirement of yard long bean ranged from 662 – 1022 mm. The highest requirement of 1004.5 mm was registered under daily irrigation at 10

Table 35. Effect of irrigation, nitrogen levels and method of application on uptake of potassium, kg ha$^{-1}$

| Treatments | Leaf (source) | Stem | Root | Pod (sink) | Total |
|---|---|---|---|---|---|
| Irrigation Levels | | | | | |
| $I_1$ - Daily at 10 mm depth | 47.31 | 69.67 | 4.27 | 38.14 | 159.40 |
| $I_2$ – Alternate days at 20 mm depth | 32.45 | 60.22 | 2.97 | 41.21 | 136.85 |
| $I_3$ - Once in three days, 20 mm depth | 36.45 | 78.33 | 4.15 | 41.29 | 160.23 |
| $I_4$ - $I_3$ up to flowering followed by $I_2$ | 25.84 | 63.58 | 3.15 | 41.68 | 134.26 |
| SEm (±) | 0.474 | 1.178 | 0.117 | 0.760 | 0.984 |
| CD (0.05) | 1.071 | 2.664 | 0.264 | 1.719 | 2.226 |
| Nitrogen Levels | | | | | |
| $N_0$ - RD N | 38.33 | 67.57 | 3.83 | 44.07 | 153.81 |
| $N_1$ - 25 % less of RD N | 32.70 | 68.33 | 3.44 | 37.09 | 141.56 |
| SEm (±) | 0.446 | 0.668 | 0.133 | 0.467 | 1.106 |
| CD (0.05) | 0.904 | NS | 0.270 | 0.946 | 2.242 |
| Method of application | | | | | |
| $M_1$ - Soil application | 36.19 | 72.04 | 3.91 | 40.40 | 152.55 |
| $M_2$ – Soil + foliar application | 34.84 | 63.86 | 3.36 | 40.75 | 142.82 |
| SEm (±) | 0.446 | 0.668 | 0.133 | 0.467 | 1.106 |
| CD (0.05) | 0.904 | 1.355 | 0.270 | NS | 2.242 |

Table 36. Effect of irrigation, nitrogen levels and method of application on available soil nitrogen, phosphorus and potassium after the experiment, kg ha$^{-1}$

| Treatments | N | P | K |
|---|---|---|---|
| Irrigation Levels | | | |
| $I_1$ - Daily at 10 mm depth | 332.31 | 187.98 | 283.86 |
| $I_2$ – Alternate days at 20 mm depth | 288.71 | 145.57 | 301.07 |
| $I_3$ - Once in three days, 20 mm depth | 326.27 | 159.17 | 306.58 |
| $I_4$ - $I_3$ up to flowering followed by $I_2$ | 320.54 | 117.56 | 232.56 |
| SEm (±) | 18.171 | 3.650 | 14.56 |
| CD (0.05) | NS | 8.255 | 32.94 |
| Nitrogen Levels | | | |
| $N_0$ - RD N | 352.86 | 169.29 | 246.79 |
| $N_1$ - 25 % less of RD N | 281.06 | 135.84 | 315.24 |
| SEm (±) | 9.525 | 3.784 | 6.89 |
| CD (0.05) | 19.317 | 7.675 | 13.97 |
| Method of application | | | |
| $M_1$ - Soil application | 317.47 | 166.33 | 282.35 |
| $M_2$ – Soil + foliar application | 316.45 | 138.80 | 279.69 |
| SEm (±) | 9.525 | 3.784 | 6.89 |
| CD (0.05) | NS | 7.675 | NS |

Table 37. Interaction effect of irrigation, nitrogen and method of application on uptake of potassium, kg ha$^{-1}$

| Treatments | Leaf (source) | Stem | Root | Pod (sink) | Total |
|---|---|---|---|---|---|
| I x N | | | | | |
| $i_1 n_0$ | 46.57 | 73.84 | 4.55 | 52.79 | 177.75 |
| $i_1 n_1$ | 48.06 | 65.51 | 3.98 | 23.49 | 141.04 |
| $i_2 n_0$ | 38.08 | 51.92 | 2.89 | 40.74 | 133.63 |
| $i_2 n_1$ | 26.82 | 68.52 | 3.04 | 41.69 | 140.08 |
| $i_3 n_0$ | 42.23 | 77.10 | 4.34 | 39.00 | 162.67 |
| $i_3 n_1$ | 30.68 | 79.57 | 3.96 | 43.58 | 157.80 |
| $i_4 n_0$ | 26.45 | 67.42 | 3.52 | 43.78 | 141.18 |
| $i_4 n_1$ | 25.23 | 59.74 | 2.78 | 39.59 | 127.34 |
| SEm (±) | 0.892 | 1.336 | 0.266 | 0.933 | 2.211 |
| CD (0.05) | 1.809 | 2.710 | NS | 1.893 | 4.485 |
| I x M | | | | | |
| $i_1 m_1$ | 51.36 | 82.21 | 4.92 | 37.64 | 176.13 |
| $i_1 m_2$ | 43.27 | 57.13 | 3.62 | 38.64 | 142.67 |
| $i_2 m_1$ | 35.84 | 69.09 | 3.72 | 40.85 | 149.49 |
| $i_2 m_2$ | 29.07 | 51.35 | 2.21 | 41.58 | 124.22 |
| $i_3 m_1$ | 32.60 | 72.28 | 4.09 | 38.31 | 147.28 |
| $i_3 m_2$ | 40.31 | 84.39 | 4.21 | 44.27 | 173.19 |
| $i_4 m_1$ | 24.96 | 64.59 | 2.92 | 44.83 | 137.30 |
| $i_4 m_2$ | 26.73 | 62.57 | 3.38 | 38.53 | 131.22 |
| SEm (±) | 0.892 | 1.336 | 0.266 | 0.933 | 2.211 |
| CD (0.05) | 1.809 | 2.710 | 0.540 | 1.893 | 4.485 |
| N x M | | | | | |
| $n_0 m_1$ | 38.13 | 66.83 | 4.04 | 42.74 | 151.74 |
| $n_0 m_2$ | 38.54 | 68.30 | 3.62 | 45.41 | 155.87 |
| $n_1 m_1$ | 34.25 | 77.25 | 3.78 | 38.07 | 153.36 |
| $n_1 m_2$ | 31.15 | 59.42 | 3.10 | 36.10 | 129.77 |
| SEm (±) | 0.631 | 0.945 | 0.188 | 0.660 | 1.564 |
| CD (0.05) | 1.279 | 1.917 | NS | 1.338 | 3.171 |
| I x N x M | | | | | |
| $i_1 n_0 m_1$ | 46.62 | 71.30 | 5.24 | 55.26 | 178.43 |
| $i_1 n_0 m_2$ | 46.52 | 76.37 | 3.86 | 50.32 | 177.08 |
| $i_1 n_1 m_1$ | 56.10 | 93.12 | 4.59 | 20.02 | 173.83 |
| $i_1 n_1 m_2$ | 40.02 | 37.89 | 3.38 | 26.96 | 108.25 |
| $i_2 n_0 m_1$ | 42.30 | 66.02 | 3.42 | 32.39 | 144.14 |
| $i_2 n_0 m_2$ | 33.87 | 37.81 | 2.36 | 49.09 | 123.12 |
| $i_2 n_1 m_1$ | 29.38 | 72.15 | 4.01 | 49.3 | 154.85 |
| $i_2 n_1 m_2$ | 24.27 | 64.89 | 2.08 | 34.07 | 125.31 |
| $i_3 n_0 m_1$ | 37.23 | 63.20 | 4.30 | 36.45 | 141.19 |
| $i_3 n_0 m_2$ | 47.23 | 90.99 | 4.38 | 41.55 | 184.15 |
| $i_3 n_1 m_1$ | 27.97 | 81.36 | 3.87 | 40.17 | 153.37 |
| $i_3 n_1 m_2$ | 33.39 | 77.79 | 4.05 | 47.00 | 162.23 |
| $i_4 n_0 m_1$ | 26.38 | 66.81 | 3.17 | 46.85 | 143.22 |
| $i_4 n_0 m_2$ | 26.53 | 68.03 | 3.87 | 40.71 | 139.14 |
| $i_4 n_1 m_1$ | 23.53 | 62.36 | 2.67 | 42.81 | 131.38 |
| $i_4 n_1 m_2$ | 26.92 | 57.12 | 2.89 | 36.36 | 123.30 |
| SEm (±) | 1.261 | 0.376 | 0.376 | 1.320 | 3.127 |
| CD (0.05) | 2.558 | 0.764 | NS | 2.677 | 6.343 |

Table 38. Interaction effect of irrigation, nitrogen and method of application on available soil nitrogen, phosphorus and potassium after the experiment, kg ha$^{-1}$

| Treatments | N | P | K |
|---|---|---|---|
| I x N | | | |
| $i_1 n_0$ | 356.10 | 160.55 | 241.71 |
| $i_1 n_1$ | 308.53 | 215.41 | 326.00 |
| $i_2 n_0$ | 303.71 | 160.78 | 248.22 |
| $i_2 n_1$ | 273.71 | 130.35 | 353.93 |
| $i_3 n_0$ | 365.69 | 216.8 | 284.26 |
| $i_3 n_1$ | 286.85 | 101.53 | 328.91 |
| $i_4 n_0$ | 385.92 | 139.04 | 212.97 |
| $i_4 n_1$ | 255.15 | 96.07 | 252.15 |
| SEm (±) | 19.050 | 7.569 | 13.78 |
| CD (0.05) | 38.634 | 15.351 | 27.94 |
| I x M | | | |
| $i_1 m_1$ | 336.48 | 198.49 | 294.00 |
| $i_1 m_2$ | 328.14 | 177.47 | 273.71 |
| $i_2 m_1$ | 271.19 | 192.84 | 351.30 |
| $i_2 m_2$ | 306.23 | 98.29 | 250.85 |
| $i_3 m_1$ | 330.59 | 159.17 | 291.54 |
| $i_3 m_2$ | 321.95 | 159.16 | 321.62 |
| $i_4 m_1$ | 331.60 | 114.82 | 192.55 |
| $i_4 m_2$ | 309.47 | 120.29 | 272.57 |
| SEm (±) | 19.050 | 7.569 | 13.78 |
| CD (0.05) | NS | 15.351 | 27.94 |
| N x M | | | |
| $n_0 m_1$ | 356.81 | 184.18 | 277.46 |
| $n_0 m_2$ | 348.90 | 154.40 | 216.12 |
| $n_1 m_1$ | 278.12 | 148.47 | 287.24 |
| $n_1 m_2$ | 283.99 | 123.2 | 343.25 |
| SEm (±) | 13.470 | 5.352 | 9.74 |
| CD (0.05) | NS | NS | 19.76 |
| I x N x M | | | |
| $i_1 n_0 m_1$ | 380.22 | 187.79 | 316.53 |
| $i_1 n_0 m_2$ | 331.98 | 133.31 | 166.90 |
| $i_1 n_1 m_1$ | 292.75 | 209.18 | 271.48 |
| $i_1 n_1 m_2$ | 324.31 | 221.63 | 380.52 |
| $i_2 n_0 m_1$ | 281.72 | 213.36 | 349.94 |
| $i_2 n_0 m_2$ | 325.71 | 108.20 | 146.49 |
| $i_2 n_1 m_1$ | 260.66 | 172.32 | 352.65 |
| $i_2 n_1 m_2$ | 286.75 | 88.39 | 355.20 |
| $i_3 n_0 m_1$ | 373.22 | 216.13 | 291.40 |
| $i_3 n_0 m_2$ | 358.17 | 217.48 | 277.12 |
| $i_3 n_1 m_1$ | 287.97 | 102.21 | 291.69 |
| $i_3 n_1 m_2$ | 285.73 | 100.85 | 366.12 |
| $i_4 n_0 m_1$ | 392.09 | 119.45 | 151.96 |
| $i_4 n_0 m_2$ | 379.74 | 158.64 | 273.97 |
| $i_4 n_1 m_1$ | 271.12 | 110.19 | 233.13 |
| $i_4 n_1 m_2$ | 239.18 | 81.95 | 271.17 |
| SEm (±) | 26.940 | 10.704 | 19.48 |
| CD (0.05) | NS | 21.709 | 39.51 |

Table 39. Water requirement of yard long bean

| Treatment combinations | Water requirement (mm) | Mean WR (mm) |
|---|---|---|
| $i_1\ n_0\ m_1$ | 1012 | $I_1$ - 1004.5 |
| $i_1\ n_0\ m_2$ | 1022 | |
| $i_1\ n_1\ m_1$ | 982 | |
| $i_1\ n_1\ m_2$ | 1002 | |
| $i_2\ n_0\ m_1$ | 922 | $I_2$ - 927 |
| $i_2\ n_0\ m_2$ | 942 | |
| $i_2\ n_1\ m_1$ | 922 | |
| $i_2\ n_1\ m_2$ | 922 | |
| $i_3\ n_0\ m_1$ | 662 | $I_3$ - 662 |
| $i_3\ n_0\ m_2$ | 662 | |
| $i_3\ n_1\ m_1$ | 662 | |
| $i_3\ n_1\ m_2$ | 662 | |
| $i_4\ n_0\ m_1$ | 822 | $I_4$ - 822 |
| $i_4\ n_0\ m_2$ | 822 | |
| $i_4\ n_1\ m_1$ | 822 | |
| $i_4\ n_1\ m_2$ | 822 | |

Table 40. Effect of irrigation, nitrogen levels and method of application on water use efficiency and water productivity, kg ha.mm$^{-1}$

| Treatments | WUE | Water productivity |
|---|---|---|
| Irrigation Levels | | |
| $I_1$ - Daily at 10 mm depth | 9.32 | 4.96 |
| $I_2$ – Alternate days at 20 mm depth | 10.12 | 5.21 |
| $I_3$ - Once in three days, 20 mm depth | 14.58 | 6.84 |
| $I_4$ - $I_3$ up to flowering followed by $I_2$ | 11.61 | 5.78 |
| SEm (±) | 0.177 | 0.032 |
| CD (0.05) | 0.401 | 0.071 |
| Nitrogen Levels | | |
| $N_0$ - RD N | 11.25 | 5.75 |
| $N_1$ - 25 % less of RD N | 11.56 | 5.65 |
| SEm (±) | 0.086 | 0.038 |
| CD (0.05) | 0.175 | 0.078 |
| Method of application | | |
| $M_1$ - Soil application | 11.95 | 5.82 |
| $M_2$ – Soil + foliar application | 10.86 | 5.58 |
| SEm (±) | 0.086 | 0.038 |
| CD (0.05) | 0.175 | 0.078 |

Table 41. Interaction effect of irrigation, nitrogen and method of application on WUE and water productivity, kg ha.mm$^{-1}$

| Treatments | WUE | Water productivity |
|---|---|---|
| I x N | | |
| $i_1 n_0$ | 9.51 | 4.96 |
| $i_1 n_1$ | 9.14 | 4.95 |
| $i_2 n_0$ | 9.51 | 5.22 |
| $i_2 n_1$ | 10.73 | 5.21 |
| $i_3 n_0$ | 14.02 | 6.86 |
| $i_3 n_1$ | 15.14 | 6.82 |
| $i_4 n_0$ | 11.96 | 5.95 |
| $i_4 n_1$ | 11.26 | 5.61 |
| SEm (±) | 0.173 | 0.077 |
| CD (0.05) | 0.351 | 0.156 |
| I x M | | |
| $i_1 m_1$ | 9.52 | 5.11 |
| $i_1 m_2$ | 9.13 | 4.81 |
| $i_2 m_1$ | 10.61 | 5.32 |
| $i_2 m_2$ | 9.63 | 5.10 |
| $i_3 m_1$ | 15.58 | 7.01 |
| $i_3 m_2$ | 13.57 | 6.68 |
| $i_4 m_1$ | 12.11 | 5.84 |
| $i_4 m_2$ | 11.11 | 5.72 |
| SEm (±) | 0.173 | 0.077 |
| CD (0.05) | 0.351 | NS |
| N x M | | |
| $n_0 m_1$ | 11.65 | 5.90 |
| $n_0 m_2$ | 10.85 | 5.60 |
| $n_1 m_1$ | 12.26 | 5.74 |
| $n_1 m_2$ | 10.87 | 5.56 |
| SEm (±) | 0.122 | 0.054 |
| CD (0.05) | 0.248 | NS |
| I x N x M | | |
| $i_1 n_0 m_1$ | 9.80 | 5.14 |
| $i_1 n_0 m_2$ | 9.21 | 4.78 |
| $i_1 n_1 m_1$ | 9.23 | 5.08 |
| $i_1 n_1 m_2$ | 9.05 | 4.83 |
| $i_2 n_0 m_1$ | 9.75 | 5.43 |
| $i_2 n_0 m_2$ | 9.28 | 5.01 |
| $i_2 n_1 m_1$ | 11.48 | 5.21 |
| $i_2 n_1 m_2$ | 9.98 | 5.20 |
| $i_3 n_0 m_1$ | 14.76 | 7.07 |
| $i_3 n_0 m_2$ | 13.27 | 6.66 |
| $i_3 n_1 m_1$ | 16.40 | 6.94 |
| $i_3 n_1 m_2$ | 13.87 | 6.70 |
| $i_4 n_0 m_1$ | 12.27 | 5.95 |
| $i_4 n_0 m_2$ | 11.65 | 5.95 |
| $i_4 n_1 m_1$ | 11.95 | 5.73 |
| $i_4 n_1 m_2$ | 10.58 | 5.49 |
| SEm (±) | 0.244 | 0.109 |
| CD (0.05) | 0.495 | 0.221 |

mm depth ($I_1$) and the lowest requirement (662 mm) was for irrigating once in three days at 20 mm depth ($I_3$).

Irrigating once in three days at 20 mm depth recorded significantly higher WUE and water productivity (14.58 kg ha.mm$^{-1}$ and 6.84 kg ha.mm$^{-1}$) compared to all other irrigation levels. Daily irrigation registered the lowest values of WUE and water productivity.

Nitrogen levels and application methods also exerted a favorable influence on both parameters. Providing N @ 25 per cent less of RD ($N_1$) recorded higher WUE (11.56 kg ha.mm$^{-1}$) while, water productivity was significantly higher for RD of N ($N_0$). Among the two application methods, soil application resulted in higher WUE and water productivity (11.95 kg ha.mm$^{-1}$ and 5.82 kg ha.mm$^{-1}$ respectively).

Regarding the combination effects, I x N was found to be significant for both WUE and water productivity. $i_3n_1$ resulted in the highest WUE (15.14 kg ha.mm$^{-1}$) and was significantly superior whereas, $i_3n_0$ registered maximum water productivity (6.86 ha.mm$^{-1}$) which was on par with $i_3n_1$.

Among I x M interactions, $i_3m_1$ was significantly superior in WUE while in N x M combinations, $n_1m_1$ was found superior.

WUE and water productivity varied significantly with I x N x M combinations. $i_3n_1m_1$ registered superior WUE, while $i_3n_0m_1$ recorded the highest water productivity which was on par with $i_3n_1m_1$.

**4.8.2 Moisture Depletion Pattern**

The moisture depletion pattern of different plots under the combined influence of irrigation levels, nitrogen levels and method of application are given in Table 42.

At 0 to 15 cm depth, the highest soil moisture depletion (80.08 per cent) was recorded by daily irrigation with RD N as soil application ($i_1n_0m_1$) and the lowest moisture depletion (72.85 per cent) was recorded by irrigation once in three days with 25 per cent less of RD N as soil application ($i_3n_1m_1$).

At 15 to 30 cm depth, the maximum soil moisture depletion (51.35 per cent) was recorded in irrigating once in three days with RD N as soil application ($i_3n_0m_1$) and the minimum depletion was observed in daily irrigation at 10 mm depth with RD N as soil + foliar application ($i_1n_0m_2$).

## 4.9 ECONOMIC ANALYSIS

### 4.9.1 Gross Income

Economic analysis data presented in Table 43 revealed that among the main effects, only method of application had significant influence on gross returns. Soil application of N and K ($M_1$) resulted in superior gross income (₹ 3,98,856) compared to soil + foliar application ($M_2$).

Among the interactions, I x N, I x M and N x M were significant. The combination $i_2n_1$ resulted in the highest gross income of ₹ 3,95,422 and was on par with $i_1n_0$, $i_4n_0$ and $i_3n_1$. Regarding I x M interactions, $i_3m_1$ gave the highest gross returns and was on par with $i_4m_1$.

In the case of N x M interactions, $n_1m_1$ was observed significantly superior.

### 4.9.2 Net Income

Similar to gross returns, the net returns was also significantly influenced by method of application where soil application of N and K was found to be superior (₹ 2,95,918).

Among the interactions, I x N, I x M and N x M were significant. $i_2n_1$ resulted in the highest net returns of ₹ 2,92,133 and was on par with $i_3n_1$, $i_4n_0$ and $i_1n_0$. Regarding I x M interactions, $i_3m_1$ gave the highest net income.

In the case of N x M interactions, $n_1m_1$ was observed significantly superior.

**4.9.3 B : C Ratio**

Different irrigation levels, method of application of nutrients and interactions significantly influenced the B : C ratio (Table 43). Irrigating once in three days at 20 mm depth ($I_3$) recorded the highest BCR (3.77) which was on par with irrigating once in three days up to flowering followed by irrigating in alternate days ($I_4$) and irrigating in alternate days ($I_2$). There was no variation in BCR by reducing nitrogen levels to 75 per cent of RD. Soil application was found to be superior with a BCR of 3.88 over soil + foliar application.

Among I x N interactions, $i_3n_1$ recorded the highest BCR (3.89) and was on par with $i_4n_0$ and $i_2n_1$. Regarding I x M interactions, $i_3m_1$ gave the highest BCR.

In the case of N x M interactions, $n_1m_1$ was found to have significantly superior BCR over other combinations. I x N x M interaction did not have any influence on BCR.

4.10 CORRELATION OF YIELD WITH OTHER IMPORTANT PARAMETERS

Results in Table 45 indicated that the pod yield showed significant positive correlation with major yield attributes, *viz.*, pod number per plant and pod yield per plant (0.985 and 0.986 respectively). Harvest index, nitrogen and phosphorus uptake by sink also had significant positive correlation with pod yield. The source : sink ratio showed significant negative correlation with yield (-0.775). Though not significant, LAI also showed negative correlation with yield. The total dry matter production was positively correlated with LAI, total N uptake, uptake of N by source and uptake of N by sink.

Table 42. Effect of irrigation, nitrogen levels and method of application on moisture depletion pattern, per cent

| Treatments | 0-15 cm | 15-30 cm |
|---|---|---|
| Irrigation Levels | | |
| $I_1$ - Daily at 10 mm depth | 62.49 | 23.70 |
| $I_2$ – Alternate days at 20 mm depth | 57.50 | 33.15 |
| $I_3$ - Once in three days, 20 mm depth | 38.50 | 44.53 |
| $I_4$ - $I_3$ up to flowering followed by $I_2$ | 55.80 | 37.25 |
| SEm (±) | 0.068 | 0.045 |
| CD (0.05) | 0.153 | 0.102 |
| Nitrogen Levels | | |
| $N_0$ - RD N | 53.67 | 34.59 |
| $N_1$ - 25 % less of RD N | 53.47 | 34.72 |
| SEm (±) | 0.082 | 0.057 |
| CD (0.05) | 0.166 | 0.116 |
| Method of application | | |
| $M_1$ - Soil application | 53.56 | 34.64 |
| $M_2$ – Soil + foliar application | 53.58 | 34.67 |
| SEm (±) | 0.082 | 0.057 |
| CD (0.05) | NS | NS |

Table 43. Effect of irrigation, nitrogen levels and method of application on economics of cultivation

| Treatments | Gross income (₹) | Net income (₹) | BCR |
|---|---|---|---|
| Irrigation Levels | | | |
| $I_1$ - Daily at 10 mm depth | 383447 | 273155 | 3.48 |
| $I_2$ – Alternate days at 20 mm depth | 374934 | 271602 | 3.63 |
| $I_3$ - Once in three days, 20 mm depth | 380560 | 279548 | 3.77 |
| $I_4$ - $I_3$ up to flowering followed by $I_2$ | 381574 | 279402 | 3.74 |
| SEm (±) | 6713.85 | 6713.85 | 0.063 |
| CD (0.05) | NS | NS | 0.142 |
| Nitrogen Levels | | | |
| $N_0$ - RD N | 377456 | 273211 | 3.62 |
| $N_1$ - 25 % less of RD N | 382802 | 278642 | 3.68 |
| SEm (±) | 3754.62 | 3754.62 | 0.035 |
| CD (0.05) | NS | NS | NS |
| Method of application | | | |
| $M_1$ - Soil application | 398856 | 295918 | 3.88 |
| $M_2$ – Soil + foliar application | 361401 | 255935 | 3.43 |
| SEm (±) | 3754.62 | 3754.62 | 0.042 |
| CD (0.05) | 7614.71 | 7614.71 | 0.072 |

Table 44. Interaction effect of irrigation, nitrogen and method of application on economics of cultivation

| Treatments | Gross income (₹) | Net income (₹) | BCR |
|---|---|---|---|
| I x N | | | |
| $i_1$ $n_0$ | 393539 | 283205 | 3.57 |
| $i_1$ $n_1$ | 373356 | 263106 | 3.39 |
| $i_2$ $n_0$ | 354445 | 251071 | 3.43 |
| $i_2$ $n_1$ | 395422 | 292133 | 3.83 |
| $i_3n_0$ | 368775 | 267721 | 3.65 |
| $i_3$ $n_1$ | 392346 | 291376 | 3.89 |
| $i_4$ $n_0$ | 393065 | 290850 | 3.85 |
| $i_4$ $n_1$ | 370084 | 267955 | 3.63 |
| SEm (±) | 7509.25 | 7509.25 | 0.071 |
| CD (0.05) | 15229.40 | 15229.40 | 0.144 |
| I x M | | | |
| $i_1$ $m_1$ | 393839 | 284811 | 3.61 |
| $i_1$ $m_2$ | 373056 | 261500 | 3.34 |
| $i_2$ $m_1$ | 391275 | 289207 | 3.83 |
| $i_2$ $m_2$ | 358593 | 253997 | 3.43 |
| $i_3$ $m_1$ | 412375 | 312627 | 4.14 |
| $i_3$ $m_2$ | 348746 | 246470 | 3.41 |
| $i_4$ $m_1$ | 397937 | 297029 | 3.94 |
| $i_4$ $m_2$ | 365212 | 261776 | 3.53 |
| SEm (±) | 7509.25 | 7509.25 | 0.071 |
| CD (0.05) | 15229.4 | 15229.40 | 0.144 |
| N x M | | | |
| $n_0$ $m_1$ | 389250 | 286248 | 3.78 |
| $n_0$ $m_2$ | 365662 | 260174 | 3.47 |
| $n_1$ $m_1$ | 408463 | 305588 | 3.98 |
| $n_1$ $m_2$ | 357141 | 251696 | 3.39 |
| SEm (±) | 5309.84 | 5309.84 | 0.050 |
| CD (0.05) | 10768.80 | 10768.80 | 0.102 |
| I x N x M. | | | |
| $i_1$ $n_0$ $m_1$ | 403573 | 294481 | 3.70 |
| $i_1$ $n_0$ $m_2$ | 383505 | 271928 | 3.44 |
| $i_1$ $n_1$ $m_1$ | 384105 | 275141 | 3.53 |
| $i_1$ $n_1$ $m_2$ | 362606 | 251071 | 3.25 |
| $i_2$ $n_0$ $m_1$ | 359530 | 257398 | 3.52 |
| $i_2$ $n_0$ $m_2$ | 349360 | 244743 | 3.34 |
| $i_2$ $n_1$ $m_1$ | 423019 | 321015 | 4.15 |
| $i_2$ $n_1$ $m_2$ | 367825 | 263250 | 3.52 |
| $i_3$ $n_0$ $m_1$ | 390626 | 290814 | 3.92 |
| $i_3$ $n_0$ $m_2$ | 346924 | 244627 | 3.39 |
| $i_3$ $n_1$ $m_1$ | 434123 | 334439 | 4.36 |
| $i_3$ $n_1$ $m_2$ | 350568 | 248313 | 3.43 |
| $i_4$ $n_0$ $m_1$ | 403271 | 302299 | 4.00 |
| $i_4$ $n_0$ $m_2$ | 382858 | 279401 | 3.70 |
| $i_4$ $n_1$ $m_1$ | 392603 | 291759 | 3.89 |
| $i_4$ $n_1$ $m_2$ | 347565 | 244150 | 3.36 |
| SEm (±) | 10619.70 | 10619.70 | 0.100 |
| CD (0.05) | NS | NS | NS |

Table 45. Correlation of yield with other important parameters

| | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X8 | X9 | X10 | X11 | X12 | X13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X1 | 1.000 | | | | | | | | | | | | |
| X2 | -0.282 | 1.000 | | | | | | | | | | | |
| X3 | 0.985** | -0.231 | 1.000 | | | | | | | | | | |
| X4 | 0.986** | -0.237 | 0.999** | 1.000 | | | | | | | | | |
| X5 | 0.311 | 0.556* | 0.350 | 0.352 | 1.000 | | | | | | | | |
| X6 | -0.775** | 0.572* | -0.778** | -0.778** | 0.224 | 1.000 | | | | | | | |
| X7 | 0.913** | -0.474* | 0.874** | 0.872** | 0.121 | -0.753** | 1.000 | | | | | | |
| X8 | 0.091 | 0.615 | 0.156 | 0.157 | 0.741** | 0.318 | -0.025 | 1.000 | | | | | |
| X9 | 0.628 | 0.273 | 0.644** | 0.646** | 0.608* | -0.403 | 0.482 | 0.387 | 1.000 | | | | |
| X10 | 0.232 | -0.359 | 0.174 | 0.173 | -0.125 | -0.302 | 0.278 | -0.088 | -0.047 | 1.000 | | | |
| X11 | 0.711** | -0.333 | 0.714** | 0.713** | -0.139 | -0.857** | 0.603* | -0.243 | 0.309 | 0.483 | 1.000 | | |
| X12 | -0.247 | 0.712** | -0.182 | -0.181 | 0.310 | 0.282 | -0.418 | 0.265 | 0.293 | -0.032 | -0.097 | 1.000 | |
| X13 | 0.191 | 0.083 | 0.202 | 0.203 | -0.014 | -0.113 | 0.239 | 0.205 | 0.338 | -0.389 | -0.011 | -0.230 | 1.000 |

X1 – Pod yield (q $ha^{-1}$)

X2 – LAI

X3 - Pod number $plant^{-1}$

X4 – Pod yield $plant^{-1}$ (g)

X5 – Total DMP (q $ha^{-1}$)

X6 – Source : sink ratio

X7 – Harvest index

X8 - N uptake-source (kg $ha^{-1}$)

X9 – N uptake-sink (kg $ha^{-1}$)

X10 – P uptake-source (kg $ha^{-1}$)

X11 - P uptake-sink (kg $ha^{-1}$)

X12 – K uptake-source (kg $ha^{-1}$)

X13 - K uptake-sink (kg $ha^{-1}$)

* - Significant at 5 % level

** - Significant at 1 % level

# Discussion

# 5. DISCUSSION

A study entitled "Stress induced source-sink modulation in yard long bean (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt)" was undertaken during summer, 2014 to evaluate the influence of irrigation and nitrogen stress and method of application on the performance of yard long bean. The salient results of the study presented in the previous chapter are discussed in this chapter.

## 5.1 INFLUENCE ON GROWTH, YIELD AND BIOCHEMICAL CHARACTERS

### 5.1.1 Irrigation on Growth, Yield and Biochemical Characters

Review of results revealed that the different levels of irrigation did not influence the vegetative / growth characters at early growth stages. During later stages, irrigation levels exhibited differential response to growth attributes. Irrigating the crop once in three days up to flowering followed by irrigation in alternate days ($I_4$) registered the highest number of branches, while daily irrigation ($I_1$) produced the highest leaf number. The mild water stress experienced by the crop in alternate day irrigation might have stimulated the production of more number of branches. Increase in branching under mild stress has been reported by Fageria and Bajpal (1971) in peas, Subramanian *et al.* (1976) in green gram and Balakumaran (1981) in grain cowpea. The better availability of nutrients under favourable moisture regimes in daily irrigation enhanced the nutrient uptake and leaf production. This improvement in leaf number with daily irrigation has also reflected in increased LAI in $I_1$. Mini (1997) reported an improvement in leaf area of yard long bean by frequent light irrigation at 10 mm depth.

The different levels of irrigation did not have any significant influence on the yield of yard long bean. Yield of any plant is contributed by the combined influence of yield attributes and in the present study, the major yield attributes *viz.*, pod yield per plant and pod number per plant were not influenced by irrigation regimes which in turn caused non-significant variation on total yield. Correlation studies revealed the positive significance of yield attributes like pod yield per plant and number of pods per plant on total yield (Table 45). The different levels of irrigation behaved differently in terms of pod characters. Irrigating the crop once in three days up to flowering followed by irrigation in alternate days ($I_4$) recorded the maximum pod length and daily irrigation ($I_1$) registered the maximum pod girth. Being an indeterminate plant, crop duration and number of pickings also had significance on crop yield. Daily irrigation ($I_1$) favoured the crop duration and inducing stress by increasing irrigation interval reduced the crop duration. The crop duration was 105 days in daily irrigation while, in $I_4$ (irrigation once in three days up to flowering followed by irrigation in alternate days) the duration was 95 days, *i.e.*, about 10 days reduction in crop duration was observed under irrigation at wider intervals (Table 11). However, this reduction in duration under mild stress did not cause in any variation in pod yield. In treatments subjected to moisture stress, flowering started slightly early and earlier harvests registered more yield than daily irrigated plots (Table 11 and Fig. 5), whereas in non-stressed plots (daily irrigated plots), the onset of flowering was slightly delayed and hence yield was less in earlier harvests, but the number of pickings were more (20.97) and more yield was registered in later harvests. This variation in yield at different harvests led to non-significant variation in yield among different irrigation levels. The results of this study indicated that daily irrigation is not essential for yard long bean. Providing irrigation in alternate days or once in three days or once in three days up to flowering and then in alternate days is sufficient to obtain higher yield. However, when the irrigation interval was increased to two or three days, the irrigation depth has to be increased to 20 mm. This observation holds greater significance in the point of water economy.

Varying irrigation interval imparted significant influence on biochemical attributes like chlorophyll content, proline, crude protein and crude fibre. The highest value of total chlorophyll was observed under daily irrigation at 10 mm depth ($I_1$) (Table 24). The leaf chlorophyll content was positively correlated with leaf water potential and negatively with water stress suggesting that chlorophyll degradation is associated with reduction in soil water content or internal water deficit experienced by the plant (Herbinger *et al.*, 2002). Significant reduction in

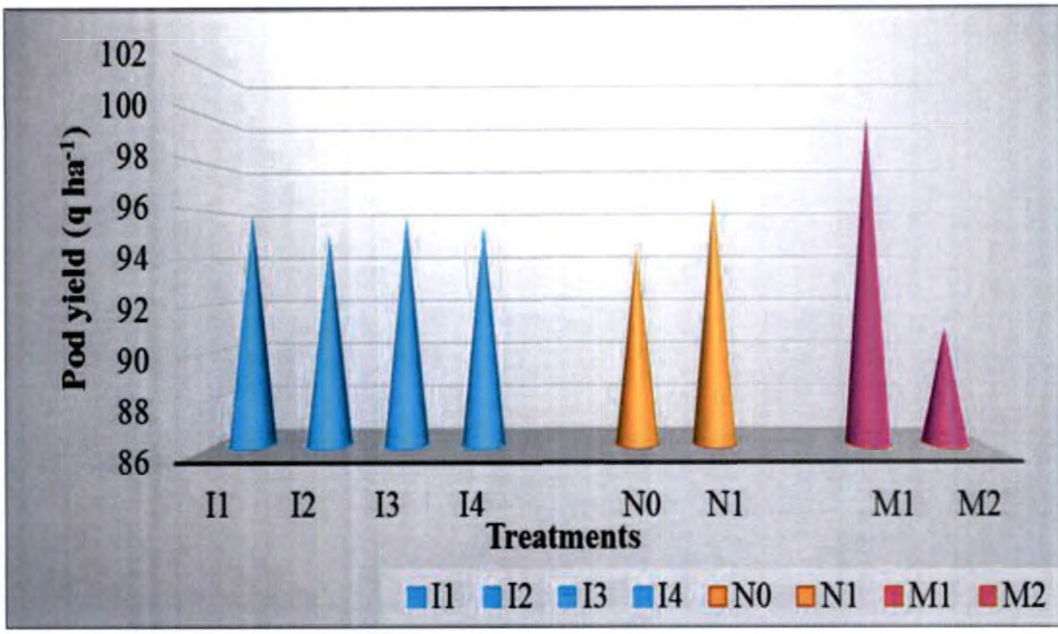


Fig 3. Pod yield as influenced by influenced by irrigation, nitrogen levels and method of application

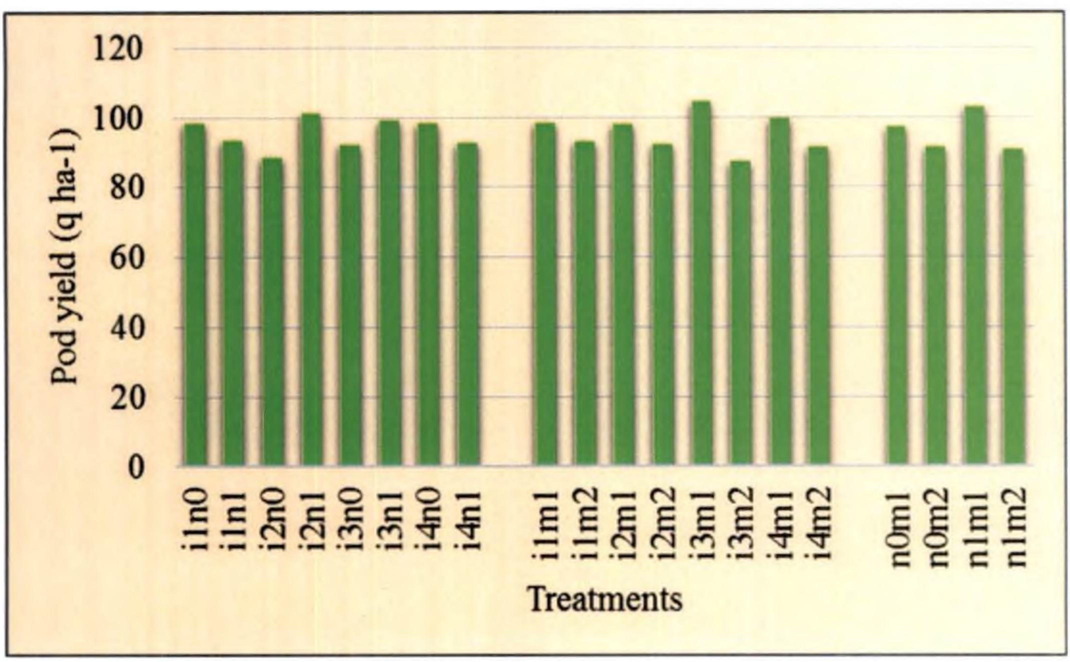


Fig.4 Pod yield as influenced by combined effect of irrigation, nitrogen levels and method of application

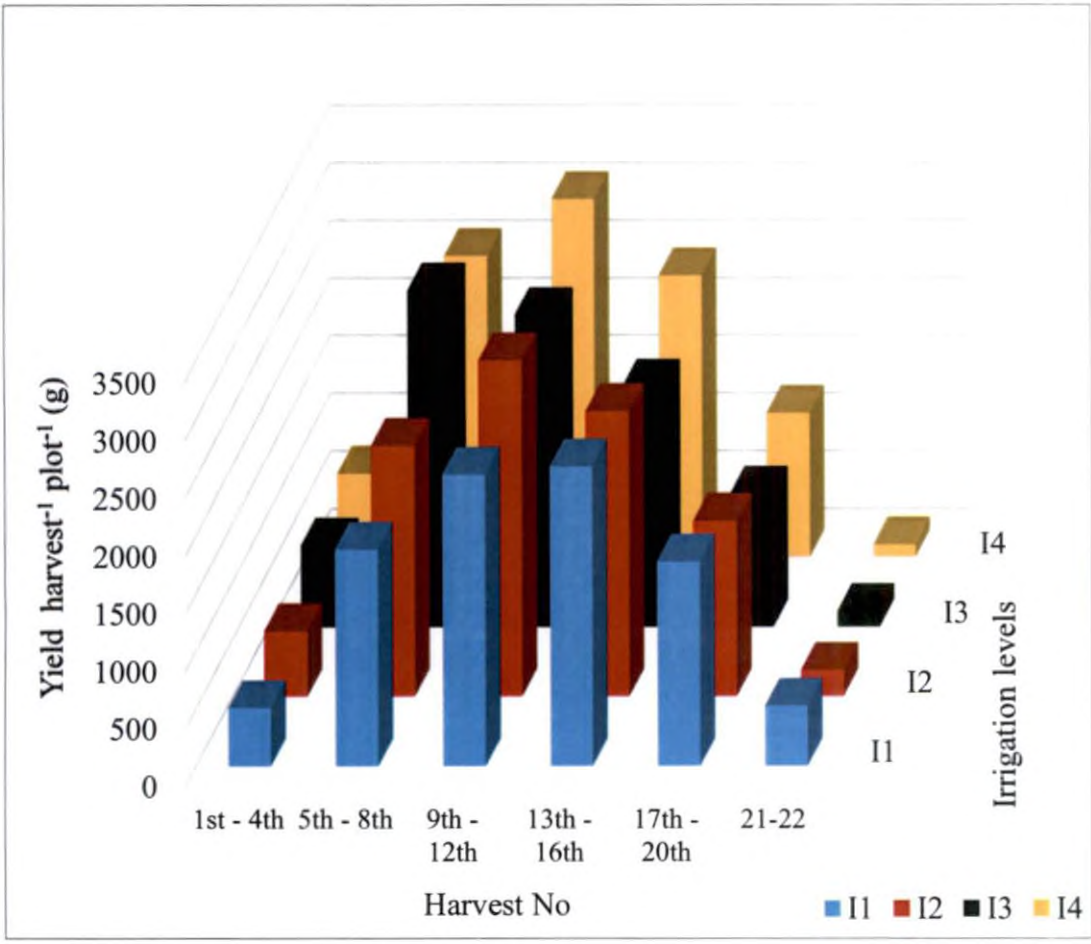


Fig. 5. Pod yield per plot per harvest as influenced by influenced by irrigation levels


a. 1st harvest


b. 6th harvest

Plate 5. Comparison of pod yield plot$^{-1}$ at different harvests at different levels of irrigation


c. 15th harvest


d. 19th harvest

Plate 5 continued. Comparison of pod yield plot$^{-1}$ at different harvests at different levels of irrigation chlorophyll content under conditions of water stress was reported by Diputado and del Rosario (1985) in grain cowpea. Mafakheri *et al.* (2010) reported that drought stress imposed at vegetative stage or reproductive stage significantly decreased chlorophyll *a*, chlorophyll *b* and total chlorophyll content in chickpea. The results of the present study is in conformity with these findings.

Proline analysis of leaves at flowering indicated that maximum content was observed in $I_3$ (irrigating once in three days) and the minimum in daily irrigation at 10 mm depth. A higher level of proline during water stress due to enhanced proline synthesis is well established. El Sayed (1992) reported that the proline content in leaves and roots increased steadily with increase in the intensity of water stress. Earlier studies also indicated that providing mild stress to yard long bean by irrigating with micro sprinklers at 10 mm CPE and 20 mm depth recorded the highest proline content compared to daily irrigation (Geetha, 1999). Proline accumulation is believed to play adaptive role in plant stress tolerance (Verbruggen and Hermans, 2008) and can affect the solubility of various proteins, thus protecting them against denaturation under water stress conditions.

Daily irrigation at 10 mm depth enhanced the crude protein content and it was on par with irrigation in alternate days ($I_2$). The increased protein content in this frequently irrigated treatments might be due to the increased N uptake (Table 31), since N plays a crucial role in protein synthesis. A decreased protein content in soybean due to stress at pod formation stage was observed by Pritoni *et al.* (1990).

Crude fibre content in vegetables play an important role in human digestion and yard long bean is a rich source of dietary fibre. Fibre content showed an inverse relationship with moisture status. Treatment receiving irrigation once in three days at 20 mm depth ($I_3$) recorded the highest crude fibre and daily irrigation at 10 mm depth ($I_1$) registered the lowest fibre content. Similar increase in crude fibre by imparting stress was also noticed by Samaila *et al.* (2011) in tomato.

**5.1.2 Nitrogen on Growth, Yield and Biochemical Characters**

Nitrogen levels significantly influenced the growth parameters *viz.*, number of leaves at 90 DAS and LAI at flowering. Application of RD N (30 kg $ha^{-1}$) enhanced the number of functional leaves and LAI. Availability of sufficient quantity of N along with other major nutrients resulted in enhanced nutrient uptake (Table 31) resulting in higher leaf number and LAI. Similar improvement in LAI at 30 DAS with N application @ 30 kg $ha^{-1}$ was earlier reported by Suja (2006). Kumawat (2012) also noticed that LAI in yard long bean increased with increase in N level. The application of RD N (30 kg N $ha^{-1}$) resulted in prolonging the crop duration only by three days. Though LAI and crop duration was more in RD N, this did not produce any marked improvement on yield attributes (except length of pod) and yield. Application of N at recommended dose and 25 per cent less of RD N resulted in comparable yield. The major yield attributes like pod number and pod yield per plant were not influenced by N levels and this in turn resulted in non-significant variation in crop yield. Among the pod characters, only pod length was increased by RD N. The results indicated that under a favourable LAI, yield of yard long bean was not affected by reducing nitrogen to 25 per cent less of RD (22.5 kg $ha^{-1}$). Being a leguminous plant, yard long bean might have utilized a part of fixed N at later stages and it was reported that the quantity of N fixed will be more under N stressed situations. Application of higher N (RD) might have reduced nodule number and adversely affected the nitrogen fixation capacity (Singh and Nair, 1995). Hence it could be concluded that in soils with medium N status, N level of 22.5 kg $ha^{-1}$ is sufficient for better yield in yard long bean. Akter *et al.* (1998) and Geetha (1999) opined that 20 kg N $ha^{-1}$ is sufficient for better productivity in yard long bean. Suja (2006) stated that increasing the N levels from 30 to 60 kg $ha^{-1}$ did not have any impact on pod yield.

As in the case of irrigation levels, the N levels influenced the biochemical and quality characters. Total chlorophyll was significantly higher in N application @ 30 kg $ha^{-1}$ compared to 25 per cent less (22.5 kg $ha^{-1}$) (Table 24). Nitrogen being an integral part of chlorophyll is necessary for the synthesis of chlorophyll. Application of higher N levels tend to increase the chlorophyll content of leaves. Tisdale *et al.* (1993) reported that adequate supply of N is associated with a dark green colour of leaves. Simiar improvement in chlorophyll content in yard long bean with increase in N level has also been reported by Kumawat (2012).

Imparting N stress enhanced the proline content. (Table 25) The reduced N availability in N stressed treatments might have stimulated the degradation of proteins and resulted in accumulation of proline as a nitrogen reserve. Increased proline export from leaves during water stress could add to nitrogen remobilization and thus improve the nitrogen use efficiency (Carceller *et al.*, 1999). A reduction in proline during initial growth stages in yard long bean with higher N levels was reported earlier by Geetha (1999).

Crude protein content was more in RD of N ($N_0$) compared to 25 per cent less of RD ($N_1$). The higher N uptake by the plants in this treatment (Table 31) owing to the higher N availability resulted in higher crude protein. Jyothi (1995) reported a higher protein content in yard long bean when N was applied @ 30 kg $ha^{-1}$ compared to 20 and 40 kg $ha^{-1}$. Similar increase in protein content with increased rates of N application had been reported by Chandran (1987) in vegetable cowpea. Crude fibre content was unaffected by nitrogen levels.

**5.1.3 Method of Application on Growth, Yield and Biochemical Characters**

The number of primary branches and functional leaves recorded by the crop at later growth stages (60 and 90 DAS) were more in soil + foliar application compared to soil application. A superior LAI (1.28) was also registered in soil + foliar application of N and K. The readily available N and K from foliar application might have encouraged the vegetative growth attributes. Potassium is essential to obtain maximum leaf extension and stem elongation. Potassium regulates the osmotic turgor of cells and water balance which is the driving force for cell division and elongation. A similar result of increase in leaf area due to foliar spray of potassium was reported by Besma *et al.* (2011) in potato and Rao *et al.* (2015) in mung bean.

Soil application of nutrients significantly improved the pod yield over soil + foliar application (Table 20 and Fig. 3). Yield attributes like pod weight, number of pods per plant and pod yield per plant were significantly superior in soil application which resulted in higher yield. The quantity of nutrients supplied through soil application was higher than soil + foliar treatment *i.e.,* the total quantity of N and K applied were 2.2 and 1.3 times more in soil application than in soil + foliar application. The reduced N and K availability in soil+ foliar treatment might have restricted the productivity of yard long bean. Moreover, N and K were given in four splits (basal, 20, 30 and 40 DAS) in soil application treatment. The split application of higher dose of N and K along with controlled irrigation might have ensured better utilization of nutrients and reduced leaching loss resulting in higher yield under soil application (10.25 per cent yield improvement). This result is in agreement with the findings of de Oliveira *et al.* (2003) where soil application was found better than foliar application of N in vegetable cowpea. Yard long bean is an indeterminate plant which will exhibit continued vegetative growth and fruit production up to completion of its life cycle. Hence the reduced quantities of N and K supplied through soil and foliar application (10.1 kg and 12.6 kg N, 15.7 kg K) might not have been sufficient to meet the requirement in later crop growth stages. Though the readily available N and K in foliar treatments improved the growth parameters, the reduction in total quantity of nutrients applied reduced the total crop yield.

The biochemical characters like chlorophyll and proline content and the quality characters *viz.* crude protein and crude fibre were also influenced by the nutrient application method. The total chlorophyll was significantly higher in soil + foliar application compared to soil application. Immediate availability of N in foliar application might have increased the chlorophyll content in soil + foliar treatments. Kumawat *et al.* (2015) observed that foliar application of one per cent urea before flowering alone or before and after flowering in cluster bean registered significant improvement in chlorophyll content at different stages of growth compared to no spray. Proline content of leaves at flowering was found to be higher in soil + foliar application of nutrients. This was in conformity with the findings of Thalooth *et al.* (2006) who observed that foliar application of two per cent $KNO_3$ significantly increased the proline content in mung bean compared to water spray, foliar spray of zinc and foliar spray of magnesium. Similar increase in leaf proline by foliar spray of one per cent $KNO_3$ under conditions of water stress was reported by Rao *et al.* (2015) in black gram.

Crude protein content of pods, which is a direct reflection of N uptake was the highest in soil application of N and K. In the current study, soil application of N and K registered high N uptake and it resulted in high crude protein content. Regarding the crude fibre content, higher fibre content was recorded in soil application of nutrients. Being a green vegetable, fibre content is a desirable quality and application of required quantity of nutrients improved this quality. Abdel-Hakim *et al.* (2012) also observed reduced crude fibre content when foliar application of KCl was adopted along with soil application of nutrients.

## 5.2 INFLUENCE OF IRRIGATION, NITROGEN LEVELS AND METHOD OF APPLICATION ON SOURCE : SINK RELATIONSHIP

The ratio between leaf dry weight and pod dry weight is expressed as source : sink ratio and this ratio assumes more significance in explaining the partitioning of assimilates from the source to economically important parts. Lower ratios indicate efficient translocation of assimilates to economic parts. A better (lower) source : sink ratio (0.75 ) was recorded by irrigation once in three days at 20 mm depth ($I_3$) (Table 21 and Fig. 6). Providing irrigation once in three days up to flowering followed by irrigating in alternate days ($I_4$) and irrigating once in three days ($I_3$) registered the highest harvest index of 0.396 and 0.391 respectively (Fig. 6). Ichi *et al.* (2013) reported an increase in harvest index when irrigation interval was increased to ten days from five days in grain cowpea. When an optimum LAI is achieved, a reduction in source : sink ratio and an improvement in harvest index is always considered as ideal in productivity enhancement. The optimum development of photosynthetic apparatus (leaf) and leaf dry matter production with a better partitioning of photosynthates to the economic part (pod dry matter) in $I_3$ resulted in better source : sink ratio.

Regarding nitrogen levels, application of N @ 25 per cent less than RD registered the ideal source : sink ratio (0.79). The total dry matter production and leaf dry matter production was superior in RD N (30 kg $ha^{-1}$) and the pod dry matter production was non-significant between two N levels. This resulted in reduced source : sink ratio in 25 per cent less of RD N (22.5 kg N $ha^{-1}$). Moreover, the harvest index was also higher at the reduced N level. This observation indicates that the recommended dose of 30 kg N $ha^{-1}$ enhanced the leafiness (evident from the leaf dry matter production) and did not contribute to yield. Geetha (1999) also observed that increasing N from 20 to 40 kg $ha^{-1}$ enhanced the vegetative growth without any improvement in yield.

Method of application significantly influenced the total dry matter production and dry matter partitioning towards the sink, where soil application ($M_1$) was found to be superior over soil + foliar application ($M_2$) (Table 12). Higher quantities of N and K available to the crop in soil application might have enhanced the total dry matter production. Reduced source : sink ratio and superior harvest index were recorded for soil application of nutrients (Fig. 6). The higher quantities of nutrients available in soil application did not result in any variation on source (leaf dry matter) but enhanced the pod dry matter yield leading to ideal source : sink ratio.

The importance of partitioning of assimilates to economic parts is evident from correlation studies. Pod dry matter production was positively correlated with yield. The source : sink ratio had significant negative correlation with crop yield indicating better translocation of assimilates to the pods, while the harvest index had significant positive correlation with yield (Table 45).

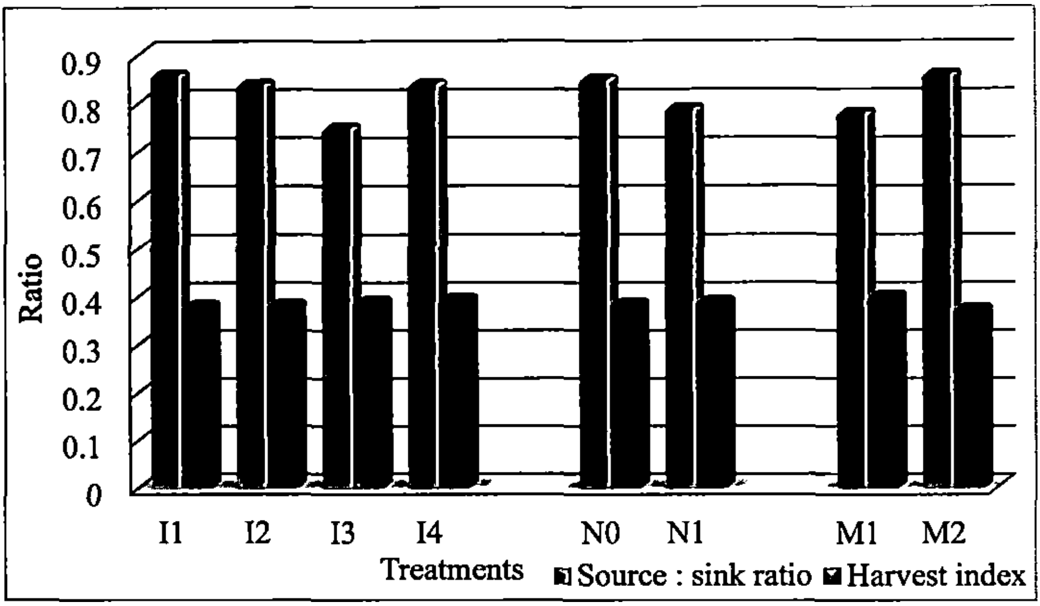


Fig. 6. Source : sink ratio and harvest index as influenced by irrigation, nitrogen levels and method of application.

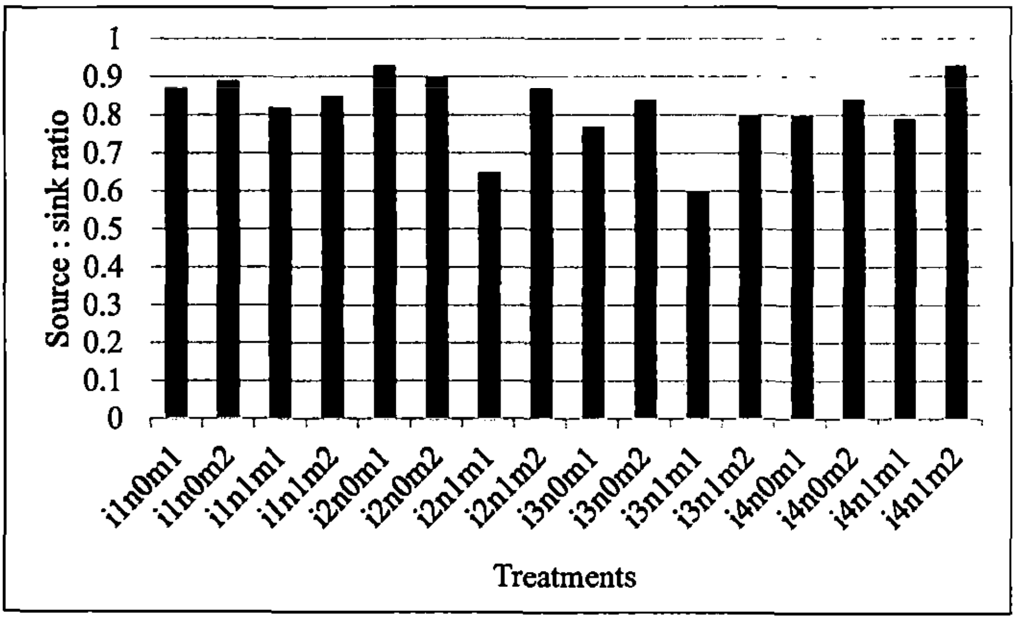


Fig. 7. Source : sink ratio as influenced by combined effect of irrigation, nitrogen levels and method of application

## 5.3 INFLUENCE OF IRRIGATION, NITROGEN LEVELS AND METHOD OF APPLICATION ON UPTAKE OF NITROGEN, PHOSPHORUS AND POTASSIUM

Nitrogen and phosphorus uptake were significantly improved in treatments receiving daily irrigation. The availability of adequate moisture in the root zone throughout the crop growth stage might have enhanced mineralization, solubility and availability of nutrients in this treatment. This also enhanced the total dry matter production and resulted in highest total uptake of nutrients. Regarding K uptake, daily irrigation was observed to be on par with irrigation once in three days. Observing the partitioning of nutrients in plant parts, it is evident that daily irrigation registered highest uptake values of N in different plant parts. Phosphorus and potassium uptake values of different plant parts behaved differently at different levels of irrigation (Table 32 and Table 35). In general, when higher amount of nutrients is absorbed by the plant, it is deposited in the unproductive parts like stem and root (48.85, 49.79, 47.61 and 48.05 per cent in $I_1$, $I_2$, $I_3$ and $I_4$ respectively) rather than utilizing the same for pod production. Moreover, higher N uptake in daily irrigation ($I_1$) also stimulated more leaf production (Table 8) and LAI, but its impact on yield is negligible.

The total N uptake and uptake of nitrogen by different plant parts were higher for recommended dose of N ($N_0$). According to Tanaka *et al.* (1964), the nutrient uptake is controlled by factors like nutrient availability in soil, nutrient absorption power of the roots and rate of increase in dry matter. The higher availability of N in the root zone and the higher total dry matter production enhanced the total N uptake. This increase in N uptake at higher N level was in agreement with the reports of Jyothi (1995) and Geetha (1999).

Uptake of P was the highest in 25 per cent less of RD N. The nitrogen stress might have promoted N fixation and this enhanced N fixation necessitated higher production of ATP which might have resulted in higher P uptake. Kumar *et al.* (1979) observed that application of a reduced N dose of 20 kg N $ha^{-1}$ in combination with 40 kg $P_2O_5$ recorded the maximum uptake of N and P in cowpea. In this experiment also N applied @ 22.5 kg $ha^{-1}$ (25 per cent less RD N) and P @ 30 kg $ha^{-1}$ recorded highest P uptake. Application of lesser amount of N and more of P is ideal for a leguminous crop like yard long bean.

It was also observed from the present study that potassium uptake increased at higher level of N (recommended dose). The higher level of N might have stimulated the uptake of K leading to higher values in $N_0$ (Tisdale *et al.*, 1993). Moreover, the enhanced dry matter production resulted in higher K uptake values. Similar results were reported by (Geetha, 1999) in yard long bean.

The total uptake of N, P and K were higher in soil application of nutrients. The increased total dry matter production and availability of more quantity of nutrients in soil application also resulted in a higher uptake of N, P and K. The uptake of N, P and K by source and N and P by sink were also found to be superior in soil application, while K uptake by sink was non-significant.

## 5.4 INFLUENCE OF IRRIGATION, NITROGEN LEVELS AND METHOD OF APPLICATION ON AVAILABLE NITROGEN, PHOSPHORUS AND POTASSIUM IN SOIL

Irrigation levels did not have significant influence on the available N content in soil after the experiment, while available P content was the highest in daily irrigation at 10 mm depth ($I_1$). Continued availability of moisture might have enhanced the mineralization of P. In case of potassium, irrigation once in three days at 20 mm depth ($I_3$), irrigation in alternate days ($I_2$) and daily irrigation at 10 mm depth ($I_1$) were on par and registered higher values (Table 36).

Recommended dose of N registered higher content of N and P, while K content was higher in 25 per cent less of RD. Application of a higher dose of N might have helped the crop to absorb more N from the applied fertilizer and therefore the depletion from the soil pool might have been lesser leading to high soil N after the experiment. Similar increase in N content with higher dose of fertilizer was reported by Gill *et al.* (1972) and Faroda and Tomer (1975) in fodder cowpea and Geetha (1999) in yard long bean. Phosphorus uptake was less in RD N compared to lower level (25 per cent less RD N) resulting in higher available P (Table 32). Regarding soil K content, as the uptake was less in 25 per cent less of RD N, the same treatment resulted in high K content in soil.

Method of application influenced only the available P content in soil, where soil application of N and K was found to be superior to soil + foliar application.

Compared to the initial soil status (medium N and K and high P), the final soil analysis data revealed a comparable nutrient status (medium N, high P and medium to high K) indicating the sustainability of the system. Nutrient addition from leaf fall and fixed nitrogen might have also helped in supplementing nutrients to the crop indirectly helping in maintaining the sustainability of the system.

## 5.5 INFLUENCE OF IRRIGATION, NITROGEN AND METHOD OF APPLICATION ON WATER REQUIREMENT, WUE AND WATER PRODUCTIVITY

The total water requirement was 1004.5 mm in daily irrigation ($I_1$), 927 mm in irrigation alternate days ($I_2$), 662 mm in irrigation once in three days ($I_3$) and 822 mm in $I_3$ up to flowering followed by $I_2$ (Table 39 and Fig. 8). Of this, the contribution from rainfall was 28.5, 30.5, 43 and 34 per cent in $I_1$, $I_2$, $I_3$ and $I_4$ respectively. Providing irrigation at wider intervals ($I_3$) recorded the highest WUE (14.38 kg ha.mm$^{-1}$). In $I_3$, irrigation was scheduled once in three days and the irrigation water requirement was less (380 mm). The same treatment registered a yield which was comparable to $I_1$ and $I_2$ *i.e.,* treatments receiving daily and alternate day irrigation. This reduced water use has resulted in higher values for WUE (Fig. 9). In the lower range of optimum soil moisture of any crop, the plant may tend to economize the water loss leading to high WUE (Raghu and Choubey, 1983). In general, plants have a tendency for high consumptive use immediately after irrigation. Daily irrigation thus results in proportionately higher consumptive use than other levels of irrigation, thus leading to reduced WUE. This trend is observed in the present study. Geetha (1999) also observed similar reduction in WUE of yard long bean under daily irrigation. Increased WUE due to less frequent irrigation was also reported by Kumar *et al.* (1992) in lentil, Bachchhav *et al.* (1993) in green gram, Dubey (1993) in soybean, Vijayalekshmi and Aruna (1994) in black gram and Yadav *et al.* (1994) in bengal gram. The results of the study also indicated that when irrigation is adopted at wider intervals more quantity of water is depleted from the lower layers (Table 42 and Fig. 10) without causing any stress to the crop plant. Based on the results on yield and WUE, it could be concluded that daily irrigation is not necessary in yard long bean for yield improvement as it results in more water consumption leading to leafiness. Moreover, the labour requirement is more for daily irrigation causing economic loss.

Similar to WUE, water productivity was also the highest (6.84 kg $ha.mm^{-1}$) for $I_3$. Reduced water required in this irrigation level (662 mm) resulted in this high water productivity (Fig. 9).

Considering the effect of N on WUE, efficiency was higher for application of N @ 25 per cent less than RD. WUE is a parameter influenced by yield and water requirement. Though statistically non-significant, the yield was slightly higher in plots receiving 25 per cent less of RD N. This led to improvement in WUE which is in accordance with the report of Geetha (1999) who reported higher WUE for 20 kg N $ha^{-1}$ compared to 0 N and 40 kg N $ha^{-1}$. Similar results of improvement in WUE with varying levels of N were also reported by Thomas (1984), Thambatti *et al.* (1993) and Lakshmi (1997) in cucurbits. In the present study, water productivity was the highest for RD N. This could be attributed to the enhanced dry matter production as a result of enhanced vegetative growth characters in higher N level.

Among the methods of application, soil application registered significantly superior WUE and water productivity (Table 40). In soil application, 30 kg and 22.5 kg N $ha^{-1}$ (in $N_0$ and $N_1$ level) and 20 kg K $ha^{-1}$ were applied, while in soil +

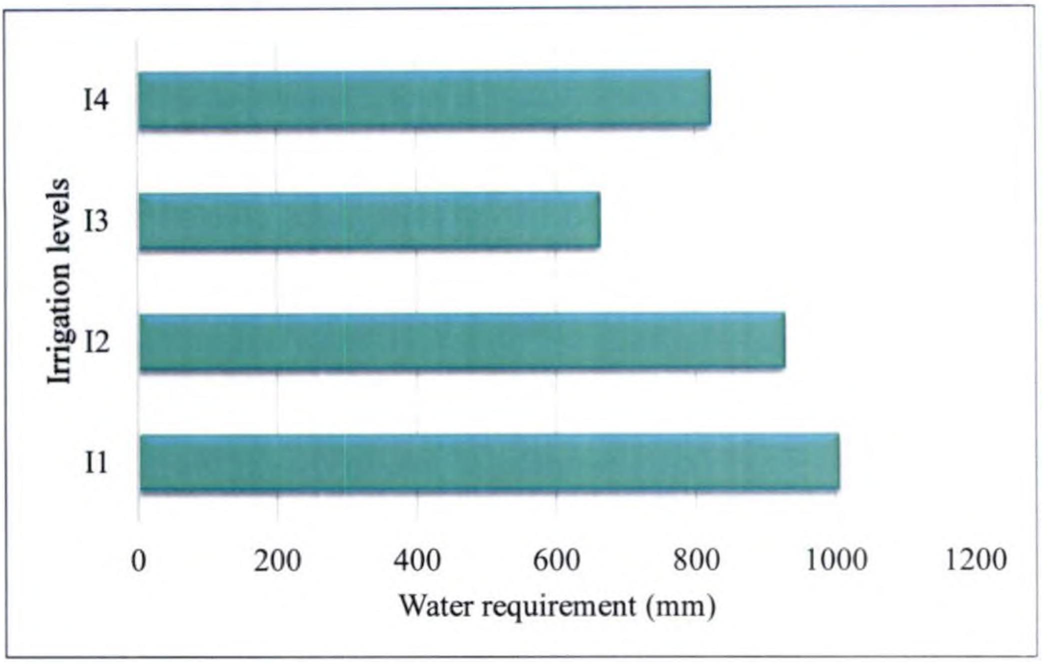


Fig. 8. Water requirement of different irrigation levels

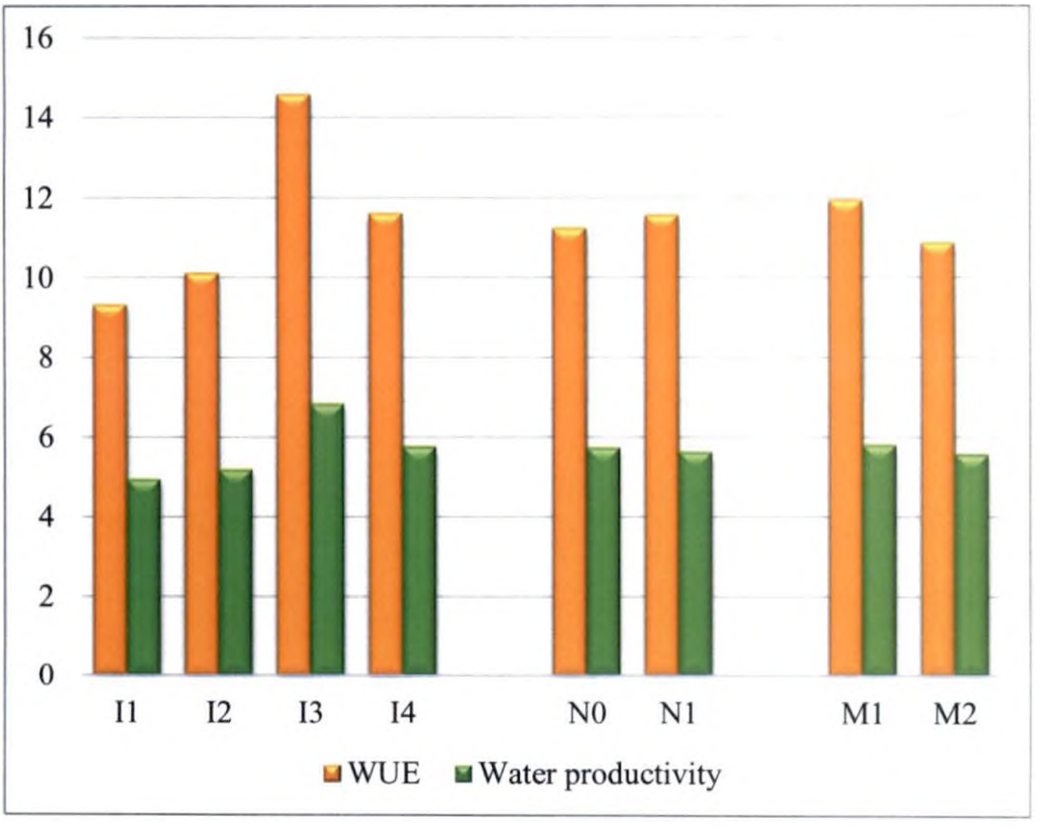


Fig. 9. WUE and water productivity as influenced by irrigation, nitrogen levels and methods of application

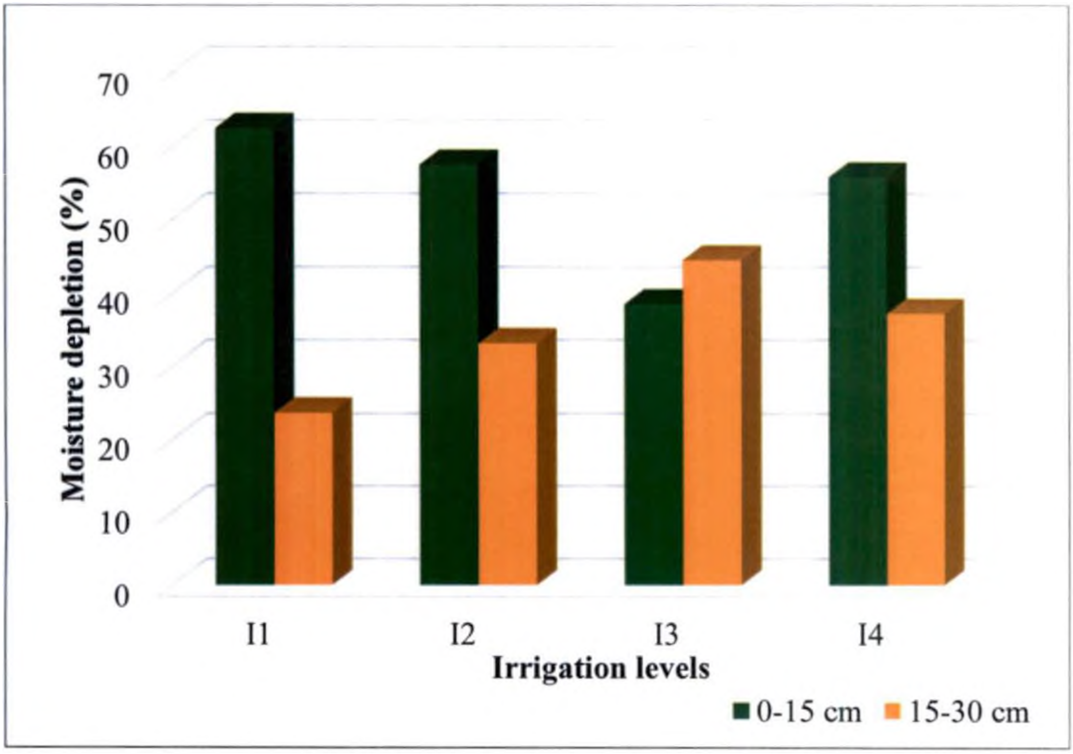


Fig 10. Soil moisture depletion at different levels of irrigation

foliar application, the amount of N applied was only 12.6 and 10.1 kg N $ha^{-1}$ (in $N_0$ and $N_1$) along with 15.7 kg K $ha^{-1}$. This additional nutrients in soil application enhanced the yield by 10 per cent over soil + foliar application and thus resulted in higher WUE. The total dry matter production was improved by three per cent in soil application resulting in an enhanced water productivity.

## 5.6 EFFECT OF IRRIGATION, NITROGEN AND METHOD OF APPLICATION ON ECONOMICS OF CULTIVATION

The levels of irrigation and N stress had no influence on the economic parameters like gross income and net income, while these parameters were significantly superior in soil application of N and K over soil + foliar application (Fig. 11). However, irrigation at wider intervals registered high BCR (Fig. 12). The reduced man days required for irrigation at wider intervals (9 to 13) over daily irrigation (25) resulted in high BCR. Jyothi (1995) observed that irrigating the crop at 75 per cent field capacity recorded higher net income and BCR over daily irrigated treatments. Similar results on high BCR at lower frequency of irrigation was also reported by Mini (1999).

Soil application recorded higher BCR (15 per cent increase) compared to soil + foliar application. The higher gross income, net income and BCR in soil application of N and K ($M_1$) is due to the higher yield and lower cost of soil applied fertilizers. In soil application of nutrients, the total cost for fertilizers were ₹ 1132 and ₹ 1004 per ha for RD and 75 per cent RD N respectively. While the corresponding fertilizer cost for soil + foliar application worked out as ₹ 4777 and ₹ 4735 (high cost of 13:0:45) *i.e.*, approximately four times higher than soil application.

## 5.7 INTERACTION EFFECT OF IRRIGATION, NITROGEN AND METHOD OF APPLICATION

An assessment on the effect of I x N interaction revealed that maximum pod yield was obtained for irrigation in alternate days with 25 per cent less than the RD N ($i_2n_1$) which was on par with $i_1n_0$, $i_4n_0$ and $i_3n_1$ (Table 22 and Fig. 4).

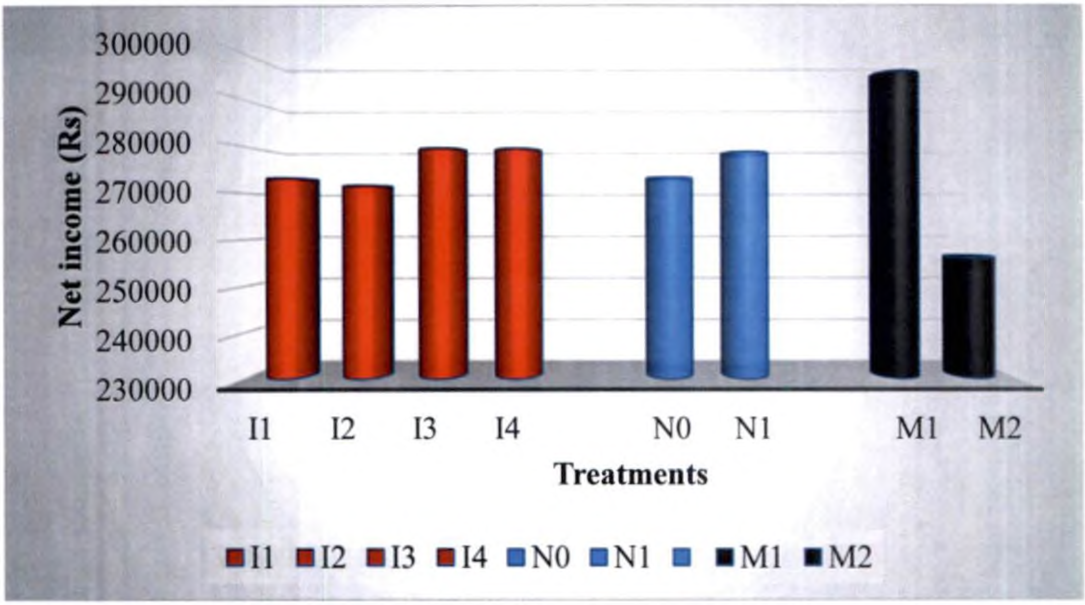


Fig 11. Net income as influenced by irrigation, nitrogen stress and method of application

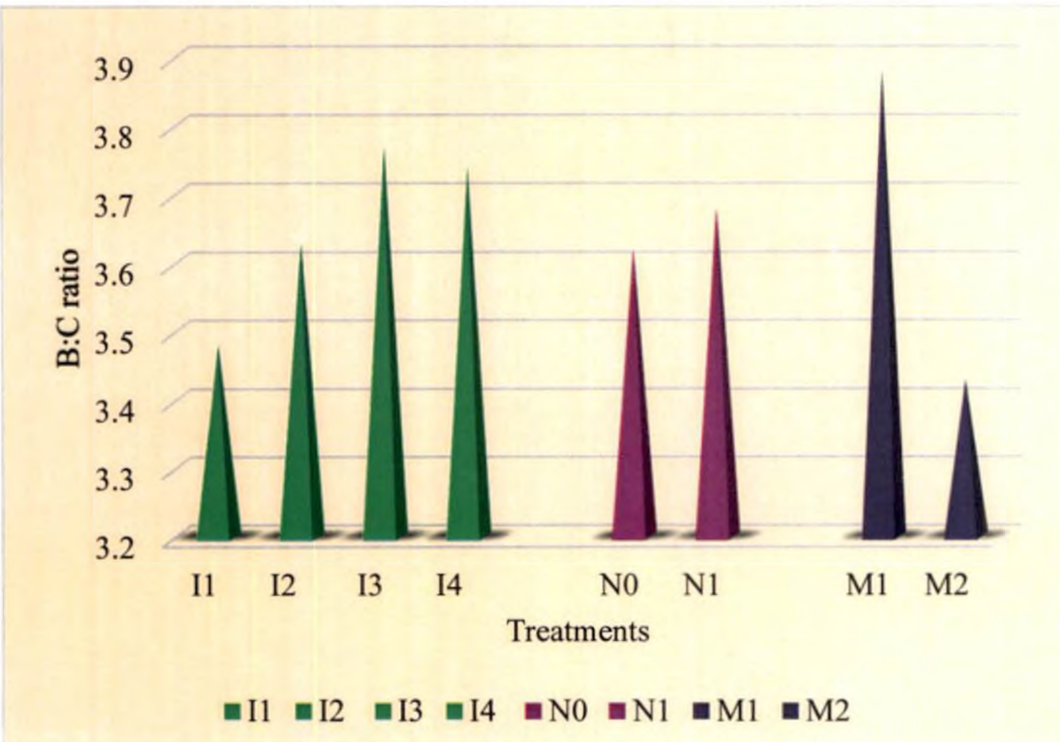


Fig 12. BCR as influenced by irrigation, nitrogen stress and method of application

The same trend was noticed in the major yield attributing characters *viz.,* pod number per plant and pod yield per plant, where $i_2n_1$ recorded maximum values and was on par with $i_1n_0$, $i_4n_0$ and $i_3n_1$. From this, it is inferred that when there is sufficient moisture supply as in daily irrigation, the recommended level of N (30 kg $ha^{-1}$) is required for higher yield, while when there is moisture stress, providing a lower a level of N resulted in an optimum yield. Among the pod characters, only the pod length was influenced by the combination, where the longest pods were obtained in $i_4n_0$, which was on par with $i_2n_0$, $i_4n_1$ and $i_1n_0$. The highest LAI (1.71) was recorded in daily irrigation with RD N which was significantly superior, while the total dry matter production was not influenced by the combination of irrigation with nitrogen levels.

The partitioning of dry matter towards the source was not influenced by the interaction, whereas the partitioning towards the sink was favourably influenced by the combination effect. Similar to yield, $i_1n_0$, $i_2n_1$ $i_3n_1$, and $i_4n_0$ were on par and recorded superior partitioning towards the pod. The lowest source : sink ratio (0.70) was obtained for irrigation once in three days with 25 per cent less than the RD N, which could be attributed to the increased partitioning of photosynthates towards the sink while the partitioning towards source remained unaffected by the combinations. The harvest indices were higher for $i_2n_1$, $i_4n_0$, $i_3n_1$, $i_4n_1$ and $i_1n_0$. The uptake of N by source, sink and total N uptake were found to be superior in daily irrigation with RD N ($i_1n_0$). This is due to the availability of sufficient amount of moisture and N in root zone. The total P uptake and uptake by source and sink were superior in irrigation once in three days with 25 per cent less than RD of N ($i_3n_1$). The total K uptake and uptake by sink were the highest in daily irrigated plots with RD N ($i_1n_0$) while, K uptake by source was superior in $i_1n_1$, which was on par with $i_1n_0$.

Considering the water use efficiency and water productivity, the WUE was superior for $i_3n_1$. The lowest water requirement coupled with higher yield in this combination resulted in maximum WUE. Considering water productivity no variation was observed between $i_3n_0$ and $i_3n_1$. This could be attributed to the higher dry matter production and reduced water use.

Irrigating in alternate days and once in three days along with 75 per cent of RD N registered the highest net income and it was on par with daily irrigation with RD N and irrigation once in three days up to flowering followed by irrigation in alternate days with RD N. The improvement in net income could be attributed to the enhanced yield realized in the above combinations The net income was observed to be superior for the combinations, $i_2n_1$, $i_3n_1$, $i_4n_0$ and $i_1n_0$ owing to the higher yield obtained. The B : C ratio was maximum in treatments receiving irrigation once in three days with 25 per cent less RD N ($i_3n_1$) which was on par with $i_4n_0$ and $i_2n_1$ (Fig. 44).The higher yield realized in these combinations along with reduced man days required for irrigation resulted in high B:C ratio.

Regarding, I x M interaction, it was observed that irrigation once in three days with soil application of nutrients registered the highest yield which was superior to other combinations. This improvement in yield is attributed to increase in pod yield per plant, pod number per plant and pod girth. The total dry matter production and dry matter contribution to the source were not influenced by the combination of irrigation and method of application. However, partitioning towards the sink was the highest in $i_3m_1$ (irrigation once in three days with soil application). The same combination also resulted in the lowest source : sink ratio (0.68) and maximum harvest index (0.416). In case of harvest index, $i_3m_1$ was on par with $i_4m_1$. All these indicate that irrigation at wider intervals with soil application of nutrients in different splits is ideal for better translocation of photosynthates to the pods and registering high harvest index and ideal source : sink ratio. The nutrient uptake values showed differential performance at different I x M combinations. The combination registering the highest yield ($i_3m_1$) also recorded maximum total uptake of phosphorus, uptake by source and sink while the total N uptake was superior in $i_2m_1$, $i_1m_2$ and $i_1m_1$. K uptake by source was superior in daily irrigation with soil application of nutrients ($i_1m_1$), while uptake by sink was superior in $i_4m_1$ and $i_3m_2$. The best yielding treatment

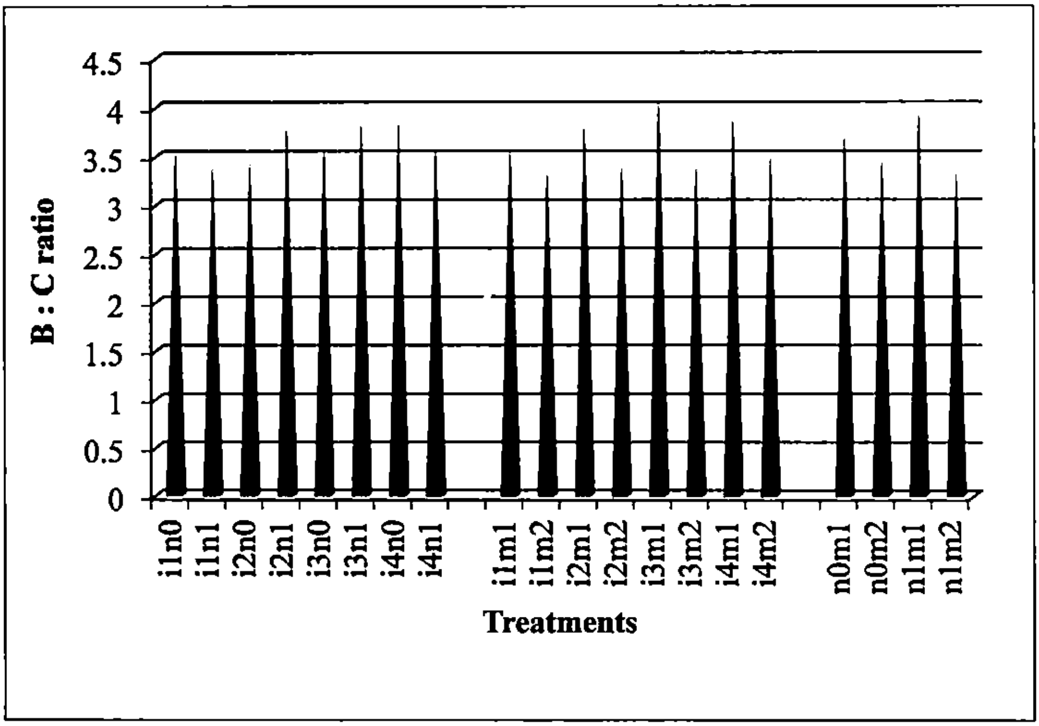


Fig. 13. BCR as influenced by combined effect of irrigation, nitrogen levels and method of application

($i_3m_1$) also registered maximum WUE, highest net income and BCR (Tables 41 and 44).

The interaction between nitrogen level and method of application indicated that providing N stress (25 per cent less RD N) along with soil application of nutrients *i.e.,* $n_1m_1$ resulted in significantly superior pod number per plant, pod yield per plant and total pod yield per hectare. This indicated that a lower level of N supply is required for optimum yield in yard long bean provided, prolonged availability of N is assured through split application. The LAI was found to be significantly superior in $n_0m_2$ (RD N with soil and foliar application) due to immediate availability of nutrients from foliar application, but its effect was not pronounced in pod yield. The total dry matter production was not influenced by N x M interaction. Partitioning of photosynthates towards the source was the highest in $n_0m_1$ due to enhanced N availability while, partitioning towards the sink was maximum in $n_1m_1$. A better source : sink ratio (0.71) and the highest harvest index were also realized in $n_1m_1$ (75 per cent RD N as soil application). Uptake of N by source was superior in $n_0m_1$, while uptake by sink was the maximum in $n_1m_1$. The highest total P uptake was noted in $n_1m_2$ and $n_1m_1$, while the uptake by source and sink were observed to be superior in $n_1m_1$. The total potassium uptake, uptake by source and sink were the highest in $n_0m_2$. Significantly superior WUE was noted in $n_1m_1$. Regarding the economics of cultivation, $n_1m_1$ (75 per cent RD N as soil application) registered the highest net income and B : C ratio. In general, when recommended dose of N was applied, the partitioning of assimilates was more to the source rather than to the sink. The results indicated that application of 75 per cent RD N with soil application in four splits is ideal for enhanced yield, harvest index and ideal source : sink ratio.

The interaction between irrigation levels, nitrogen levels and method of application indicated that the combined effect of these treatments did not have any influence on major yield attributes and yield. Though, total dry matter production was found to be the highest in daily irrigation with RD N as soil application ($i_1n_0m_1$), it was found to be on par with irrigation in alternate days with RD N as soil application ($i_2n_0m_1$). Partitioning of photosynthates to the source was the highest in combinations $i_1n_0m_1$, $i_1n_0m_2$ and $i_2n_0m_1$, while the partitioning towards the sink was non-significant. An ideal source : sink ratio was recorded in $i_3n_1m_1$ and $i_2n_1m_1$ (0.60 and 0.65 respectively) which were on par. The harvest index was not influenced by I x N x M interaction. The different I x N x M combinations showed varying response on N, P and K uptake and its partitioning to source and sink. Maximum WUE and water productivity were observed in $i_3n_1m_1$, and was on par with $i_3n_0m_1$ in case of water productivity. The economic parameters *viz.*, net income and BCR were not influenced by I x N x M combination. Though the third order interaction did not have any significant effect on crop yield and economics, based on the source : sink ratio, WUE and water productivity it is inferred that the combination, $i_3n_1m_1$ (irrigation once in three days with soil application of 25 per cent less RD N) is ideal for yard long bean.

Analysis of results of the study indicated that though daily irrigation and recommended dose of nitrogen could result in more leafiness and enhanced dry matter production, its effect was not reflected in the translocation of assimilates to economic parts. This is evident from the source : sink ratio and pod yield. Moreover, increasing the interval of irrigation can enhance the WUE without any detrimental effect on crop yield. Hence, it could be inferred that yard long bean can be irrigated once in three days with 25 per cent less RD N (22.5 kg). Soil application of nutrients in four splits was found ideal than soil application of one-third of N and K followed by foliar nutrition of 13:0:45 @ 0.5 per cent concentration.

# Summary

# 6. SUMMARY

An experiment was conducted at College of Agriculture, Vellayani, Kerala, to assess the influence of moisture-nutrient stress and foliar nutrition on source-sink relationship, productivity and profitability of yard long bean. The research was under taken in split plot design with four main plot and four sub plot treatments replicated four times. Different levels of irrigation *viz.,* daily irrigation at 10 mm depth ($I_1$), irrigation in alternate days at 20 mm depth ($I_2$), irrigation once in 3 days at 20 mm depth ($I_3$) and irrigation once in 3 days up to flowering and then in alternate days at 20 mm depth ($I_4$) constituted the main plot treatments. Combinations of nitrogen levels and method of application formed the sub plot treatments. The two nitrogen levels tried were recommended dose of N [($N_0$): 30 kg $ha^{-1}$)] and 25 per cent less of RD N [($N_1$): 22.5 kg $ha^{-1}$]. The two fertilizer application methods adopted were soil application of N and K in four splits as basal, at 20, 30 and 40 DAS ($M_1$) and soil application of 1/3 of N and K as basal followed by foliar application of 13:0:45 ( 0.5 per cent concentration) at fortnightly interval ($M_2$). Farm yard manure @ 20 t $ha^{-1}$ and full P were applied as basal dose, uniformly for all treatments. The nutrient status of soil in the experimental field was analyzed for high organic carbon and phosphorus and medium nitrogen and potassium.

The salient results of the study are summarized in this chapter.

The growth parameters *viz.,* primary branches per plant and functional leaves per plant in the later crop growth stages and LAI at flowering indicated varying response under different levels of irrigation. Irrigating the crop once in three days up to flowering followed by irrigation in alternate days ($I_4$) registered the highest number of branches, while daily irrigation ($I_1$) produced maximum leaf number and LAI at flowering. RD N registered the highest LAI and number of functional leaves per plant (90 days). Soil + foliar application of nutrients ($M_2$) was found to be superior in terms of primary branches per plant, functional leaves per plant at later growth stages and LAI at flowering. Considering the interactions, $i_1n_0m_1$ (daily irrigation with RD N as soil application) registered maximum number of functional leaves during later stages of growth (90 DAS).

Irrigation levels influenced the number of days to 50 per cent flowering, where irrigation once in three days ($I_3$) registered slightly lesser number of days. Application of N @ 25per cent less than the RD ($N_1$) resulted in early flowering. Among the combinations, $n_1m_1$ (25 per cent less of RD N as soil application) recorded lesser time for 50 per cent flowering.

Considering the crop duration and number of pickings, daily irrigation ($I_1$) resulted in the longest duration (104.87 days) and maximum number of pickings. In the case of nitrogen levels, crop duration and number of pickings were significantly higher under RD N. The method of application influenced only the duration of the crop where soil + foliar application ($M_2$) was significantly superior. Regarding the combination effect, $i_1n_0$, $i_1m_2$, $n_0m_2$ and $i_1n_0m_2$ recorded maximum duration in I x M, I x M, N x M and I x N x M combinations respectively. Number of pickings was found to be higher for $i_1n_0$ and $i_1m_1$ among I x N and I x M respectively.

The different levels of irrigation and N tried in the present experiment did not have any significant influence on the major yield attributes *viz.,* pod yield per plant and pod number per plant and on the yield of yard long bean. However, different levels of irrigation behaved differently in terms of pod characters. $I_4$ recorded the maximum pod length and $I_1$ registered the maximum pod girth. Considering the interactions, Ix N, I x M and N x M were found to be significant. $i_2n_1$ $i_3n_1$, $i_1n_0$ and $i_4n_0$ registered superior yield among I x N interaction, while $i_3m_1$ and $n_1m_1$ registered the highest yield in I x M and N x M combinations respectively. Among the pod characters, only pod length was increased by RD N. Soil application of major nutrients ($M_1$) significantly improved pod weight, number of pods per plant, pod yield per plant and pod yield per hectare over soil + foliar application in yard long bean.

Regarding the effect of irrigation levels on dry matter production, daily irrigation ($I_1$) was significantly superior in total dry matter production and partitioning of photosynthates towards the source. N application @ 30 kg $ha^{-1}$ registered superior total dry matter production and partitioning towards the source, while partitioning towards the sink was non-significant. Soil application ($M_1$) was found to be superior over soil + foliar application ($M_2$) in total dry matter production and dry matter partitioning towards the sink. $i_1n_0m_1$ and $i_2n_0m_1$ registered higher total dry matter production among the combinations.

A better (lower) source : sink ratio (0.75 ) was recorded by irrigation once in three days at 20 mm depth ($I_3$) while, providing irrigation once in three days up to flowering followed by irrigating in alternate days ($I_4$) and $I_3$ registered superior harvest index. Regarding nitrogen levels, application of N @ 25 per cent less than RD registered the ideal source : sink ratio (0.79) and higher harvest index. Reduced source : sink ratio and superior harvest index were recorded for soil application of nutrients. $i_3n_1$, $i_3m_1$, $n_1m_1$ and $i_3n_1m_1$ recorded favourable values for source : sink ratio among I x N, I x M, N x M and I x N x M combinations respectively.

Considering the biochemical and quality characteristics, the chlorophyll content was significantly improved by daily irrigation and RD N. Soil + foliar application of N and K fertilizers was found to register higher chlorophyll content. Regarding the proline content of leaves it was observed that moisture and nitrogen stress ($I_3$ and $N_1$) increased the proline content of leaves significantly. Soil + foliar application of N and K ($M_2$) registered higher proline content. Daily irrigation, RD N and soil application of N and K were found to register superior crude protein content of pods. The highest content of fibre in pods was noted in plants subjected to maximum water stress ($I_3$). The fibre content was not influenced by N levels. Among the application methods, soil application of N and K registered higher fibre content. Considering the combinations, $i_1n_0m_1$ and $i_2n_0m_2$ recorded higher content of chlorophyll, while higher protein content in pods were recorded by $i_2n_0m_1$ and $i_1n_0m_1$. Proline content was the maximum in $i_3n_1m_2$.

Observations on root characters *viz.,* root volume and root fresh weight indicated that daily irrigation registered maximum root volume and root fresh weight. Recommended dose of N recorded higher root volume while, application of N and K through soil alone recorded higher values of root volume and root weight. The root dry weight was not influenced by irrigation, nitrogen levels and method of application.

Analysis of post-experiment soil nutrient status noticed that irrigation levels significantly influenced both soil P and K where, daily irrigation recorded highest content of soil P and irrigating once in three days at 20 mm depth registered superior K content. RD N recorded superior N and P content in soil over 25 per cent less of RD N ($N_1$), while K content was found to be higher for $N_1$. Method of application significantly influenced phosphorus, where soil application ($M_1$) recorded higher P content.

Nitrogen and phosphorus uptake were significantly improved in treatments receiving daily irrigation, while K uptake was observed to be superior in irrigation once in three days and daily irrigation. The total N and K uptake were higher for recommended dose of N ($N_0$), while uptake of P was the highest in 75 per cent of RD N. Considering the effect of method of application, uptake of N, P and K were higher in soil application of nutrients. Considering the combination effect, $i_1n_0m_1$ registered maximum N uptake, $i_3n_1m_1$ registered maximum P uptake and $i_3n_0m_1$ and $i_1n_0m_1$ registered maximum K uptake.

From this study, the total water requirement for yard long bean was computed to be 1004.5 mm, 927 mm, 662 mm and 822 mm in $I_1$, $I_2$ $I_3$ and $I_4$ respectively. Providing irrigation at wider intervals ($I_3$) recorded the highest WUE and water productivity (14.38 kg $ha.mm^{-1}$ and 6.84 kg $ha.mm^{-1}$). Application of N @ 75 per cent RD registered superior WUE, while water productivity was higher for RD N. Among the two application methods, soil application of nutrients registered superior WUE and water productivity.

The levels of irrigation and N stress had no influence on the economic parameters *viz.,* gross income and net income. Irrigation at wider intervals registered higher BCR over daily irrigation. Soil application recorded higher gross income, net income and BCR compared to soil + foliar application. Irrigation once in three days at 20 mm depth along with application of 25 per cent less of RD N (22.5 kg N $ha^{-1}$) registered significantly higher B : C ratio of 3.89.

From the results of the present study it could be concluded that the following irrigation and nutrient management schedule holds good for ideal source : sink ratio, higher productivity and profitability of yard long bean:

- FYM @ 20t $ha^{-1}$ -basal application
- $N:P_2O_5:K_2O$ @ 22.5:30:20 kg $ha^{-1}$ as soil application (P applied as basal, N and K application in 4 equal splits as basal, at 20, 30 and 40 DAS).
- Irrigation once in three days at 20 mm depth during rain free periods.

**Future line of work**

- The possibility of yield improvement in yard long bean by nutrient supplementation through foliar sprays needs further studies.
- Efficiency of a P source for foliar fertilization to improve flowering and yield has to be investigated.
- Quantification of lime requirement for yield improvement in different soil types.
- Quantification of nutrient addition through leaf fall and N fixation to supplement crop nutrition needs further investigation.

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# STRESS INDUCED SOURCE-SINK MODULATION IN YARD LONG BEAN

# (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt)

*by*

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**ABSTRACT**

The investigation entitled "Stress induced source-sink modulation in yard long bean (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt)" was carried out during January to May, 2014 at the Instructional Farm, College of Agriculture, Vellayani, Kerala. The objective was to assess the influence of moisture- nutrient stress and foliar nutrition on source-sink relationship, productivity and profitability of yard long bean.

The experiment was laid out in split plot design with four replications. The main plot treatments included four different levels of irrigation *viz.,* daily irrigation at 10 mm depth ($I_1$), irrigation in alternate days ($I_2$), irrigation once in 3 days ($I_3$) and irrigation once in 3 days up to flowering and then in alternate days ($I_4$) each at 20 mm depth. Combinations of nitrogen levels [recommended N ($N_0$) and 25 per cent less of recommended N ($N_1$)] and method of application [soil application of N and K in 4 splits ($M_1$) and soil application of one-third N and K as basal followed by foliar application of 13:0:45 @ 0.5 per cent at fortnightly interval ($M_2$)] formed the sub plot treatments. The *adhoc* recommendation for yard long bean (30:30:20 kg NPK $ha^{-1}$) was adopted for this study. Farm yard manure @ 20 t $ha^{-1}$ and full P were applied as basal dose, uniformly for all treatments.

Daily irrigation at 10 mm depth recorded significantly higher values for growth parameters *viz.,* functional leaves plant per plant and leaf area index (1.56). Chlorophyll content of leaves at flowering (1.47 mg $g^{-1}$), crude protein content and N and P uptake were also superior in daily irrigated treatments. K uptake was found to be the maximum in irrigation once in three days and it was on par with daily irrigation. The major yield attributes like number of pods per plant and pod yield per plant and total pod yield were not influenced by levels of irrigation. A better source : sink ratio (0.75) was registered in $I_3$ (irrigation once in three days at 20 mm depth) while, the harvest index was higher for $I_3$ and $I_4$. The water use efficiency and water productivity (14.58 and 6.84 kg $ha.mm^{-1}$) were

found to be significantly superior in irrigation once in three days. Increasing the irrigation interval enhanced the proline accumulation in leaves and crude fibre in pods.

Application of recommended dose (RD) of nitrogen registered significantly higher values for functional leaves at later crop growth and leaf area index. Leaf chlorophyll content was found to be superior in $N_0$ while, proline content (2.57 μ mols $g^{-1}$) was higher in $N_1$. Uptake of N and K were superior in RD N. Reducing the nitrogen levels to 75 per cent of RD did not cause any reduction in yield attributes and yield. Lower source : sink ratio and higher P uptake were noted in application of 25 per cent less of RD N. Recommended dose of N registered the highest value of water productivity, whereas WUE was the highest at 25 per cent less RD N.

Soil application of nutrients registered significantly higher yield (100.03 q $ha^{-1}$) and uptake of nutrients over soil + foliar application. The biochemical characters *viz.*, chlorophyll content and proline content were higher in soil + foliar application. The source : sink ratio and harvest index were favourably influenced by soil application of nutrients. WUE and water productivity (11.95 and 5.82 kg $ha.mm^{-1}$ respectively) were superior in soil application of nutrients.

Irrigation once in three days at 20 mm depth registered the highest B : C ratio. Among the methods of application, soil application was found more economical.

From the study it could be inferred that daily irrigation is not necessary for yard long bean. Irrigation once in three days at 20 mm depth along with application of 25 per cent less of RD N (22.5 kg N $ha^{-1}$) registered favourable source : sink ratio (0.70) and enhanced the B:C ratio (3.89). Soil application of nutrients recorded 10.25 per cent increase in yield and 15 per cent increase in B : C ratio compared to soil + foliar application.

# സംഗ്രഹം


പ്രധാന ഉല്പാദന ഘടകങ്ങളായ ജലസേചനം, പാക്യജനകം ഇവയുടെ വ്യതിയാനം, മൂലകങ്ങൾ നൽകുന്ന രീതി എന്നിവ വള്ളിപയറിന്റെ ഉല്പാദനക്ഷമതയെ എങ്ങനെ ബാധിക്കുന്നു എന്നു മനസ്സിലാക്കുന്നതിനുള്ള ഒരു പരീക്ഷണം 2014 ജനുവരി മുതൽ മേയ് വരെയുള്ള കാലയളവിൽ വെള്ളായണി കാർഷിക കോളേജ്, ഇൻസ്ട്രക്ഷണൽ ഫാമിൽ നടത്തുകയുണ്ടായി. 'വെള്ളായണി ജ്യോതിക' എന്ന പയറിനമാണ് പഠനവിധേയമാക്കിയത്.

ദിവസേന ജലസേചനം നൽകുന്നത് പയറിന്റെ വളർച്ചാ ഘടകങ്ങളിൽ വർദ്ധനവ് ഉണ്ടാക്കിയെങ്കിലും ഉല്പാദനശേഷി കൂട്ടുന്നതിനു സഹായകരമായില്ല. മൂന്നു ദിവസത്തിലൊരുക്കലുള്ള ജലസേചനം കായിക വളർച്ച ക്രമീകരിച്ച് ഉല്പാദനക്ഷമത കൂട്ടുന്നതിനു സഹായകരമാണെന്ന് കാണാൻ കഴിഞ്ഞു. കൂടാതെ ജലസേചനത്തിനു വേണ്ട വെള്ളത്തിന്റെ അളവു കുറയ്ക്കാനും ജലവിനിയോഗം കാര്യക്ഷമമാക്കുവാനും ഈ രീതി സഹായകരമാണ്. പയറിനു വേണ്ട പാക്യജനകത്തിന്റെ അളവ് 30 കി./ഹെ. നിന്നും 22.5 കി./ഹെ. ആയി കുറച്ചാലും ഉല്പാദനത്തെ ദോഷകരമായി ബാധിക്കുന്നില്ല. പയറിനുവേണ്ട വളം നാലു തവണയായി (അടിസ്ഥാന വളം, നട്ട് 20, 30, 40 ദിവസങ്ങളിൽ) നൽകുന്നത് മൂലക നഷ്ടം കുറച്ച് ഉല്പാദന ക്ഷമത കൂട്ടാൻ സഹായകരമാണ്.

ഈ പഠനത്തിൽ നിന്നും 3 ദിവസത്തിൽ ഒരിക്കൽ 20 മില്ലി. മീ. താഴ്ചയിൽ ജലസേചനം നൽകുന്നതും പാക്യജനകവും (22.5 കി./ഹെ.) ക്ഷാരവും (30 കി./ഹെ.) 4 തവണയായി മണ്ണിൽ കൂടി നൽകുന്നതും വള്ളിപ്പയറിന്റെ ഉല്പാദന വർദ്ധനവിനും ആദായം കൂട്ടുന്നതിനും സഹായകരമാണെന്നു തെളിഞ്ഞു.

# Appendices

## APPENDIX - I

**Weather parameters during the crop period (Feb. 2014 – May 2014)**

| Period | Standard week | Temperature | | Rainfall (mm) weekly total | Evaporation (mm) weekly total | Relative humidity (Percentage) |
|---|---|---|---|---|---|---|
| | | Max. | Min. | | | |
| 2014 | 4 | 31.3 | 20.7 | 0.5 | 27.4 | 90.4 |
| | 5 | 31.1 | 21.9 | 0 | 26.0 | 92.3 |
| | 6 | 30.7 | 20.2 | 0 | 26.0 | 95.1 |
| | 7 | 31.4 | 22.8 | 3 | 24.9 | 92.0 |
| | 8 | 31.5 | 23.8 | 18.0 | 25.3 | 90.6 |
| | 9 | 31.9 | 23.1 | 25.0 | 20.5 | 92.3 |
| | 10 | 31.9 | 23.4 | 0 | 28.8 | 90.4 |
| | 11 | 32.4 | 21.4 | 0 | 33.1 | 93.0 |
| | 12 | 33.0 | 24.1 | 6.5 | 8.0 | 93.7 |
| | 13 | 33.0 | 22.2 | 0 | - | 89.1 |
| | 14 | 32.4 | 24.5 | 19.0 | 24.5 | 89.9 |
| | 15 | 32.0 | 24.2 | 32.0 | - | 91.0 |
| | 16 | 32.0 | 25.0 | 18.0 | 3.8 | 90.7 |
| | 17 | 32.8 | 24.4 | 45.5 | - | 94.0 |
| | 18 | 32.2 | 23.8 | 131.1 | 14.0 | 93.1 |
| | 19 | 30.7 | 24.3 | 132.3 | 4.5 | 92.0 |
| | 20 | 32.5 | 25.1 | 0 | 21.7 | 88.3 |

## APPENDIX – II

### Scoring of mite attack

| Score | Criteria |
|---|---|
| 0 | no symptom |
| 1 | 1 – 25 % leaves/plant showing curling or damage |
| 2 | 26 – 50% leaves/plant showing curling or damage |
| 3 | 51 – 75 % leaves/plant showing curling or damage |
| 4 | more than 75 % leaves/plant showing curling or damage complete destruction of growing points |

**Percentage intensity of damage**

$$PDI = \frac{\text{Sum of grades of plants} \times 100}{\text{No. of plants assessed} \times \text{maximum grade used}}$$

## APPENDIX – III

### Percentage disease incidence

| | |
|---|---|
| Percentage disease incidence (PDI) | $\frac{\text{No of plants dead} \times 100}{\text{Total no of plants}}$ |

## APPENDIX – IV

### Quantity of fertilisers (kg ha$^{-1}$) and their cost (₹ kg$^{-1}$) used in the experiment

| Treatments | Urea | Rock phosphate | MOP | 13:0:45 |
|---|---|---|---|---|
| $n_0 m_1$ | 65.0 | 150 | 34 | - |
| $n_0 m_2$ | 21.6 | 150 | - | 20 |
| $n_1 m_1$ | 49.0 | 150 | 34 | - |
| $n_1 m_2$ | 16.3 | 150 | - | 20 |
| *Cost (₹kg$^{-1}$) | 8.0 | 10 | 18 | 220 |

## APPENDIX – V

Cost of cultivation of yard long bean, ₹ $ha^{-1}$

| Treatments | Cost excluding treatments | Treatment cost | Total cost of cultivation |
|---|---|---|---|
| $i_1 n_0 m_1$ | 84180 | 24912 | 109092 |
| $i_1 n_0 m_2$ | 84180 | 27397 | 111577 |
| $i_1 n_1 m_1$ | 84180 | 24784 | 108964 |
| $i_1 n_1 m_2$ | 84180 | 27355 | 111535 |
| $i_2 n_0 m_1$ | 84180 | 17952 | 102132 |
| $i_2 n_0 m_2$ | 84180 | 20437 | 104617 |
| $i_2 n_1 m_1$ | 84180 | 17824 | 102004 |
| $i_2 n_1 m_2$ | 84180 | 20395 | 104575 |
| $i_3 n_0 m_1$ | 84180 | 15632 | 99812 |
| $i_3 n_0 m_2$ | 84180 | 18117 | 102297 |
| $i_3 n_1 m_1$ | 84180 | 15504 | 99684 |
| $i_3 n_1 m_2$ | 84180 | 18075 | 102255 |
| $i_4 n_0 m_1$ | 84180 | 16792 | 100972 |
| $i_4 n_0 m_2$ | 84180 | 19277 | 103457 |
| $i_4 n_1 m_1$ | 84180 | 16664 | 100844 |
| $i_4 n_1 m_2$ | 84180 | 19235 | 103415 |

## APPENDIX – V1

**Market price of the produce**

| Produce | Market price (₹) |
|---|---|
| Pod | 40 $kg^{-1}$ |