PHYSIOLOGICAL ASPECTS OF FOLIAR NUTRITION IN RELATION TO THE CONTROL OF BUD AND BOLL SHEDDING IN COTTON (*Gossypium Spp.*)

Thesis submitted in part fulfillment of the requirements for the degree of

MASTER OF SCIENCE (AGRICULTURE) IN CROP PHYSIOLOGY

to the Tamil Nadu Agricultural University, Coimbatore – 641 003.

By

S. KARTHIK

I.D. No. 07-609-001

DEPARTMENT OF CROP PHYSIOLOGY

AGRICULTURAL COLLEGE AND RESEARCH INSTITUTE

TAMIL NADU AGRICULTURAL UNIVERSITY

COIMBATORE – 641 003

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CERTIFICATE

This is to certify that the thesis entitled, "**PHYSIOLOGICAL ASPECTS OF FOLIAR NUTRITION IN RELATION TO THE CONTROL OF BUD AND BOLL SHEDDING IN COTTON (*Gossypium Spp.*)**" submitted in part fulfillment of the requirements for the degree of **MASTER OF SCIENCE (AGRICULTURE) in CROP PHYSIOLOGY** to the Tamil Nadu Agricultural University, Coimbatore is a record of bonafide research work carried out by **Mr. S. KARTHIK** under my supervision and guidance and that no part of the thesis has been submitted for the award of any other degree, diploma, fellowship or other similar titles or prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

Place: Coimbatore

Date: 18.06.2009

Dr. H.VIJAYARAGHAVAN

Chairperson

Approved by

Chairperson: **Dr. H.VIJAYARAGHAVAN**

Members : **Dr. S. VINCENT**

Dr. K. RAJENDRAN

Date:

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With regardful memories …….

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(S. KARTHIK)

ABSTRACT

PHYSIOLOGICAL ASPECTS OF FOLIAR NUTRITION IN RELATION TO THE CONTROL OF BUD AND BOLL SHEDDING IN COTTON *(Gossypium Spp.)*

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S. KARTHIK

Degree : **Master of Science (Agriculture) in Crop Physiology**

Chairperson : **Dr. H. VIJAYARAGHAVAN**
Professor and Head
Department of Crop Physiology
Tamil Nadu Agricultural University
Coimbatore - 641 003

2009

Field experiment was conducted to evaluate the foliar nutrition on growth attributes, physiological, biochemical, and yield related components in Bunny hybrid Bt cotton. The trial was carried out from August 2008 to January 2009 at Field No. 73, Eastern block of Tamil Nadu Agricultural University, Coimbatore. The experiment was laid out in randomized block design with three replications. The objectives of the study are (i) To record the flower and boll shedding, analyzing the endogenous hormone levels (ii) To have an insight into the root histological, anatomical study under foliar spray (iii) To develop a hormone based nutrient mix for the control of flower and boll shedding in cotton hybrid.

The treatment consists of T_1-NAA @ 40ppm, T_2-Potassium chloride (KCl) @ 2%, T_3-Potassium nitrate (KNO_3) @3%, T_4-Salicylic acid @100ppm, T_5-Diammonium Phosphate (DAP) @ 2%, T_6-Polyfeed+Multi-K @ 1.5%, T_7-PGR (Formulation-I), T_8-PGR (Formulation-II), T_9-PGR (Formulation-III) and T_{10}-PGR (Formulation-IV). Two sprays were given at stray flowering and boll formation stages as per different treatments. Observations were recorded on morphological, physiological and yield attributes besides attempting to study the root anatomy and ABA profiles in all treatments.

PGR Formulation-III (T_9) was found that significant increase in growth expressed in terms of plant height, root length, growth parameters such as LA, TDMP, LAI, CGR, RGR and NAR. It was recorded delayed flowering and boll formation and boll opening when compared

to control (NAA @ 40ppm-T_1). Among the physiological parameters, PGR Formulation-III (T_9) enhances the SPAD chlorophyll value, Stomatal Diffusive Resistance (SDR), Quantum yield and Relative Water Content (RWC). The biochemical parameters, such as the total chlorophyll content, chl-'a', chl-a/b ratio, Chlorophyll Stability Index (CSI), Cell Membrane Index (CMI), Soluble protein, Proline, Epicuticular Wax content (ECW) and Nitrate Reductase activity was influenced by PGR Formulation-III (T_9). Studies on ABA profile also indicated that foliar application of growth regulators highly reduced the ABA content especially in PGR Formulation-III (T_9) than control. Plant hormones are notably having significant impact on cellular metabolism.

In the present investigation attempts were made to study the influence of foliar formulation on root and leaf anatomical aspects particularly the vascular bundles. Interestingly the application of PGR formulation III (T_9) has pronounced impact in increasing the number of xylem vessels, and size of the xylem vessels.

The PGR Formulation-III (T_9) sprayed at squaring stage showed significant increase in fertility coefficient and boll weight than other treatments. With respect to seed cotton yield and HI, the PGR Formulation-III (T_9) consistently maintained a higher yield (23.8 percent) and HI than control under irrigated situation.

With respect to quality parameters, foliar application of nutrients at boll development stage had increased the Ginning Out Turn (GOT), fibre length and the 2.5% Staple length, Uniformity ratio, Micronaire value, Maturity ratio, Elongation percentage and Tenacity are have no significant difference among the various foliar nutrition formulations. The highest net return was recorded in the PGR formulation III (T_9).

In the present investigation, the PGR formulation III (T_9) is much impressive from the yield point of Bunny hybrid Bt cotton.

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ABBREVIATIONS

ABA	-	Abscisic acid
B	-	Boron
B:C	-	Benefit-Cost
Bt	-	Bacillus thuringiensis
°C	-	Centigrade degree
Ca	-	Calcium
CD	-	Critical difference
CGR	-	Crop growth rate
Chl	-	Chlorophyll
Cm	-	Centimeter
CMI	-	Cell Membrane Integrity
CSI	-	Chlorophyll Stability Index
DAS	-	Days after sowing
DAP	-	Di-Ammonium phosphate
TDMP	-	Total Dry Matter Production
dSm^{-1}	-	Deci-Siemen per meter
EC	-	Electrical Conductivity
ECW	-	Epicuticular Wax
ESP	-	Exchangeable Sodium Percentage
et al.,	-	and others
Fig.	-	Figure
GA_3	-	Gibberellic Acid
GOT	-	Ginning Out Turn
Ha	-	Hectare
HI	-	Harvest Index

HPLC	-	High Praliferation Liquid Cromatography
IAA	-	Indole Acetic Acid
K / K_2O	-	Potassium
K_2SO_4	-	*Potassium sulfate*
KCl	-	Potassium Chloride
Kg	-	Kilogram
kg ha^{-1}	-	Kilogram per hectare
KNO_3	-	Potassium nitrate
LA	-	Leaf Area
LAI	-	Leaf Area Index
lit ha^{-1}	-	Litre per hectare
m	-	Meter
m^2	-	Square meter
mg	-	Milligram
m.ha	-	Million hectare
$MgSO_4$	-	Magnesium sulfate
mm	-	Millimetre
Mn	-	Manganese
MOP	-	Muriate of Potash
MSL	-	Mean Sea Level
N	-	Nitrogen
NAA	-	Naphthalene acetic acid
$NaNO_3$	-	Sodium Nitrate
NAR	-	Net assimilation rate
NO_3	-	Nitrate
NS	-	Non-Significant

P / P_2O_5	-	Phosphorus
PGR	-	Plant Growth Regulator
pH	-	Percent hydroxyl ions
ppm	-	Parts per million
RGR	-	Relative Growth Rate
RWC	-	Relative Water Content
SA	-	Salicylic Acid
SDR	-	Stomatal Diffusive Resistance
t ha^{-1}	-	Tonnes per hectare
TNAU	-	Tamil Nadu Agricultural University
Zn	-	Zinc

CHAPTER I

INTRODUCTION

Cotton the "*white gold* or the *king of fibres"* is one of the most important commercial crops in India and world. Cotton is known for the fibre and oil from seed, which plays a prominent role in the national and international economy. India is the second largest producer of cotton in the world next to China with production of 3.95 million bales. About 9.5 million hectares is under cotton cultivation, which contributes about 21% in world area and keeps fluctuating owing to monsoon and other factors. Cotton is cultivated in three distinct agro-ecological regions *viz.*, North, Central and South. The South zone is typical of all types of cotton viz., irrigated and rainfed, hybrids (inter and intra-specific, diploids, and tetraploids) and varieties (diploids and tetraploids) (Khadi, 2005). In India, Bt cotton cultivation had gone up to 80 per cent of the total cotton acreage. (The Cotton Corporation of India, 2008).

In Tamil Nadu, during 2007-08, around 0.5 million bales was produced here while sowing was done in 0.13 million hectares. (AICCIP 2007-08 Annual Report). In Tamil Nadu, Coimbatore, Ramanathpuram, Virudha Nagar districts are high cotton producing areas.

Indian cotton production in terms of productivity is substantially low, about 30% of the cotton crop losses were due to pests, diseases and weeds. Of which 10% of losses are due to one major insect pest notably American bollworm (*Helicoverpa sp.)*; Spotted boll worm (*Earis vitella*, *Earis insulana)*; and pink boll worm (*Pectinophora gossypoiella).* Around 55% of the totally used pesticides are only for cotton cultivation (Barwale *et.al.,* 2004). Bt cotton carries the *Cry1Ac* gene derived from the soil bacterium *Bacillus thuringiensis* var *kurstaki.* The Bt gene expression confers high level of tolerance to the bollworms.

In India cotton is sown during March to September and harvested during September to April. The peak marketing season for the crop is during November to March. At present about 40 percent of the 5 million hectares of total area under cotton in India is under hybrid cotton.

Foliar nutrient sprays have been used in agriculture for a long time. If they did not have merit, they would not have lasted this long. Foliar sprays are used for three main purposes. They are (i) to maintain optimum nutrition of a particular nutrient, (ii) to give a crop nutritional boost at a critical junctures of different phenophases and (iii) to correct deficiency disorders (Wittwer and Teubner,1959). The efficiency of foliar fertilization depends on nutrient mobility within a plant. Nutrient absorption mechanism by the above-ground parts is crucial to optimize foliar fertilization (Pawel Wojcik, 2004). There are three ways of absorption of foliar nutrients; they are (i) penetration through the epicuticular wax and the cuticular membrane (ii) penetration through the cell wall (iii) penetration through the plasma membrane. Some factors influencing absorption of mineral nutrients are (i) environmental factors such as light and temperature, air humidity; (ii) factors related to spray solution such as solution concentration, pH, surfactants, chelates and (iii) biological factors such as species and variety, leaf surface and leaf age, nutritional status and plant development stages (Alexander, 1986).

For achieving higher seed cotton yield, it is necessary to improve the fruiting coefficient. The application of plant growth substances in the correct concentration and at a specific time during plant development may improve the fruit set. It is well established that plant growth regulators (PGR) modify physiological processes, e.g. increased photosynthetic rate, altered photosynthetic export from leaves, and altered respiration rates (Carns and Mauney, 1979). They also play an important role in flower initiation and development, fruit set and fruit growth (Leopold and Kriedemann, 1980). Application of growth regulators was found to be most effective in increasing plant height, dry weight, rate of photosynthesis and seed cotton yield (Kiran Kumar *et al.,* 2005). Beneficial effects of plant growth regulators under irrigated conditions have also been reported (Zhao and Oosterhuis, 1997).

Recently much emphasis are given to Bt cotton hybrids which are high yielding and resistant to pests, particularly, the boll worms. Systematic studies on nutritional requirements and hormonal regulations were not investigated and this needs immediate attention of the scientists.

Cotton is basically an indeterminate type and the development processes are regulated by natural plant hormones. These processes may be manipulated either by altering the plant hormone level or by changing the capacity of plants to response to its natural hormone. In recent years, plant growth regulators which are synthetic hormones have been employed to alter cotton growth and development in an attend to improve production. Essentially plant growth regulators are weapons in the producer's arsenal that can be used to ensure efficient production. It is estimated that over 80 percent of the yield is produced on first position fruiting sites, the retention and maturation of these bolls is critical. Increased boll retention at the early fruiting sites enhances crop maturity, allowing quicker harvest and improved lint quality (Cothren, 1994).

Of late, in the commercial agricultural market many plant growth regulator formulations are available for many crops including cotton. Sometimes these formulations become costly and not affordable.

Considering the above facts investigations were carried out to designed and develop appropriate hormone based nutrient foliar formulations for increasing yield and quality of cotton. The objective of the investigation broadly falls under the following:

1. To record the extent of flower and boll shedding, analyzing the causes including endogenous hormone levels
2. To have an insight into the root histological, anatomical and hormone changes that take place under foliar spray
3. To develop a hormone based nutrient mix for the control of flower and boll shedding in cotton hybrid that ultimately improves yield and quality of the lint.

CHAPTER II

REVIEW OF LITERATURE

In the recent years, uses of plant growth regulators have assumed significant increase in the yield of variable crops by over coming the physiological constraints (Prabakaran, 2002). Plant growth regulators may be effective in reducing pest populations by altering the morphological and biochemical characteristic of cotton (Graham *et al.,* 1987). The effects of plant growth regulators on cotton root growth (Oosterhuis and Zhao, 1994a) and shoot growth and development (Guo and Oosterhius, 1995; Oosterhuis, 1995; Oosterhuis *et al.,* 1995; Oosterhuis and Zhao, 1993) have generally been positive.

Foliar application of nutrients through fertilizers such as DAP, KCl, KNO_3, plant growth regulators and micronutrient mixtures during flower and boll development stages were found to reduce flower and boll shedding and increase the seed cotton yield and fibre quality (Bodnarz *et al.,* 1999). Potassium plays a role in a wide range of functions in plants: photosynthesis, enzyme activation, protein synthesis, osmotic potential, and as a counterion to inorganic ions and organic biopolymers (Marschner, 1995).

Foliar application of super phosphate and di-ammonium phosphate was found beneficial than soil application (Chandrasekhar and Bangarusamy, 2003). Several cytokinin and cytokinin-like compounds (Burst, Cytokin) have been tested for PGR activity in cotton. Specific modes of action have not been elucidated, but these compounds theoretically promote fruit set and retention, and increase the ability of the plant to fill existing fruit (Cothren, 1994).

In this regard, the literatures available on the effect of foliar application of nutrients either individually or as mixture of nutrients on cotton crop is reviewed in this chapter under the following captions.

2.1. Influence of foliar nutrition on growth attributes

2.1.1. Germination percentage

The foliar application of hormone NAA @ 10ppm on 60 and 75 days of seed crop growth enhanced the seed germination percentage and plant height. (Rathinavel *et al.,* 2004).

2.1.1. Plant height and root length

The positive role of Boron in biosynthesis of cell wall and shoot elongation (Kouchi, 1977) which in turn will influence the growth and development of crop plant (Padma *et al.,* 1989 and Rajesh Kumar *et al.,* 1996).

A growth promoter GA_3, thus causing shortening of plant height (Reddy *et al.,* 1996; Thakar Singh and Brar, 1999). The use of phytohormones such as GA_3 has been found to be sufficiently effectual in enhancing the growth and productivity of various plants by promoting the uptake of nutrients (Khan *et al.,* 1998; Shah *et al.,* 2006). GA_3, slightly increased root growth was detected repeatedly under nutrient deficiency (Marschner, 1995). Gutierrez-Coronado *et al.* (1998) observed no effect of SA on soybean photosynthetic rate, but they did observe increases in shoot growth, root growth and plant height. SA performs important actions in the growth and development processes of plants. These actions include stimulating adventives root formation (Riov and Yang, 1989).

NAA applied at 90 DAS increased the plant height compared to control. This might be due to biological activity of auxins viz., stimulation of cell elongation and promotion of cell division (Pothiraj *et al.,* 1995). In cheena millet (*Panicum miliaceum* L.), SA increased plant height and grain number (Datta and Nanda, 1985). Effect of PGR modifying root systems to increase water use efficiency or determining morpho-physiology of plants, especially in cotton roots (Ball *et al.,* 1994; Nepomuceno *et al.,* 1998; Pace *et al.,* 1999; Howard *et al.,* 2001). Application of PGR was found to be most effective in increasing plant height, dry weight, photosynthetic rate and seed cotton yield (Kiran Kumar *et al.,* 2005).

2.1.2. Leaf Area (LA)

Leaf Area in cotton has been reported to control the number of bolls produced and retained (Ashley *et al*., 1965). Shibles and Weber (1966) reported that in general, high yielding varieties of crops recorded 10 per cent more Leaf Area than Low yielders. Leaf area affected the number of bolls produced and retained in cotton (Bhatt, 1987). Foliar spray of SA reduces leaf shed (Ferrarese et al., 1996). Morse and Oosterhuis (1996) revealed that foliar fertilizer in cotton under growth chamber condition at the rate of 17 kg ha^{-1} of urea (7.9 kg ha^{-1}) as mid season application was found to increase leaf area, number of leaves and total dry matter.

2.1.4. Leaf Area Index (LAI)

Leaf Area Index, number of open bolls per plant were increased by application of B and decreased by Cu (Hosney *et al.*, 1984).The growth regulators enhances LAI in transplanting of seedlings during *Kar* season might be due to better absorption of nutrients as a result of more foraging roots and this ultimately led to higher dry matter accumulation (Anbumani *et al.,* 1999). Leaf area index increased with concurrent increase in potassium-levels. A highly significant relationship between potassium levels and leaf area index. There were highly significant relationships between leaf area index and number of total fruit, number of bolls per plant, plant height, total dry weights and leaf dry weights (Pervez *et al.,* 2006).

2.1.5. Crop Growth Rate (CGR)

The CGR, RGR and NAR of cotton during vegetative growth were unaffected by foliar spray of either B or Cu application (Dong Jin Feng, 1995).

2.1.5. Relative Growth Rate (RGR)

EL-Mousri *et al*. (1980) and Pandey *et al*. (1981) observed a positive relationship between RGR and biomass production in cowpea. Higher stem-wood production can be achieved through a faster rate of total biomass production and/or by allocating a larger proportion of the biomass produced to stem growth (Olov Norgren (1996). The major determinant of RGR is the development and maintenance of photosynthetically active LA. This fact was supported by the report of Matusura *et al.* (1996) in four graminaceous crops.

2.1.5. Net Assimilation Rate (NAR)

Net photosynthesis normally increases because the increasing leaf area intercepts more of the incident radiation (Hay and Walker, 1989). Tanaka (1972) reported asymptotic relationship between LA1 and net assimilation rate and had higher optimum LAI values in various rice varieties when the LAI is optimum. Excess nitrogen nutrition enhances leaf growth and the grain yield of rice is depressed because of higher mutual shading. High levels of phosphorus and potassium nutrition cannot counteract this negative effect of nitrogen.

2.1.6. Total Dry Matter Production (TDMP)

Total Dry Matter Production has a direct relationship with crop productivity. Dastur (1960) emphasized that for a better yield capacity, the rainfed crop of cotton should produce adequate quantities of dry matter. Higher grain and dry matter production of maize crop foliar application of boron fertilization may be attributed to low available B content of the experimental soil (Sakal *et al.,* 1988). Howell *et al*. (1984) observed a linear relationship between TDMP and transpiration rate. The effect of potassium on total dry weight was found previously, as well as opposite for the partitioning between root and shoot (Cakmak *et al.,* 1994*a*; White, 1997). Bhatt (1992) reported that TDMP observed in the vegetative growth stage was directly correlated with the final yield. The incorporation of GA_3, to result in enhanced growth, dry mass, and biomass production as well as photosynthetic rate (Khan and Samiullah, 2003; Shah and Samiullah, 2006; Shah *et al.,* 2007).

2.2. Influence of foliar nutrition on Physiological parameters

2.2.1. Relative Water Content (RWC)

There was a increase in RWC whenever plant growth regulators given (Begg and Turner, 1979). In cotton, increment in RWC was reported by Janagoudar *et al.* (1983).

2.2.2. Leaf Temperature

When crops are well supplied with water, transpiration would be at the potential rate and the crop would be relatively cool (Idso *et al*., 1978b). They also observed a declining trend in transpiration during foliar application of growth regulators. Such situation not only increased photosynthesis but also ultimately the yield. Mtui *el al.* (1981) reported that the leaf temperature could be reduced under foliar nutrient application of KNO_3 in corn which may be due to plant water stress and reduced stomatal conductance.

2.2.3. Stomatal Diffusive Resistance (SDR)

Foliar application of NAA increased stomatal conductance. Such increase in the rate of photosynthesis is due to increased stomatal apertures, which facilitate more CO_2 conductance (Guinn and Brummett, 1993). The extent of opening and closing of stomata depends on the turgor maintained in the guard cells. The reduction of epidermal turgor in plants surrounded by dry air can result in stomatal closure, even though bulk leaf water potential is high. Stomatal diffusive resistance was unaffected by the leaf water potential (Cutler *et al*., 1977). In general, the effects of foliar applied SA compounds enhanced

photosynthetic rates and growth of both soybean and corn. Stomatal conductance and transpiration were also increased (Wajahatullah Khan *et al.,* 2002). Exogenous application of salicylic acid (SA) may influence a range of diverse processes in plants, including stomatal closure (Larque-Saaverda, 1979). SA naturally participates in the regulation of physiological processes in plant such as stomatal closure, chlorophyll synthesis, protein synthesis, inhibition of ethylene biosynthesis, transpiration and photosynthesis (Raskin, 1992; Khan and Saimullah, 2003; Shakirova *et al.,* 2003).

2.2.4. Transpiration Rate

The rate of transpiration is directly related to the gradient of water vapour concentrations between intercellular spaces of the leaf and the ambient air. Rate of transpiration was positively correlated with leaf water potential (Schulze and Hall, 1982). Photosynthetic rate and transpiration rate were influenced by growth substances in all stages. Foliar spray of NAA increased the photosynthetic rate and transpiration rate (Guinn and Brummett, 1993).

2.2.5 SPAD Value

The nondestructive nature of SPAD readings makes it very useful when it is desirable to take repeated measurements, over time, on the same leaf. A strong positive correlation between chlorophyll meter (SPAD) readings and extracted chlorophyll content has been already been established (Dwyer *et al.,* 1991). Taking Chlorophyll meter readings is easy and quick and has been employed to predict Chlorophyll content in a large number of plant species, including soybean. Stomatal vs. non-stomatal limitations of photosynthesis is still the subject of debate. There is an increasingly large body of evidence that plant growth regulators may have a positive effect on photosynthetic capacity (Chaves, 2002).

2.2.6. Number of days taken for First Square, Flower, Boll formation and first Boll opening.

Delayed fruiting in cotton is important phenomenon for improved yield and quality which was achieved through PGR spray and fruiting branches removal at 35 and 41 DAP in 2000 and 41 and 48 DAP in 2001 such that the first fruiting branch occurred approximately at main stem node 9 in all plants with in a plot under irrigated condition (Disha Dumka *et. al.,* 2004).

2.3. Influence of foliar nutrition on Biochemical aspects

All enzymes related to these main processes of photosynthesis may have a decreased activity or amount. Although theoretically possible, inadequate inorganic phosphate supply due to low recycling to the chloroplast, and low content of reductants in the chloroplast, are very unlikely in the case of water stress (Lawlor and Cornic, 2002).

2.3.1. Chlorophyll content (Chl)

The chlorophyll pigment of the plant had influenced the photosynthetic rate and thereby the efficiency of the plant for increased biomass production was obtained (Chandrababu, 1990 and Sujatha, 2001). In this study, foliar spray of 1% urea recorded higher chlorophyll content compared to control. This result might be due to the fact that nitrogen is the constituent of chlorophyll molecule, which is exported during rapid grain filling stage from leaves (Gomathi, 1996). Mitra *et al.,* (1987) reported foliar application of nitrogen must be essential for maintaining chlorophyll content during pod development stage and thus resulting in higher photosynthetic rate as well as higher yield. NAA is known to increase the rate of photosynthesis by increasing the chlorophyll content per unit area and leads to more rapid exchange of CO_2 into mesophyll cells (Dulizhao and Oosterhius, 2000). Total chlorophyll content expressed on leaf area basis was higher with NAA sprayed when compared to CCC, MC and control (More *et al.,* 1993 and Reddy *et al.,* 1996). Chlorophyll content of young mature leaves increased with the application of potash and inadequate levels of potash resulted in reduction of total chlorophyll content in leaves (Oosterhuis, 1995 and Oosterhuis and Wullschleger, 1987); low rate of chlorophyll degradation as reported by Yeo and Flowers (1983).

Exogenous application of SA increase in photosynthetic rate and chlorophyll content (Rhoads and McIntosh, 1991; Chandra and Bhatt, 1998). Bharadwaj and Singh (1988) observed that the cotton plants with higher leaf conductance, chlorophyll content and higher biomass productivity. The decrease caused by high concentrations of SA in Chlorophyll amount resulted inhibition of chlorophyll biosynthesis, acceleration of chlorophyll destruction or both (Yang *et al.,* 2002). Salicylic acid significantly increased chl. ‘a’, chl. ‘b’ and carotenoids recording maximum values at 100 mg/l (Gharib, 2006). Shakirova *et al.* (2003) and Iqbal and Ashraf, (2006) on wheat plants and Abdel-Wahed *et al.,* 2006 and El-Mergawi and Abdel-Wahed, 2007) on maize plants

found that salicylic acid caused significant increased in chlorophyll content. Foliar application of growth regulators and the effect of photosynthetic photon flux density on the leaf Chl *a/b* ratio is one of the most characteristic differences between sun and shade leaves (Bjorkman *et al.,* 1972; Boardman, 1977; Lichtenthaler *et al.,* 1981; Anderson, 1986). Due to its predictable response to irradiance, the Chl *a/b* has been proposed as a bioassay to assess the irradiance of a plant (Dale and Causton, 1992). The foliar application of Multi-K in cotton plants influences the leaves turned to a darker green. This is due to increased chlorophyll, cellular activity and metabolism in the leaves. (Stephen Mruma, 2006).

2.3.2. Chlorophyll Stability Index (CSI)

Kaloyereas (1958) was the first to suggest a correlation between CSI and foliar nutrition of plant growth regulators in pine trees. Later, Sahadevan (1961) and Murthy and Majumdhar (1962) reported a similar relationship between CSI and photosynthetic efficiency in rice.

2.3.3. Nitrate Reductase (NRase)

The higher NRase activity was related to the yield of grain and grain protein content in many crops (Mishra *et al.,* 1980). The increase in enzyme NRase activity by nitrogen was also reported by Akhtar *et al.* (1991). The level of NRase was found to fluctuate in response to environmental condition (Sinha and Nicholas, 1981). Application of NAA @ 20ppm sprayed at 90 DAS resulted in higher nitrate reductase activity (Eid *et al.,* 1986). The effect of N on protein content was found to arise through an enhancement of NR activity. NR is the regulatory enzyme in the N metabolism and is responsible for the reduction of nitrate to ammoniacal N, which is then incorporated in the production of amino acids (Hopkins, 1995). The various factors also regulate the activity of NRase. These include the presence or absence of hormones, such as gibberellins, cytokinins (Roth-Bejerano and Lips, 1970), auxins (Ahmad and Hayat, 1999). Sarangthem and Singh (2003) found that the level of N, proteins and nitrate reductase activity were increased in *Phaseolus vulgaris* by foliar application of SA at 0.1%. KNO_3 was supplied; uptake and storage of nitrate as well as nitrate reductase activity in the leaves were increased when compared to $NaNO_3$ as the nitrogen-source (Blevins *et al.,* 1978).

2.3.4. Soluble Protein

Martigone *et al.* (1981) reported that soluble proteins are the nitrogenous compounds, which usually decline during pod filling stage. Hence, spraying of 1% urea might have increased the soluble protein content and recorded maximum NRase activity. Evans (1983) reported that nearly 30 to 50 per cent of the total leaf soluble protein was contributed by Ribulose 1, 5 bi-5-phosphate carboxylase (RuBpcase) which was considered to be an important enzyme involved in the reduction of Co_2 in the photosynthetic process. Potassium is well documented in photosynthesis, enzymatic activity, synthesis of proteins, translocation of photosynthates and enabling the plant to resist pest and diseases (Tisdale *et al.,* 1993). Nitrogen is vital in basic protein structure as well as being an active constituent of RNA and DNA, which are essential for protein synthesis (Marschner, 1995). SA and other salicylates have on protein synthesis mechanism (Pennazio *et al.*, 1983; Francesco *et al.*, 1986).

2.3.5. Proline content

Osmoprotectans such as proline, glycine betaine (GB), and mannitol occurs commonly in plants. Earlier studies indicated that proline is a common compatible in many different organisms, including higher plants, and some plant species accumulate proline in response to drought. Growth regulators enhance praline content (Koheil *et al.*, 1992). Singh and Singh (1986) attempted to correlate the leaf proline with drought tolerance in sugarcane and confirmed this relationship. Rice plant stressed at tillering and boot stage showed maximum free proline accumulation (Ram *et al*., 1988).

2.3.6. Cell Membrane Integrity (CMI)

The foliar application of plant growth regulators are induced nutrient uptake and reduced cell membrane leakage (Guo and Oosterhuis, 1995). Phenolic compounds such as salicylic acid play a central role in plant metabolism and growth and they are known to increase photosynthetic electron transport, improve or protect membrane integrity, and increase enzyme or protein production (Robinson, 1980).

2.3.7. Epicuticular Wax (ECW)

The foliar spray of growth regulators enhances, ECW has been shown to reduce the net radiation load of the canopy as well as cuticular transpiration and to improve stomata control over transpiration (Blum, 1979). Plant chemical processes change in response to environmental conditions, such as temperature, light, or soil moisture, and

would likely affect ECW regulating mechanisms, thus, causing a shift in the ECW chemical components (Baker, 1974; Bondada *et al.,* 1996; Rama Das *et al.,* 1979; Shepherd *et al.,* 1995).

2.3.7. Root Anatomy

Perumalla *et al.* (1990) observed that the existence of uni- bi- or multiseriate exodermis in over 90% of the species examined, including monocots and dicots, and members of primitive and advanced plant families. However, no hypodermis or exodermis was found in cotton plants, as well as in other species of the Malvaceae and Fabaceae. The most pronounced structural responses to growth regulators and environmental conditions are often related to cell wall modifications (Wilson and Peterson, 1983). SA may play a part in the flowering of cocklebur plants, since its concentration increased in the phloem when they were induced to flower by manipulating day length (Cleland and Ajami, 1974). As the number of vascular bundles increased, high branching intensities of lateral roots also increased in cotton (McMichael *et al.,* 1987).

2.3.8. Leaf Anatomy

The addition of GA_3 treatment, the accentuation of all the positive effects of N on yield might have resulted from an increase in vascular capacity (Kuang *et al.,* 1991a; 1991b) brought about by GA_3 under an enhanced sink potential, thereby facilitating increased translocation of photoassimilates to the developing reproductive organs. Plants modulate leaf anatomy and physiology to irradiance, developing thicker leaves with a greater mesophyll to surface-area ratio (Boardman, 1977; Lichtenthaler *et al.,* 1981; Anderson, 1986). Cakmak *et al.,* (1994b) reported higher magnesium, potassium and amino acid concentration reduced phloem leakage in bean.

2.3.9. ABA quantification

Varma (1978) reported that application of NAA to flower buds or boll explants completely counteracted the abscission-promoting effect of abscisic acid (ABA). Slightly decreased ABA level in wheat grains by the foliar applied potassium (Haeder and Beringer, 1981). Foliar spray of SA has also been reported to reverse the stomatal closure induced by ABA (Rai *et al.,* 1986). SA also providing resistance against different stress factors in plants (Bergmann *et al.,* 1994; Agnes *et al.,* 2005) by modifying the effects of

abscisic acid (Apte and Laloraya, 1982). Hartung *et al.* (1983) recently demonstrated that growth regulators alters partitioning of ABA between pools in the mesophyll and thereby increases ABA accumulation in the epidermis. The effect of nutrient deficiency on long-distance ABA signals has been studied in detail (Peuke *et al.*, 1994*b*; Jeschke *et al.*, 1997*b*).

2.3.10. Cry 1Ac gene

Phenolic compounds namely salicylic acid play a central role in plant metabolism and growth and they are known to increase photosynthetic electron transport, improve or protect membrane integrity, and increase enzyme or protein production (Robinson, 1980). This hypothesis was that utilization of the phenolic properties of Chaperone (it is a combination of nitrophenols, namely sodium 5-nitroquaiacolate and phenolics compounds like salicylic acid) in transgenic cotton would aid in alleviating non-expression of Cry1Ac or a combination of Cry1Ac with Cry2Ab, which are the genes currently utilized for expression of the endotoxin protein *Bacillus thuringensis*. Plant growth regulators may be effective in reducing pest populations by altering the morphological and biochemical characteristic of cotton (Graham *et al.*, 1987).

The Cry 1Ac gene content was estimated in leaves by the method described by (Adamczyk and Sumerford, 2001). It was seen that the toxins (e.g. gossypol in squares) are influenced by the foliar feeding of growth hormones probably due to increased metabolic activity due to the treatments (Lukefahr *et al.*, 1975; Stewart *et al.*, 2001). Greenplate (1999) and Adamczyk *et al.*, (2001) showed that the level of Cry1Ac was significantly different among various cotton plant structures. Greenplate, (1999) showed that the terminal portion of the Bollgard plant contained significantly more Cry1Ac than any other plant structure, it increased plant vigour.

2.4. Influence of foliar nutrition on yield and yield components

2.4.1. Number of sympodial branches per plant

The foliar treatments of NAA @ 10ppm significantly enhanced the number of sympodial branches per plant (Thandapani and Subharayalu, 1986).

2.4.1. Number of flowers and bolls per plant

Flower production is directly associated with number of fruits and yield in any crop. Foliar application of 1% urea increased the pod number in green gram (Thandapani, 1981).

Bud and boll shedding decreased significantly by combined application of NAA + DAP + topping (Venkatakrishnan, 1995). Hsu *et al.* (1974) found that application of exogenous auxin to unfertilised bolls reduced shedding and stimulated the development of young bolls. Abdel-Al *et al.,* (1982) found that the reduction of young boll shedding with NAA application was connected with an increase in the total phenols and polyphenol content in young bolls. These findings may be due to indirect effect to polyphenols in inhibiting the action of indole acetic acid oxiase, yet tending to reduce boll shedding percentage (Addicott, 1970). Increased number of bolls per plant were also observed by Khan and Hanif, (1980) through spray of 20ppm NAA per acre.

SA induces flowering, increase flower life, retards senescence and increases cell metabolic rate. The sustained level of salicylic acid may be a prerequisite for the synthesis of auxin and/or cytokinin (Metwally *et al*., 2003). In cotton, there was an increase in the number of bolls per plant through GA_3 application (Sawan *et al.,* 1989). Foliar application of this cytokinin product was reported to promote bud initiation and development that caused an increase in plant fruitfulness and efficiency of the plant to develop (Murry *et al.*, 1976).

2.4.2. Fertility Coefficient and boll weight per boll

Limitation in cotton productivity is mainly associated with climatic conditions which affect the fruiting efficiency and boll retention. The number of bolls set or shed was decided by auxin – abscisin interaction, nutrient supply and weather conditions (Bhatt, 1982). The foliar application of hormone NAA @ 10ppm on 60 and 75 days of seed crop growth enhanced the seed setting efficiency and boll weight. (Rathinavel *et al.*, 2004). Growth regulators like GA and IAA significantly increased the number of flowers per plant and improved fruit setting (Subramanian and Palaniappan, 1981). The increase in boll weight can be attributed to the application of exogenous auxin increasing the photophosphorylation of chloroplasts (Tamas *et al.* 1972). Varma (1976) reported more than 32 per cent of flower shedding and 58 per cent of boll shedding in cotton. The increased pod set by the foliar application of 1% urea and plant growth regulators might be due to the increased source activity at pod filling stage, which could supply required assimilates for pod development (Prabakaran, 2002).

Sawan (1986), Goyal *et al.* (1988) and Pothiraj *et al.* (1995) reported that applying NAA to cotton plants increased boll weight and seed cotton yield. Growth substances as a foliar spray increased the yield either by increasing pod setting (Birari, 1976). The retention of flowers and pods are increased by either regulator as reported by Sharma and Dey (1986) in soybean. Kaur and Singh (1992) reported that flower number and percentage of boll abscission were decreased by water stress at flowering stage in cotton. The capacity of GA_3 to regulate the induction of flower/fruit set (Arteca, 1996) could also have supplemented the other causes to result in an overall enhancement of yield. Zheng and Zu (1982) reported that exogenous application of IAA in cotton stimulated growth and decreased boll shedding.

2.4.3. Seed cotton yield

Considerable loss in yield is always encountered due to excessive vegetative growth and shedding of squares, flowers and bolls in cotton. Seed cotton yield increased when the trace elements viz., Zn, Cu, Fe, Mn, Mo, and B were applied individually than together (Haq-Nawaz *et al.,* 1994). Seed soaking followed by foliar application of IAA @ 10ppm or boron @ 0.1% were also found useful in increasing the productivity over control (Karnail singh, 1976). A linear increase in lint production was observed by Reginato (1983) as the seasonal average stress index decreased. Exogenous applications of SA to different crop species have been shown to elicit effects on yield and yield components. An increase in the number of pods and yield has been found in mung bean (Singh and Kaur, 1980).

Application of growth regulators was found to be most effective in increasing plant height, dry weight, rate of photosynthesis and seed cotton yield (Kiran Kumar *et al.,* 2005). Lint yield is generally reduced because of reduced boll production, primarily because of fewer flowers and also due to increased boll abortions when the stress is extreme and when it occurs during reproductive growth (Pettigrew, 2004). Namken (1984) applied single and multiple foliar applications of a cytokinin product to cotton at first one-third-grown square and at first bloom; treated cotton produced a significantly higher lint cotton yield than the untreated check.

Nitrogen (N) is the single most important growth limiting factor for crops and, when supplied in the form of urea, has proved to be most instrumental among all major

elements in boosting the yield of numerous plants (Kumar *et al.*, 2004; Ashraf and Noman, 2006; Ashraf *et al.*, 2006). Exogenous application of salicylic acid (SA) may influence a range of diverse processes in plants, including seed germination, fruit yield (Cutt and Klessig 1992). In mung bean (*Vigna radiata* L.), three foliar sprays of salicylic acid increased seed yield per plant (Singh and Kaur, 1980). Salicylic acid may have increased yield by decreasing transpiration in a water-limited environment (Patil and Wele, 1992). The foliar application of wheat plants with salicylic acid combined with ascorbic acid were more effective in increasing yield and its components in addition to photosynthetic pigments content in the leaves, total carbohydrate percentage in wheat grains as compared with other treatments or untreated plants (Amin *et al.*, 2008). SA also increased yield and its components of maize (Shehata *et al.*, 2001). KNO_3, and urea applied at first bloom and repeated 9 to 13 days after first bloom has potential to increase yield 7 to 10%. Sawan *et al.*, (1986) observed that higher rate of nitrogen and phosphorus on cotton sprayed with IAA, IBA and NAA gave increased seedling vigour, length and seed cotton yield. In India (Chaudhri and Bathkal, 1977) and in Pakistan (Jalis and Chaudhri, 1977) got increased seed cotton yield with the spray of planofix (NAA) to cotton. In Arkansas with a mixture of complexes containing various bacterially active cytokinins, auxins and amino-acid chelated minerals showed trends towards increased yields (Cathey, 1983). A positive effect with a significant difference in the number of bolls between the test plots and the control plots. The increase in number of bolls is the direct result of the Multi-K applied (Stephen Murma, 2006). Foliar spray of 3 per cent urea in the morning at weekly intervals from squaring to boll development stage appeared to be an efficient technique of foliar urea fertilization and gave better yield than control (Orpia *et al.*, 1997).

2.4.4. Harvest Index (HI)

Yield is a function of HI and total biomass. Harvest Index was maintained in sorghum by high osmotic adjustment, when foliar application of macro nutrients was given (Ludlow and Muchow, 1990). Ramesh (1988) observed a increase in HI under irrigated condition in wheat at all stages of growth. Foliar application of potassium fertilizers changed the pattern of portioning of photosynthates at the expenses of the quantity or quality of economic yield rather than soil application (Sinclair *et al.*, 1985).

2.5. Influence of stress stages on fibre quality characters

Fibre being one of the important components of yield, qualitative parameters of fibre characteristics likes length, strength, fineness; maturity and uniformity are also of interest in cotton. Sawan (1986) reported that low concentrations of NAA increase fibre fineness but had reverse effect at high concentrations. Goyal *et al.* (1988) found that application of NAA at pre-square-initiation, flowering and boll formation stages, increased fibre length and fineness. Mehetre *et al.* (1990) found that fibre bundle strength was highest when NAA was applied. Under optimum irrigated conditions, seed cotton yield as well as fibre qualities increased (Cudrak and Reddel, 1988), but same showed a declining trend at higher levels of applied water (Grimes *et al*., 1969).

Khan *et al*. (1986) reported that pre monsoon sowing of cotton under limited irrigation levels reduced span length, whereas other characters like uniformity ratio, bundle strength and maturity coefficient were not much affected. Howell *et al*. (1984) reported that the fibre length and micronaire values diminished under water stress condition. Micronaire index and fibre length decreased but fibre maturity percentage and uniformity ratio remained unaffected by water stress (Marur, 1991). The overall studies revealed that fibre qualities were slightly increased due to foliar application of growth regulators.

CHAPTER III

MATERIALS AND METHODS

A field experiment was conducted with a view to evaluate the newly developed foliar nutrient formulations on Bt cotton. The trial was carried out from August 2008 to January 2009 at the Eastern Block area of Tamil Nadu Agricultural University, Coimbatore. The details of the experiment, the materials and methods of analysis followed and the statistical procedures adopted are presented in this chapter.

3.1. MATERIALS

3.1.1. Location

The field experiment was conducted in Field No 73 of Eastern Block, Central Farm, Tamil Nadu Agricultural University, Coimbatore. It was situated in the Western Zone of Tamil Nadu at 11° N latitude and 77° S longitude with an altitude of 426.74 m above mean sea level.

3.1.2. Weather and Climate

The mean rainfall of Coimbatore during cropping season is 438.8 mm distributed in 29 rainy days on. The mean maximum and minimum temperature were 30.4°C and 20.7° C respectively. The meteorological data on maximum, minimum temperatures, relative humidity, rainfall and solar radiation that prevailed during the cropping period are given in Table 1; Fig 1 and 2.

3.1.3. Soil

The soil was clay loam in texture with low in available nitrogen, medium in available phosphorus and high in available potassium. The Physico – chemical properties of the experimental soil are furnished in Table 2.

3.1.4. Crop and variety

The Bunny hybrid Bt cotton selected for the study for cultivation in south and central India. This hybrid is high yielding with good quality fibre and has wider adaptability. The salient features of the bunny hybrid are furnished in Table 3.

Table-1 Temperature and rainfall distribution during cropping season

S. No	Month	Temperature (°C)		Rainfall (mm)	No. of Rainy days
		Maximum	Minimum		
1	August	32.1	22.5	52.7	5.0
2	September	31.6	21.6	18.5	3.0
3	October	30.5	21.0	312.9	14.0
4	November	29.9	21.5	45.4	5.0
5	December	28.7	19.1	9.3	2.0
6	January	29.8	18.7	0.0	0.0
	Total	**30.4**	**20.7**	**438.8**	**29.0**

Table-2 Soil Physico – chemical characteristics of experimental site

Constitutions		Content	Methods used
A. Mechanical analysis			
1	Clay (%)	28.15	Piper (1966)
2	Silt (%)	18.26	
3	Fine sand (%)	23.10	
4	Coarse sand (%)	30.33	
5	Texture	Sandy Clay loam	
B. Chemical analysis			
1.	Available Nitrogen (Kg ha $^{-1}$)	168.0	Subbiah and Asija (1956)
2.	Available Phosphorus (Kg ha $^{-1}$)	21.0	Olson *et al*. (1954)
3.	Available Potassium (Kg ha $^{-1}$)	575.0	Stanford and English (1949)
4.	Electrical Conductivity (ds m^{-1})	0.32	Jackson (1973)
5.	pH (1:2 soil : water solution)	8.49	Jackson (1973)
6.	Organic Carbon Content (%)	0.49	Walkley and Black (1934)

Table-3 Characteristics of Bunny Bt hybrid cotton

S. No	Characteristics	Bunny
1.	Genetic background	Intra specific hybrid
2.	Plant habit	Erect
3.	Plant height	Medium
4.	Monopodia	1-2
5.	Sympodia	12-14
6.	Stem character	Strong and sturdy
7.	Leaf character	Dark green broad lobed, medium size, hairy, convex
8.	Days of squaring	40-42
9.	Days of flowering	63-66
10.	Flower characteristics	Petal cream pollen yellow, peal yellow petals
11.	Boll characteristics	Big oval, weight 4.5-5.5 g
12.	Duration in days	145-155 days
	Yield potential	
13.	Irrigated	35-40 q ha^{-1}
	Quality parameters	
14.	2.5 per cent span length	31-32.5 mm
15.	Ginning percentage	33.6
16.	Micronaire	4.0-4.75

3.2. METHODS

3.2.1. Field lay out

The experiment was laid out in a Randomized Blocks Design (RBD) with three replications. (Fig 3). The treatments are as follows.

3.2.2. Treatments

T_1 - NAA @ 40 ppm

T_2 - Potassium chloride (KCl) @ 2 %

T_3 - Potassium nitrate (KNO_3) @ 3 %

T_4 - Salicylic acid @ 100 ppm

T_5 - Diammonium Phosphate (DAP) @ 2 %

T_6 - Polyfeed 19:19:19 @ 1.5 % + Multi K 13: 0 : 45 @ 1.5 %

T_7 - PGR Consortia (Formulation - I)

T_8 - PGR Consortia (Formulation - II)

T_9 - PGR Consortia (Formulation - III)

T_{10} - PGR Consortia (Formulation - IV)

Location : Coimbatore

3.2.3. Plot size

Plot Size : 5 X 4 m^2

Two sprays were taken up at stray flowering and boll formation coinciding at 45 and 105 days after sowing at the time of 10 to 12 O'clock.

The treatments were given as foliar application at different growth stages as per the schedule.

Fertilizer dose of 120:60:60 kg NPK ha^{-1} was applied uniformly for all the treatments, of this full dose of P and 50 per cent of N and K (60:60:30 kg NPK ha^{-1}) was applied as basal dose at sowing and the balance 50 per cent of N and K was applied as top dressing at 45 and 60 DAS in equal split.

3.2.4. Preparation of the field

The experimental field was brought to optimum tilth by ploughing twice with tractor drown mould board plough, followed by harrowing twice and leveling. The plots were marked after forming ridges and furrows at 90 cm apart with ridge plough. The treatments were allotted at random to the plots.

3.2.5. Seeds and sowing

Good viable seeds of Bunny Bt hybrid were dibbled on one side of the ridge with a spacing of 45 cm between plants. The seed rate adopted was 3 kg of delinted seeds per hectare. The crop was raised under irrigated condition. The quality of irrigation water is furnished in Table 4.

3.3. Management Practices

3.3.1. Fertilizers

Nitrogen, Phosphorus and Potassium were applied in the form of Urea (46% N), Single super phosphate (16% P_2O_5) and Muriate of potash (60% K_2O) respectively, @ 120:60:60 kg NPK ha^{-1}. Then foliar feedings were given as per treatments.

3.3.2. After cultivation

The field was irrigated immediately after sowing. Life irrigation was given on the third day of sowing. Then five irrigations were given subsequently during cropping period in addition to rainfall received. Thinning was done on 15^{th} day after sowing. One healthy seedling per hill was maintained. Hand hoeing and weeding were done twice on 35 and 60 DAS. Earthing up was done during second weeding. Topping was done on 80 DAS uniformly in all the plots.

3.3.3. Plant protection

Imidachloprid (WS) was applied at pin head square for early sucking pest. Then one spray of systemic insecticide *viz*., Metasystax was carried out to check sucking pest infestation at 95 DAS. There were no plant protection sprays after 95 DAS upto harvest.

Table-4 Quality of irrigation water (Jackson, 1973)

S. No	Properties	Values
1.	pH	7.51
2.	Electrical Conductivity (dS m^{-1})	2.45
3.	**Cations (m eq l^{-1})**	
	Carbonate	0.00
	Bi-Carbonate	12.0
	Sulphate	5.0
	Chloride	12.8
4.	**Anions (m eq l^{-1})**	
	Calcium	4.40
	Magnesium	2.05
	Sodium	15.3
	Potassium	0.74
5.	Sodium Adsorption Ratio (SAR)	8.52
	Adjusted SAR	23.0
6.	Residual Sodium Carbonate (RSC)	5.55
7.	Ca/Mg Ratio	2.15
Irrigation Source – open well		

3.3.4. Harvest

The seed cotton (Kapas) was harvested in three pickings commencing from the first picking on 130 DAS, followed by second picking on 140 DAS and third picking on 155 DAS. Topping was done for a precautionary measure to avoid excessive vegetative growth on 80 DAS uniformly in all the treatmental plots.

3.4. Observation recorded

3.4.1. Morphological parameters

The following morphological parameters were recorded at squaring stage, boll development and harvest stages. The observation was taken seven days after the application of treatments by selecting five representative samples. The methods followed in estimation of each of these parameters are described below.

3.4.2. Plant height

Plant height was measured from the base of the plant to the tip of growing point and expressed in cm.

3.4.3. Root length

Root length was measured from the cotyledonary node to tip of root cap and expressed in cm.

3.4.4. Leaf Area (LA)

Leaf Area was measured with Leaf Area Meter (Model LI 3100, Li-Cor, Inc. Nebraska, U.S.A.) and expressed in square centimeter per plant.

3.4.5. Total Dry Matter Production (TDMP)

Five plants at random were cut at ground level for estimating of dry matter production. The samples were initially air dried for 24 hours and subsequently dried in oven for further 24 hours at 60 ± 5^0 C to get a constant weight. The weights were recorded on moisture free basis and expressed in kg ha^{-1}. These samples were used for chemical analysis.

3.5. GROWTH ANALYSIS

3.5.1. Leaf Area Index (LAI)

From randomly selected plants in each treatmental plot, leaf length and maximum width of the third leaf from the top was measured by five representative samples. Total number of leaves in each plant was counted. From these observations made on 60, 90, 120 DAS and at harvest stage, the LAI was calculated using the following formula as suggested by Ashley *et al*. (1965).

$$LAI = \frac{L \times W \times N \times 0.775}{\text{Land area } (cm^2) \text{ occupied by one plant}}$$

where,

L = Length of the leaf in cm

W = Width of the leaf in cm

N = Number of the leaves per plant and

0.775 = Constant value

3.5.2. Crop Growth Rate (CGR)

The CGR was calculated for the period of 0-40, 40-80 and 80-120 days, using the crop DMP recorded during the respective stages, as suggested by Watson. (1958).

$$\mathbf{CGR} = \frac{W_2 - W_1}{t_2 - t_1} \ \mathbf{g\ m^{-2}\ day^{-1}}$$

Where,

W_2 and W_1 are the shoot dry weight of the plant at times t_2 and t_1 respectively.

t_1 and t_2 are the time interval in days

3.5.3. Relative Growth Rate (RGR)

The RGR was calculated for the period 0-40, 40-80 and 80-120 days using the crop DMP recorded for the respective stages as suggested by Enyi. (1962).

$$\mathbf{RGR} = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1} \ \mathbf{g\ g^{-1}\ day^{-1}}$$

Where,

W_2 and W_1 are dry matter weight of the plant at time t_2 and t_1

t_1 and t_2 are the time interval in days

3.5.4. Net Assimilation Rate (NAR)

The NAR is the rate of increase of leaf dry weight per unit area of leaf per unit time. Williams. (1946) employed the formula.

$$\mathbf{NAR} = \frac{(W_2 - W_1)}{(t_2 - t_1)} \times \frac{(\log_e L_2 - \log_e L_1)}{(L_2 - L_1)} \quad \mathbf{g\ m^{-2}\ LA\ day^{-1}}$$

Where,

W_1 and W_2 is dry weight of whole plant at time t_1 and t_2 respectively

L_1 and L_2 are leaf weights or leaf area at t_1 and t_2 respectively

$t_1 - t_2$ are time interval in days

3.6. Physiological parameters

3.6.1. Physiological parameters

The Transpiration rate, Relative humidity, Leaf temperature, Quantum measurement, Diffusive resistance were recorded from five plants on the 10th day after the imposition of the treatment using Stead State Porometer (Li- Cor 3100) at the time of midnoon period.

3.6.2. Measurement with chlorophyll meter (SPAD 502)

A chlorophyll meter (SPAD 502) designed by the Soil Plant Analysis Development (SPAD) section, Minolta Camera Co. Ltd., Japan was used to record SPAD readings. SPAD 502 readings were taken as described by Peg *et al*. (1993).

The SPAD 502 is self calibrated for variability in the output of LED and has built in error codes that help to prevent irregular measurement. Leaf chlorophyll absorbance is measured at a wavelength of 650 nm and non-chlorophyll absorbance is measured at a wavelength of 940 nm. A microprocessor calculates the SPAD value, which is proportional to the relative optical density based on the ratio between the two wavelengths (Minolta, 1989; Monje and Bugbee, 1992).

Measurements were taken from upper most fully expanded leaf (4th or 5th leaf from the apex) (Wood *et al.*, 1992). SPAD 502 readings were recorded on 60, 80, and 120 DAS from 10 plants per plot. Five chlorophyll meter readings were taken around the

mid point of each blade of the leaf in a plant. Thus, fifty SPAD readings were taken from 10 plants to represent the mean SPAD 502 values of each plot (treatment).

3.6.3. Relative Water Content (RWC)

Leaf samples were taken from the youngest fully expanded leaves for recording relative water content. Relative water content was estimated by Weatherly. (1950) method and expressed in percentage.

$$RWC = \frac{\text{(Fresh weight – Dry weight)}}{\text{(Turgid weight – Dry weight)}} \text{ X } 100$$

3.7. Biochemical parameters

3.7.1. Chlorophyll content

The contents of chlorophyll *a*, *b*, chlorophyll *a*/*b* ratio and total chlorophyll were estimated by adopting the procedure of Yoshida *et al*. (1971) and the contents were expressed as mg g^{-1} of fresh weight.

3.7.2. Soluble protein content

Soluble protein content was estimated from TCA extract of leaf sample by adopting the method of Lowry *et al*. (1951) and expressed in mg g^{-1} fresh weight.

3.7.3. Nitrate reductase activity

Nitrate reductase activity was estimated in the physiology active leaf by following the method of Nicholas *et al*. (1976) and expressed as μg NO_2^- g^{-1} h^{-1} fresh weight.

3.7.4. Proline content

Proline content of leaves was estimated by the method described by Bates *et al*. (1973) and expressed in μ moles g^{-1} fresh weight.

3.7.5. Chlorophyll Stability Index (CSI)

Chlorophyll Stability Index was estimated by the method described by Murthy and Majumdhar (1962).

3.7.6. Cell Membrane Integrity (CMI)

Cell Membrane Integrity of leaves was estimated by the method described by Deshmukh *et al.* (1991).

3.7.7. Measurement of ABA levels

Plants were grown for four to five weeks in a controlled environment chamber under short days (10 h), 70% humidity as previously described.

Pathogen or abiotic stressed plant material was harvested into liquid nitrogen and freeze dried. Samples were next placed in a 2 ml microfuge tube and ground in a bead beater (Qiagen or equivalent) with 3 mm tungsten beads at 25 Hz/s for 3 min. Ten milligram of powdered tissue (10 mg fresh weight of leaves) was weighed into a new 2 ml microfuge tube and extracted with 400 µl of 10% methanol containing 1% acetic acid to which internal standards had been added. Each treatment also included an extraction control containing no plant material. A 3 mm tungsten bead was placed in each microfuge tube and samples were extracted in the bead beater for 2 min at 25 Hz/s, placed on ice for 30 min then centrifuged at 13,000 g for 10 min at 4°C. The supernatant was carefully removed and the pellet re-extracted with 400 µl of 10% methanol containing 1% acetic acid. Following further 30 min incubation on ice the extract was centrifuged and the supernatants pooled. The two extractions resulted in 90–95% recovery of the targeted analytes.

Samples (50 µl) were then analysed by HPLC-electrospray ionisation/MS-MS using an Agilent 1100 HPLC coupled to an Applied Biosystems Q-TRAP 2000 (Applied Biosystems, California, USA). Chromatographic separation was carried out on a Phenomenex Luna 3 µm C18(2) 100 mm × 2.0 mm column, at 35°C. The solvent gradient used was 100%A (94.9% H_2O: 5% CH_3CN: 0.1% CHOOH) to 100%B (5% H_2O: 94.9% CH_3CN: 0.1% CHOOH) over 20 min. Solvent B was held at 100% for 5 min then the solvent returned to 100% A for 10 min equilibration prior to the next injection. The solvent flow rate was 200 µl/ min. To reduce contamination of the MS, the first 2 min of the run was directed to waste using the inbuilt Valco valve. Analysis of the compounds was based on appropriate Multiple Reaction Monitoring (MRM) of ion pairs for labelled and endogenous JA, SA and ABA using the following mass transitions; $2H_2$-JA 211 > 61, JA 209 > 59, $2H_4$ SA 141 > 97, SA 137 > 93, $2H_6$ ABA 269 > 159, ABA 263 > 153, SA-glyc 299 > 93. The MS was operated in the negative mode using

Turbo- Ionspray™ as the ion source. Optimal conditions were determined using the Quantitative Optimisation feature of the Analyst software both by infusing standards into the MS by syringe pump and injecting standards into a 200 µl/min flow of 50% Solvent A/50% Solvent B. The optimised conditions were as follows: Temperature 400°C, Ion source gas 1 50 psi, Ion source gas 2 60 psi, Ion spray voltage -4500 V, curtain gas 40 psi, CAD gas setting 2; the DP (-25 V), EP (-9) and CEP (-2) were held constant for all transitions. Collision energies (CE) and dwell times (DT) were specific for each compound/internal standard pair, the parameters used were JA CE-25, DT 100 ms, ABA CE-17, DT 250 ms and SA CE-38, DT 50 ms. Data were acquired and analysed using Analyst 1.4.2 software (Applied Biosystems).

Hormones were determined in three independent samples for each treatment or time point. This ABA quantification method described by Silvia Forcat *et al.*, (2008)

3.7.8. Quantification of Bt (Cry 1Ac) Gene

Quantification of the levels of Cry1Ac present in the two cotton cultivars was made using a commercially available kit (Envirologix, Inc). On July 15, 2003, healthy plants (5) were selected from each plot for Cry1Ac quantification. Terminal leaves from the plants were used because this tissue accurately reflects overall expression differences among cultivars (Adamczyk and Sumerford, 2001). Tissue was excised from the lobed region of a terminal leaf by placing the tissue underneath the attached cap of a 0.5 ml microcentrifuge tube. Closing the cap produced a uniform circular sample of about 4.8 mg that was contained within the microcentrifuge tube. This procedure also minimized desiccation of the leaf samples. The five individual leaf samples per plot were placed into a plastic bag and transported to the laboratory in a cooler with ice. Within 1 hour, the 5 samples/ plot were combined into an individual 2.0 ml 96 deep-well microtiter plate (BioSpec Products) containing two 6.4 mm stainless steel ball-bearings (BioSpec). Cry1Ac extraction buffer (1.0 ml) (EnviroLogix) was then added to each well. The tissue was then homogenized for 30 s using a Mini-Beadbeater-96™ (BioSpec). The microtiter plate was then centrifuged at 3,000 rpm for 5 min at 4° C (Avanti J-20XP, Beckman Coulter, Inc). For each sample, a 20 µl aliquot was place in an individual 1.1 ml 96 deep-well microtiter plate containing 500 µl of Cry1Ac extraction buffer (EnviroLogix) (1:26 dilution). The microtiter plate was covered with a corresponding

silicone-based lid (BioSpec) and placed on an orbital shaker for 1 min. at 300 rpm. A commercial quantification plate kit then was utilized to quantify the amount of Cry1Ac present for each cultivar/plot (EnviroLogix). Samples were plotted against a standard curve with Cry1Ab calibrators supplied in the kit. A simple conversion was used to express values as "Cry1Ac" as dictated by the kit protocol. The amount of Cry1Ac was expressed as µg g-1 after accounting for the proper dilution factors. The Cry1Ac protein concentrations in cotton leaf samples were determined using enzyme-linked immunosorbent assay (ELISA) as described by Wang *et al*. (1998). Mean expression of Cry1Ac was analyzed using REML-ANOVA, and means were separated according to Fisher's Protected LSD (PROC MIXED, SAS Institute 2001; Littell et al. 1996).

3.7.9. Epicuticular Wax Quantity

The youngest, fully expanded leaf was excised, leaf area was measured, and ECW was removed with chloroform and quantified using a colorimetric method developed by Ebercon *et al*. (1977).

3.7.10. Microtome studies

The plant samples (root and leaf) were washed thoroughly with water and cut to a size of 5 nm. The plant materials were fixed in FAA solution (containing 40 per cent formalin, 80 per cent alcohol and acetic acid in the ratio 90:5:5). Subsequently samples were dehydrated in tertiary butyl alcohol (TBA). The dehydrated sections were infiltered with paraffin wax (melting point 52°C) and embedded. The wax blocks along the plant materials were sectioned using a rotary microtome (Leica, Germony). The plant sections were mounted on the glass slides, progressively stained with saffranin, regressively restained with fast green and observed under microscope (Johanson, 1940 and Jenson, 1962).

3.8. YIELD PARAMETERS

3.8.1. Yield and yield components

Ten random samples were collected from each replication at flowering and maturity stages for recording the following yield components.

3.8.1.1. Number of Monopodial and Sympodial branches per plant

The reproductive sympodial and monopodial branches were counted at boll development and maturity stage and expressed as number per plant.

3.8.1.2. Number of flowers per plant

Ten plants per each treated pot were tagged prior to flowering and the number of flowers produced were recorded daily from the commencement of flowering upto 30 days prior to harvest. The mean value was worked out and expressed as number of flowers per plant.

3.8.1.3. Number of bolls per plant

Number of matured bolls in the ten sample plants was counted at maturity and the mean worked out and expressed.

3.8.1.4. Boll weight

The weight of ten fully opened bolls collected from the plot was recorded and expressed as mean boll weight in gram $boll^{-1}$.

3.8.1.6. Fertility co-efficient

Fertility co-efficient was worked out using the following formula and expressed in per cent.

$$\text{Fertility co-efficient} = \frac{\text{Number of bolls per plant}}{\text{Number of flowers per plant}} \times 100$$

3.8.1.7. Seed cotton yield per hectare

Ten plants were selected randomly from each replication and seed cotton yield was recorded and the mean values expressed in kg ha^{-1}.

3.8.1.8. Harvest Index

Using the economic yield and biological yield at harvest, harvest index was calculated and expressed in per cent.

$$HI = \frac{\text{Seed cotton weight}}{\text{Biological yield}} \times 100$$

3.8.2. FIBRE QUALITY PARAMETERS

Fibre quality characters were tested at the Department of cotton, TNAU, Coimbatore. Fibre characters were determined from random lint sample collected from

each replication. All parameters were estimated in High Volume Instrument Uster Model: HVI Classic 900.

3.8.2.1. Ginning Out Turn (GOT) (%)

Kapas sample having 100 seed cotton from each plot were taken and weighed. The ratio of the weight of lint to the seed cotton was expressed in percentage (Santhanam, 1976).

$$\text{Ginning Out Turn (\%)} = \frac{\text{Weight of lint (g)}}{\text{Weight of seed cotton (g)}} \times 100$$

3.8.2.2. Fibre length (2.5 per cent staple length)

This is the length of fibre representing majority of the fibres and expressed in mm (Sundaram and Iyengar, 1968).

3.8.2.3. Uniformity Ratio

This is the ratio of the span length at 50 per cent span over that at 2.5 per cent. It was worked out as per the formula given below and was expressed in per cent.

$$\text{Uniformity ratio} = \frac{\text{50\% span length}}{\text{2.5\% span length}} \times 100$$

3.8.2.4. Fibre fineness value (Micronaire value)

This is the relative measure of size, diameter and linear density of fibres and expressed in µ g/inch Sundaram (1979).

3.8.2.5. Bundle strength (Tenacity test)

This denotes the fibre strength and otherwise known as tensile strength. It indicates the maximum specific stress that is developed in a tenacity test to rupture the fibre.

3.8.2.6. Elongation percentage

It was obtained with the help of High Volume Instrument as suggested by Sundaram (1979).

3.9. Economics

3.9.1 Gross return

Gross return was computed by multiplying the seed cotton yield in respective treatments with the unit market price of the produce and given as Rs ha^{-1}.

3.9.2. Net Return

The net return per hectare was worked out for all the treatments by subtracting the cost of cultivation from the gross return and presented as Rs ha^{-1}.

3.9.3. Benefit cost ratio (BCR)

$$\text{Benefit cost ratio} = \frac{\text{Gross return (Rs ha}^{-1}\text{)}}{\text{Cost of cultivation (Rs ha}^{-1}\text{)}}$$

CHAPTER IV

RESULTS

Field experiment was conducted in Field No. 73 in the Eastern Block area of Tamil Nadu Agricultural University, Coimbatore during winter irrigated season 2008-2009. Foliar application of different chemicals along with Salicylic acid, Gibberellic acid and Cytokinin based harmone-nutrient consortia were tried to develop an appropriate cost - effective PGR consortia. The results obtained are presented below with relevant illustrations.

4.1 GROWTH CHARACTERS

4.1.1 Germination percentage (%)

The germination percentage was recorded on 15 DAS. The mean germination percentage ranged from 89.4 to 95.2 per cent (Table 5; Fig 4).

4.1.2 Plant height (cm)

Cotton plant by nature is a slow growing crop during initial stages (up to squaring stage). Steep increase in plant height was noticed during active growth stage (flowering stage). Plant height which represents the time trend of growth was recorded at different phenophases of cotton. Foliar application of plant nutrients helped to increase the plant height after flowering stages. The plant height variations due to foliar nutrients were not significant at initial phenophase such as squaring. When flowering to boll development stages the plant height was significantly increased due to foliar nutrients application (Table 6; Fig 5).

Maximum plant height was recorded by the foliar application of PGR Formulation–III (T_9) which recorded from 112.8 cm and 147.3 cm at flowering and boll development stages respectively. This was followed by PGR Formulation–IV (T_{10}) and PGR Formulation–I (T_7) recorded high plant height. Shortest plant height ranged from 83.3 to 104.6 cm at flowering and boll development stages were noted in control (NAA @ 40ppm-T_1).

4.1.3. Root length (cm)

Root length which represents the time trend of growth was recorded at different phenophases of cotton. Foliar application of plant nutrients helped to increase the root length after flowering stages. The Root length variations due to foliar nutrients were not significant at initial phenophase like squaring. But on flowering and boll development stages the root length significantly increased due to foliar nutrients application (Table 7; Fig 6).

Maximum root length was recorded by the foliar application of PGR Formulation–III (T_9) which recorded from 77.2 cm and 107.3 cm at flowering and boll development stages respectively. This was followed by PGR Formulation–IV (T_{10}) and PGR Formulation–I (T_7) recorded high root length. Shortest root length was 67.2 and 88.4 at flowering and boll development stages were noted in control (NAA @ 40ppm-T_1).

4.1.4. Total Dry Matter Production (TDMP) (kg ha^{-1})

There was no differential effect on TDMP up to squaring stages due to different foliar application. But in later stages significant difference were recorded at flowering, boll development and harvest stages. PGR Formulation–III (T_9) recorded the maximum TDMP ranged from 7241 kg ha^{-1} at boll development stage to 7781 kg ha^{-1} at harvest stage. It was followed by Polyfeed + Multi K application @ 1.5% (T_6) and PGR Formulation–II (T_8). The lowest TDMP ranged from 6174 kg ha^{-1} at boll development stage to 6776 kg ha^{-1} at harvest stage was recorded (Table 8; Fig 7) with control (NAA @ 40ppm-T_1).

Among the different nutrient sprays PGR Formulation–III (T_9) concisely recorded higher TDMP in all the stages of observation. The control treatment showed least TDMP in all the stages. This control (NAA @ 40ppm-T_1) recorded 14.9 per cent reduction in TDMP when compared to PGR Formulation–III (T_9) application at harvest stage. The spraying of nutrients has a significantly influence on dry matter production.

4.1.5. Leaf Area (LA) (cm^2 plant^{-1})

The steady increase in leaf area was observed from squaring to boll development stages (45 to 105 DAS). The LA was significantly increased by the foliar feeding of nutrients (Table 9; Fig 8).

With reference to foliar application of nutrients, PGR Formulation–III (T_9) recorded significantly higher LA showed 5710.5, 10368.0, and 13729.5 cm^2 plant^{-1} at square, flower formation and boll development stages respectively. PGR Formulation–III (T_9)

and PGR Formulation–II (T_8 which are significantly on par with each other. The least LA of 4576.5, 6196.5, and 9639.0 was recorded with the control (NAA @ 40ppm-T_1) at different growth stages respectively.

4.1.6. Number of days taken for First Square, Flower, Boll formation and first Boll opening (DAS)

Flowering and boll formation are continuous process in cotton. The influence of different foliar treatments was studied on the days taken for first square formation until boll opening. It is seen that days taken for first square formation ranged from 38.4 days in control (NAA @ 40ppm-T_1). to 42.5 days in PGR Formulation–III (T_9). Similarly the days taken for first flower formation, first boll formation and boll opening were marginally increase in almost all the foliar treatments when compared to the control (NAA @ 40ppm-T_1). The number of days taken for first square formation, first flower formation first boll formation and first boll opening is 4.1, 5.3, 3.3 and 5.4 respectively(Table 10; Fig 9).

4.2 PHYSIOLOGICAL ATTRIBUTES

4.2.1 Leaf Area Index (LAI)

The steady increase in leaf area index was observed from squaring to boll development stages respectively. The LAI was significantly increased by the foliar feeding of nutrients (Table 11; Fig 10).

With reference to foliar application of nutrients, PGR Formulation–III (T_9) application at square formation and boll development stages recorded significantly higher LAI. It was 1.41, 2.56 and 3.39 at all the growth stages respectively. The least LAI showed 1.13, 1.53, and 2.38 was recorded with the control at different growth stages.

4.2.2 Crop Growth Rate (CGR) (g $m^{-2}day^{-1}$)

The Crop Growth Rate was not influenced by the application of foliar nutrients from squaring to flowering stages. However, CGR was significantly influenced by the foliar nutrients during flowering to boll development stages. The PGR Formulation–III (T_9) recorded higher CGR (9.33 g $m^{-2}day^{-1}$) value and control (NAA @ 40ppm-T_1) recorded the lower CGR (6.65 g $m^{-2}day^{-1}$) value Table 12(a); Fig 11.

4.2.3. Relative Growth Rate (RGR) (g $g^{-1}day^{-1}$)

The Relative Growth Rate was not influenced by the application of foliar nutrients from squaring to flowering stages. However, RGR was significantly influenced by the foliar nutrients during flowering to boll development stages. The PGR Formulation–III (T_9) recorded higher RGR (0.026 g $g^{-1}day^{-1}$) value and control (NAA @ 40ppm-T_1) recorded lower RGR (0.021 g $g^{-1}day^{-1}$) value Table 12(b); Fig 12.

4.2.4. Net Assimilation Rate (NAR) (g m^{-2} LA day^{-1})

The Net Assimilation Rate was slightly influenced by the application of foliar nutrients from squaring to flowering stage. However, NAR was significantly decreased by the foliar nutrients during flowering to boll development stages. The PGR Formulation–III (T_9) recorded higher NAR (1.18 and 0.37 g m^{-2} LA day^{-1}) value and control (NAA @ 40ppm-T_1) recorded lower RGR (0.68 and 0.16 g m^{-2} LA day^{-1}) value at both growth stages Table 12(c); Fig 13.

4.2.5. SPAD Values

Application of foliar nutrients had a significant influence on SPAD readings. (Table13; Fig 14). There was no significant difference in SPAD meter readings at squaring stage. However, SPAD meter readings which are significantly increased by the foliar nutrients during flowering to boll development stages. Application of PGR Formulation–III (T_9) recorded higher SPAD values ranged from 48.33 to 51.14 respectively at flowering and boll development stages. This treatment was on par with the combined spray of PGR Formulation–I (T_7) and PGR Formulation-IV (T_{10})at both the stages of observation with the value showed 45.44, 43.63 at flowering and 48.34, 48.78 at boll development stages respectively. The lower SPAD readings were observed in control (NAA @ 40ppm-T_1) from 38.33 to 41.03 respectively.

4.2.2. Physiological and Biochemical parameters

4.2.2.1. Total chlorophyll content (mg g^{-1})

The total chlorophyll is presented in (Table 14; Fig 15) was more in PGR Formulation–III (T_9). It was 1.79, 2.05, 2.23 mg g^{-1} at squaring, flowering and boll development stages respectively than in the control. It was 1.47, 1.59, 1.82 mg g^{-1} at different stages. Total chlorophyll content was found to slightly increase from squaring, flowering and boll development stages respective of treatments. Among these ten treatments PGR Formulation–III (T_9) maintained a higher total chlorophyll value and followed by DAP @ 2% (T_5) when compared to other treatments.

4.2.2.2. Chlorophyll 'a' content (mg g^{-1})

Chlorophyll 'a' content (Table 15; Fig 16) was found to be more in the PGR Formulation–III (T_9). It was 1.29, 1.36, 1.60 mg g^{-1} at squaring, flowering and boll development stages respectively than in the control. It was 1.01, 1.04, 1.30 mg g^{-1} at different stages. At any given treatment, Chlorophyll 'a' content was found to slightly increased at different growth stages. This trend was identical among all the treatments. Among these ten treatments PGR Formulation–III (T_9) maintained a higher total chlorophyll value and followed by DAP @ 2% (T_5) and PGR Formulation-II (T_8) which are on par with each other. The foliar spray of nutrients effect has increased the chlorophyll content.

4.2.2.3. Chlorophyll 'b' content (mg g^{-1})

The content of Chlorophyll 'b' (Table 16; Fig 17) was found to increase from squaring, flowering and boll development stages respectively. But in this case control treatment which recorded higher amount of Chlorophyll 'b' content, it was 0.45, 0.46 and 0.56 mg g^{-1} at different growth stages respectively. PGR Formulation–III (T_9) and T_{10}- PGR Formulation-IV both are having the lowest level of Chlorophyll 'b' content was 0.39 mg g^{-1} at flowering stage.

4.2.2.4. Chlorophyll 'a/b' ratio

The ratio of Chlorophyll 'a/b' (Table 17; Fig 18) was found to increased from squaring, flowering and boll development stages respectively. The Chlorophyll 'a/b' ratio was found to be more in the PGR Formulation–III (T_9); it was 3.48, 3.48, 3.63 at different

stages than in the control was 2.24, 2.26, 2.32 respectively. At any given treatment, Chlorophyll 'a/b' ratio was found to be slightly increase from all growth stages. This trend was identical among all the treatments. Among these ten treatments PGR Formulation–III (T_9) maintained higher Chlorophyll 'a/b' ratio, followed by Polyfeed + Multi K (1.5%) (T_6) and PGR Formulation–I (T_7) which are on par with each other. The foliar feeding of nutrients effect has increased the Chlorophyll 'a/b' ratio

. 4.2.2.5. Soluble protein content (mg g^{-1})

The Soluble protein content in different treatments are presented in Table 18; Fig 19. There was a steady increase of soluble protein content with respect to age of the crop up to boll development stage. The Soluble protein content was found to be more in the PGR Formulation–III (T_9), it was 52.5, 57.3 and 72.5 mg g^{-1} at squaring, flowering and boll development stages than in the control, it was 34.5, 42.6 and 57.2 mg g^{-1} respectively. Among these ten treatments PGR Formulation–III (T_9) showed higher amount of soluble protein content, followed by PGR Formulation–IV (T_{10}) and PGR Formulation–I (T_7) which are on par with each other.

4.2.2.6. Proline content (µg g^{-1})

The proline content in different treatments are presented in Table 19; Fig 20. There was a steady increase of proline content with respect to age of the crop up to flowering stage and was found to decrease during boll development stage respectively. The proline content was found to be more in the PGR Formulation–III (T_9); it was 779, 837 and 813 µg g^{-1} than in the control, it was 447, 593, and 526 µg g^{-1} at different stages respectively. Among these ten treatments PGR Formulation–III (T_9) showed higher proline content value and followed by PGR Formulation–IV (T_{10}) and PGR Formulation–I (T_7) which are on par with each other. With regard to treatmental effect, proline was found to accumulate at a greater extent when the foliar nutrients were imposed at squaring stage indicating the sensitivity of the stage.

4.2.2.7. NRase activity (µg NO_2^- g^{-1} hr^{-1})

The Nitrate Reductase activity which is the key enzyme in Nitrogen metabolism was found to have the highest activity during flowering stage followed by boll development stage respectively (Table 20; Fig 21). Foliar nutrients given at flowering stage was found to increase the NRase activity, when reverse at boll development stages respectively. There was a reduction of about 12.3 per cent from flowering to boll development stage. Among the ten treatments, PGR Formulation–III (T_9) which recorded the highest NRase activity, it was 63.0 µg NO_2^- g^{-1} hr^{-1} followed by PGR Formulation–II (T_8), it was 58.4 µg NO_2^- g^{-1} hr^{-1} at flowering stage and the control treatment which recorded lowest NRase activity was 41.1 µg NO_2^- g^{-1} hr^{-1}.

4.2.2.8. Chlorophyll Stability Index (CSI) (%)

The Chlorophyll Stability Index in different treatments are presented in Table 21; Fig 22. There was a steady increase of CSI with respect to age of the crop upto boll development stage. The CSI was found to be more in the PGR Formulation–III (T_9); it was 78.12, 83.14 and 84.56 per cent at squaring, flowering and boll development stages than in the control was 61.33, 67.94 and 70.63 per cent at different growth stages respectively. Among these ten treatments PGR Formulation–III (T_9) showed in the higher CSI per cent, followed by Formulation–I (T_7) and PGR Formulation–IV (T_{10}) which are on par with each other. With regard to treatmental effect, CSI was found to accumulate at a greater extent when the foliar nutrients were imposed at squaring and boll development stages indicating the sensitivity of the stage.

4.2.2.9. Relative Water Content (RWC) (%)

The RWC which is one of the most important parameter (Table 22; Fig 23) for increasing the seed cotton yield. There was a steady increase of RWC with respect to age of the crop upto boll development stage. Among the different treatments, foliar nutrient application at squaring and boll development stages which recorded significant increase in RWC. Among these ten treatments PGR Formulation–III (T_9) showed higher RWC value of 72.0, 74.5 and 78.6 per cent followed by Formulation–II (T8) and PGR Formulation–IV (T_{10}) which are on par with each other. The control which recorded lowest RWC value of 52.6, 56.7 and 61.3 per cent at different growth stages.

4.2.2.10. Cell Membrane Integrity (CMI) (%)

The data recorded for CMI are furnished in Table 23; Fig 24. The CMI was found to be highest with 82.4, 81.1 and 83.3 per cent in PGR Formulation–III (T_9); it was significantly higher than the rest of the treatments. The control (NAA @ 40ppm-T_1) showed lowest CMI value of 69.4, 68.1 and 70.2 per cent at different growth stages.

4.2.2.11. Epicuticular Wax content (µg cm^{-2})

The data recorded for epicuticular wax content is furnished in Table 24; Fig 25. The epicuticular wax was found to be highest with 135.8, 136.3 and 136.9 µg cm^{-2} in PGR Formulation–III (T_9) followed by T_5-Diammonium Phosphate @ 2% these are significantly higher than rest of the treatments. The control (NAA @ 40ppm-T_1) showed lowest epicuticular wax value recorded 116.4, 119.3 and 122.5 µg cm^{-2} at different growth stages. With regard to treatmental effect, epicuticular wax was found to accumulate at a greater extent when the foliar nutrients were imposed at squaring and boll development stages indicating the sensitivity of the stages.

4.2.2.12. Stomatal Diffusive Resistance (SDR) (s cm^{-1})

Mean data on SDR recorded at different stages are given in Table 25; Fig 26. Foliar nutrient application during all stages significantly induced higher SDR level than control. The SDR was found to be highest with 14.9, 15.3 and 16.4 s cm^{-1} in PGR Formulation–III (T_9) which was significantly higher than rest of the treatments. The control (NAA @ 40ppm-T_1) showed lowest SDR it was 10.1, 10.9 and 11.3 s cm^{-1}.

4.2.2.13. Leaf Temperature (°C)

Foliar application of nutrients at any growth stage significantly reduced the leaf temperature (Table 26; Fig 27). The decreased leaf temperature ranged from 1 to 2°C among the treatments with slightly fluctuations at different growth stages. Among the different treatments, foliar nutrients application was given at flowering had a major impact for the temperature reduction. The control treatment (NAA @ 40ppm-T_1) recorded the highest value (35.31 °C) throughout the crop growth stage in all treatments.

4.2.2.14. Quantum measurement (µE m^{-2} s^{-1})

Observed data on quantum measurement recorded at different stages are given in Table 27; Fig 28. Foliar application of nutrients at any growth stage increases the Quantum values. Among the different foliar nutrients application of PGR Formulation–III (T_9) was given at squaring and boll development stages had a major impact (1301.6 µE m^{-2} s^{-1}) or the Quantum measurement and the control (NAA @ 40ppm-T_1) recorded the lowest value was (i.e.1006.2 µE m^{-2} s^{-1})at boll development stage.

4.2.2.15. Transpiration rate (µg $cm^{-2}s^{-1}$)

Transpiration rate (Table 28; Fig 29) was found to decrease when there is a moisture stress. When foliar nutrients were applied, transpiration rate slightly increased at flowering stage and then decline at boll development stage. Among the treatments the highest transpiration rate was recorded in the control (NAA @ 40ppm-T_1) 3.05 and 2.96 µg $cm^{-2}s^{-1}$ when compared to other treatments which was significant at flowering and boll development stages.

4.2.2.16. ABA quantification (µg g^{-1})

Very wide fluctuation was noticed among the different foliar treatments in the ABA content was very high in control (NAA @ 40ppm-T_1) when compared to other treatments. Data on ABA quantification recorded at boll development and harvest stages are given in Table 29; Fig 30. a, b and c. The foliar application of nutrients given at squaring and boll development stages which are highly reduced the ABA content, when control has more level of ABA.

4.2.2.17. Cry 1Ac gene (µg g^{-1})

The Cry 1Ac gene which is one of the most important parameter (Table 30; Fig 31) for controlling the pest such as boll warms. Boll warms are the major pest in cotton plants. Among the different foliar nutrients application at squaring and boll development stages has resulted in the increasing of Cry 1Ac gene respectively. Among these ten treatments PGR Formulation–III (T_9) resulted a higher Cry 1Ac gene value of 4.65 µg g^{-1} followed by T_8- PGR Formulation-II (4.012 µg g^{-1}) the control treatment (NAA @ 40ppm-T_1) which recorded lowest Cry 1Ac gene value of 2.933 µg g^{-1} at boll development stage.

4.2.3. Microtome Studies

4.2.3.1. Root Anatomy

The root anatomy showed that how foliar nutrition enhances root activity. Among the ten treatments PGR Formulation–III (T_9) resulted more number of xylem vessels and also increase size of the xylem vessels when compared to control (NAA @ 40ppm-T_1). PGR Formulation–III (T_9) showed that highly enlarged xylem and also increases the volume occupied by the xylem vessels in the entire root than other treatments (Fig 35). In this slides the number of xylem vessels ranged from 75 in the control (NAA @ 40ppm-T_1) to 97 in the PGR Formulation–III (T_9).

4.2.3.2. Leaf Anatomy

The leaf anatomy showed that enlarged xylem vessels. Among the ten treatments, PGR Formulation–III (T_9) recorded highly enlarged xylem vessels located in adaxial (upper) sides of the leaf when compared to control (NAA @ 40ppm-T_1). In this case there is no significant difference in xylem vessels located in abaxial (lower) side of the leaf when compared to PGR Formulation–III (T_9) and control (NAA @ 40ppm-T_1) (Fig 36. a and b). In this cross-section the number of xylem vessels ranged from 44 (with 7 shrinked xylem) in control (NAA @ 40ppm-T_1) to 51 (with 2 shrinked xylem) in the PGR Formulation–III (T_9).

4.3. YIELD ATTRIBUTES

4.3.1 Monopodia and Sympodia

The monopodial branch and sympodial branches were significantly differed due to foliar feeding of nutrients. Higher number of monopodia (2.0) and sympodia (22.3) were observed in PGR Formulation–III (T_9). However, there was no significant difference between monopodial branch and sympodial branches with the application of PGR Formulation–II (T_8) and Polyfeed + Multi-K @ 1.5 %(T6) applications. The least number of branches were observed in control with 1.3 and 16.6 of monopodial and sympodial branches respectively (Table 31).

4.3.2 Fertility Co -efficient (%) and Boll weight (g boll^{-1})

Fertility Co-efficient was significantly influenced by the different foliar application of nutrients. The Fertility Co-efficient was higher (50.3 per cent) with the application of PGR Formulation–III (T_9) (Table 32). Next best treatments were

T_4- Salicylic acid-100ppm with 49.6 per cent and Potassium chloride-2% (T_2) with 49.5 per cent, control treatment which recorded 47.4 per cent only.

The different foliar treatments could be recorded the significant influence on boll weight. The maximum boll weight (5.1 g) was recorded with PGR Formulation–III (T_9) application compared to other foliar applications. The boll weight ranged from 3.3 gm to 5.1 gm.

4.3.3 Number of Squares, Flowers, Bolls and opened bolls per plant

Foliar feeding of plant nutrients was significantly influenced the number of fruiting points namely squares and flowers per plant. A maximum number of squares and flowers were recorded with PGR Formulation-III (T_9) application ranged from 122.9 and 77.6 per plant respectively (Table 33; Fig 32). The least number of squares and flowers was recorded in Potassium chloride-2% (T_2) ranged from 118.9 and 67.6.

The number of bolls and opened bolls per plant were differed among the foliar nutrients application studied. Among the various foliar nutrients applied, the PGR Formulation-III (T_9) was recorded maximum number of bolls and opened bolls ranged from 39.0 and 38.6 per plant respectively (Table 33). The least number of bolls and opened per plant (32.2 and 30.8) was recorded when the control (NAA @ 40ppm-T_1).

4.4.1. Seed Cotton Yield

The significant differences in seed cotton yield were observed due to different foliar feeding of nutrients to Bunny Bt hybrid cotton.

Among the different foliar feeding treatments, PGR Formulation–III (T_9) which recorded highest seed cotton yield, it was 3750 kg ha^{-1} followed by Polyfeed + Multi K-1.5%(T_6-),PGR Formulation–II (T_8) and PGR Formulation–IV (T_{10}).These above treatments which are on par with PGR Formulation–III (T_9) (Table 34; Fig 33). The least seed cotton yield was recorded in control (NAA @ 40ppm-T_1) treatment with 3029 kg ha^{-1}. All other treatment combinations which are on par with each other. Foliar application of PGR Formulation–III (T_9) increased seed cotton yield to the tune of 23.80 per cent as compared to control (NAA @ 40ppm-T_1).

The results of this study indicated that all treatments having foliar fertilizer sprays have recorded higher seed cotton yield as compared to control.

4.4.2 Harvest Index (%)

Harvest index was significantly influenced by the application of foliar nutrients. The maximum value of 48.2 per cent was observed under PGR Formulation–III (T_9) application followed by T_{10}-PGR Formulation-IV, T_8-PGR Formulation-II, T_5- Diammonium Phosphate - 2% and T_6- Polyfeed + Multi K-1.5% application. The least harvest index of 44.7 per cent calculated with control plot (NAA @ 40ppm-T_1) (Table 34).

4.5. FIBRE QUALITY ANALYSIS

4.5.1 Ginning Out turn (GOT) (%)

Application of various foliar nutrient sprays significantly altered ginning out turn in cotton. The ginning out turn was maximum 39.8 per cent with PGR Formulation–III (T_9) application followed by the foliar spray of T_6- Polyfeed + Multi K-1.5% (38.1 per cent) and T_7-PGR Formulation-I (38.0 per cent) applications. The ginning percentage was minimum in control (NAA @ 40ppm-T_1), it was 36.8 per cent (Table 35(a); Fig 34).

4.5.2 Quality characters

The Quality characters viz., 2.5 per cent staple length, uniformity ratio, micronaire, tenacity, maturity ratio and elongation percentage were not significantly altered by the foliar nutrients application, Table 35(a) and 35(b); Fig 40. The higher tenacity value was recorded 23.45 g tex^{-1} was recorded in the PGR Formulation–III (T_9) foliar spray, Table 35 (b). Application of T_8-PGR Formulation-II and T_{10}-PGR Formulation-IV resulted in equal tenacity. The higher elongation percentage value recorded at PGR Formulation–III (T_9) was recorded 6.13 per cent when compared to other treatments.

4.6. Economics

Foliar application of PGR Formulation-III (T_9) recorded highest net return of Rs.60, 767 $ha^{-1}$and B: C ratio of 2.07 (Table 36). This was followed by Polyfeed + Multi-K @ 1.5 percent (T_6) application. The corresponding values for Polyfeed + Multi-K @ 1.5 percent (T_6) were Rs.56, 222 and 1.93 respectively. The control treatment recorded a net return of Rs.45, 805 kg ha^{-1} and B: C ratio of 1.69.

CHAPTER V

DISCUSSION

The present investigation was taken basically to study the extent of flower and boll shedding in Bunny Bt cotton under irrigated condition. Recently cotton cultivation is increasingly adopted using Bt. Hybrids. The physiological nature of Bt. Cotton is to produce more number of flowers, which are converted into harvestable bolls, in contrast to traditional varieties. In Bt cotton it has been seen that the flower retention is high in early formed sympodia thereby boll retention is practically seen when compared to non Bt cotton.

Cotton is demand driven crop for continuous supply of assimilates by the developing bolls, since flowering and boll development are continuous process. Understanding the extent of flower production, flower retention and boll development will help to enhance the production potential by appropriate input management, particularly the foliar nutrition. In the present investigation, field trial was conducted by using ten different foliar treatments. Among the ten treatments, hormone based nutrient consortia were designed, developed and evaluated for the efficacy in minimizing the flower drop and consequently improve the boll yield. The results of the experiment mainly focus on the three categories namely flower retention studies, root anatomical, histological aspects and hormone profiles particularly ABA levels at boll development stage. These findings are discussed her under.

5.1. Studies on flower production

The treatments indicated that the number of days taken from planting to boll opening ranged from 123.3 in control (T_1-NAA @ 40ppm) to 128.7 in the PGR formulation III (T_9). In variably almost all the foliar treatments increased days taken from square formation until boll opening. Even though the treatmental effects were not statistically significant regarding the number of days taken for the floral events, nevertheless, there is a concomitant increase in the days taken which was from 4.1 to 5.4 days. This shows that foliar applied nutrients or hormones slightly increase the days taken for the flower initiation up to boll opening. This increase in days taken may be due to the improved foliar metabolism for carbohydrate synthesis and this assimilate may be used to prolong the days taken for square formation up to boll development (Disha Dumka *et al.,* 2004).

The incremental increase in the days taken for floral events may be significant cause for increased retention of flowers and bolls, which ultimately improve the seed cotton yield (Bodnarz *et al.,* 1999). Further basic information in the metabolic events taking place during the incremental days might through further in sight into the causes for improved productivity under the influence of foliar formulations.

5.2. Studies on Root anatomy

The cotton root anatomy was described by Hayward (1938); Baranov and Maltzev (1937) and Reinhardt and Rost (1995a, b and c). The anatomy of cotton is similar to that of a typical herbaceous dicotyledonous plant. The cotton plant has primary root or taproot from which branch secondary, tertiary and higher-order roots (Brown and Ware, 1985; Hayward, 1938; Spieth, 1933). The epidermis of a young cotton root whether primary or branch root, is made up of a single layer of epidermal cells surrounding the cortex of unspecialized parenchyma cells. The endodermis, consisting of a single layer of cells with tangential suberin thickenings, forms the innermost layer of the cortex and surrounds the stele, which contains xylem and phloem tissues. The endodermis encloses a cell layer called the pericycle, which gives rise to lateral roots. The pericycle also eventually contributes to the protective outer layers of the root as the root ages and the endodermis and rest of the cortex and epidermis.

Root cross-sectional anatomy within the cotton germplasm collection has been studied (Oosterhuis and Urwiler. 1988; Mc Michael *et al.,* 1985), and a wide range of diversity has been reported. A higher number of xylempoles does occur, especially in cotton landraces (Oosterhuis and Wullschleger, 1989; McMichael *et al.,* 1985). The range of vascular arrangements reported includes tetrach, pentarch, hexarch and heptarch (Oosterhuis and Wullschleger, 1987). This higher number of poles was first thought to be involved with improved capabilities for water transport associated with increased xylem elements (Oosterhuis and Wullschleger, 1987), but is now understood to be more directly involved with a greater potential for improved lateral root growth (McMichael *et al.,* 1987). An increased number of xylem stands could increase the ability to produce lateral roots (McMichael *et al.,* 1985) which arise from the pericycle adjacent to each xylem pole in the stele. Lateral roots are arranged in rows opposite the xylem poles, and the number of rows varies according to the number of xylem poles present in the primary root. A direct

correlation was observed between the number of xylem poles in the taproots of cotton seedlings and the number of lateral roots produced (McMichael *et al.,* 1985).

The influence of foliar nutrients particularly plant hormone based formulations is of current interest in view of the high response status of the cotton crop. Plant hormones are notably having significant impact on cellular metabolism. To cite an example, salicylic acid is reported to dilate the vascular tissues causing increased sap flow (McMichael *et al.,* 1987).

In the present investigation attempts were made to study the influence of foliar formulation on root anatomical aspects particularly the vascular bundles. Interestingly the application of foliar formulation has pronounced impact in increasing the number of xylem vessels. Further, interestingly, it is seen that the size of the xylem vessels also on the increase. The metabolic effects of hormone based nutrient formulation have indicated that the root conducting tissues may be influenced to augment transport mechanism of both water and nutrients was reported by Dittmer (1937). It is evident that the volume of xylem vessels occupied is more in the PGR formulation-III (T_9) when compared to the control, indicating the effectiveness of the treatment in the water and nutrient uptake (Cailloux, 1972; Dittmer, 1937). Earlier, Glass (1989) reported that there is a direct relationship between the number of xylem cells and the number of root hairs produced. That means, more the xylem vessels, more number of root hairs and thereby increased efficiency of water and nutrient transport. In the present study, the input of PGR formulation-III (T_9) has showed advantage in increasing not only the number of xylem cells but also the size. This is in conformity with the reports of Baranov and Maltzev, 1937 (Fig 36).

5.3. Studies on Leaf anatomy

The cotton leaf shows typical bifacial or dorsiventral organisation, with a single layer of palisade parenchyma below the epidermis on the upper (adaxial) side of the blade and spongy parenchyma below the epidermis on the lower (abaxial) side. Stomata are present on both the adaxial and abaxial epidermal layer, but are more numerous on the lower leaf blade surface. A cuticle is found on both upper and lower epidermal layer, the details of which are discussed below. Internal lysigenous glance occur in all interveinal areas of the leaf and in the ground tissue of the midrib, towards the abaxial side. A nectary occurs on the abaxial surface of the midrib, and in a few genotypes nectaries occur on the abaxial surface of the two major lateral veins as well. The main

veins have rib – like projections on the adaxial surface, consisting of collenchyma located directly beneath the epidermis. Leaf vascular bundles are collateral. The xylem, with its orderly files of cells, is towards the upper leaf surface. While the less regularly ordered phloem is towards the lower. In main veins, a narrow band of residual procambium is evident between the xylem and phloem. In cross sectional view, the petiole of the cotton leaf is circular to oval in shape, with the vascular bundles arranged in a ring of four or five large bundles and several smaller ones (Hayward, 1938). The cotton petiole has swellings at the base and distal ends which are associated with nyctinastic leaf movements. Lysigenous glands are also found in the cotton petiole.

Both surfaces of the cotton leaf, immediately above the epidermal cell layer are covered with an amorphous layer of cuticle with numerous epicuticular wax ridges (Wullschleger and Oosterhuis, 1989; Oosterhuis *et al.,* 1991b). The cuticle is composed of cutin impregnated with wax arising from the outer tangential walls of the epidermal cells (Bondada *et al*., 1994). The cuticle reduces water loss and constitutes the first line of defense against adverse environmental stresses including rainfall and chemical penetration. Cotton leaves generally have a thick waxy cuticle, with numerous stomata and few unicellular and glandular trichomes on the surface. The leaf epicuticular wax layer in cotton is about 30 m thick, although the thickness has been shown to increase by as much as 30 per cent with exposure to water deficit (Oosterhuis *et al*., 1991a; Weete *et al*., 1978). Leaf waxiness is a characteristic that has been cited as a plant adoption to unfavorable environmental conditions (Johnson *et al*., 1983). Environmental factors such as radiation, temperature and humidity have been shown to affect the amount of surface wax in plants.

The leaf anatomical sections of during boll development stage indicated that the PGR formulation-III (T_9) is able to increase the xylem vessels which was fifty one cells in the treated as against forty four cells in the control (Fig 35a and b.). The findings of foliar nutrients for increased differentiation conducting cells were earlier reported by (Delanghe, 1986). These findings are in conformity with earlier workers such as (Hayward, 1938).

5.4. Studies on ABA profile

The most distinct influence of Abscisic acid is the stomatal closure (Rai *et al.,* 1986). ABA is implicated in the development of abscission layer which causes flower and boll dropping. Cotton is one of the crops which have significant endogenous ABA level which accumulate under stressful environment. An attempt therefore made to study hormone profiles particularly the ABA levels in the boll development stages. It was interestingly seen that the maximum peak of ABA at 262 nm recorded as much as 6.79ppm in the control (T_1-NAA @ 40ppm). The ABA levels were found to lower down with that of 0.23ppm. It indicating that PGR formulation-III (T_9) is able to there is a six fold depressions. This may be a reason that foliar formulation able to retain more number of flowers and bolls when compared to control. These findings are in conformity with the report that compounds containing cytokinins might interact with ABA and suppress the activity (Cox *et al.,* 2004).

ABA is synthesised in the leaf cell organelle, chloroplast where as cytokinins are synthesised in root tips and translocated upwards. Probably foliar nutrition has helped the cotton crop increasing cytokinin activity which suppresses ABA (Cox *et al.,* 2004). The PGR formulation-III (T_9) has principle foliar component of Benzyl adenine and hence this foliar formulation might have reflected in the decrease level of ABA.

5.5. Studies on Cry 1Ac gene

The Cry 1Ac gene content was estimated in leaves by the method described by (Adamczyk and Sumerford, 2001). It was seen that the toxins (e.g. gossypol in squares) are influenced by the foliar feeding of growth hormones probably due to increased metabolic activity due to the treatments (Lukefahr *et al.,* 1975; Stewart *et al.,* 2001). The (Adamczyk *et al.,* 2001) have already reported that Cry 1Ac endotoxin will are increased the vigour of the crop. In the present investigation the vigour of the crop was found to enhance by the foliar feeding. This may be due to the increased activity of photosynthetic system and allied carbohydrate and protein synthesis. These findings are conformed to early report by (Robinson, 1980).

5.6. Growth attributes

In the present investigation, there was significant increase in growth expressed in plant height and root length respectively in all the foliar nutrients formulations. The results of the present study was supported by the work of Padma *et al.* (1989) and Rajesh Kumar *et al.* (1996) who reported that in cotton, plant height and root length influenced due to foliar nutrients application at square and boll development stages. Foliar nutrients applied at 90 DAS increased the plant height compared to control. This might be due to biological activity of auxins viz., stimulation of cell elongation and promotion of cell division (Pothiraj *et al.,* 1995). Effect of PGR modifying root systems to increase water use efficiency or determining morpho-physiology of plants, especially in cotton roots (Ball *et al.,* 1994; Nepomuceno *et al.,* 1998; Pace *et al.,* 1999; Howard *et al.,* 2001).

Our results indicate that PGR formulation-III (T_9) has increased the growth of cotton when compared to control (NAA @ 40ppm-T_1). The percent increase in plant height at flowering stage over control ranged from35.4 to 40.8 increases in PGR formulation-III (T_9). The percent increase in root length at flowering and boll development stage over control ranged from 14.8 to 21.3 increases in PGR formulation-III (T_9). One possible mechanism to maintain water uptake during an episodic drought is through augmented root development in cotton as reported by Disha Dumka *et al.* (2004).

The foliar nutrients application significantly influences the growth parameters such as LA, LAI, CGR, RGR, NAR and TDMP. The increase in these growth parameters were on a maximum when the PGR formulation-III (T_9) was experienced by the plant during flowering and boll development stages of the crop.

The mean Leaf Area (LA) was found to be increased under foliar nutrients application when compared to the control. The per cent increase in leaf area due to foliar nutrients ranged from 30.1 to 3.8 in PGR formulation-III (T_9) when compared to control (T_1-NAA @ 40ppm) at flowering and boll development stages. Leaf Area in cotton has been reported to control the number of bolls produced and retained (Ashley *et al*., 1965). Shibles and Weber (1966) reported that in general, high yielding varieties of crops recorded 10 per cent more leaf area than low yielder.

For Leaf Area Index (LAI) recorded at flowering and boll development stages, the overall treatments percent increased from 67.3 to 42.4 in PGR formulation-III (T_9) when

compared to control (T_1-NAA @ 40ppm). The growth regulators enhances LAI in transplanting of seedlings during *Kar* season might be due to better absorption of nutrients as a result of more foraging roots and this ultimately led to higher dry matter accumulation (Anbumani *et al.*, 1999). Leaf Area Index, number of open bolls per plant were increased by application of B and decreased by Cu (Hosney *et al.*, 1984).

The Crop Growth Rate (CGR) was increased due to foliar feeding of nutrients at squaring and boll development stages. However, the plants were able to recover from this at later stages. The higher CGR ranged from flowering to boll development stages were 9.33 g $m^{-2}day^{-1}$in PGR formulation-III (T_9), when 6.65 g $m^{-2}day^{-1}$in control (NAA @ 40ppm-T_1) respectively. The foliar feeding of nutrients at boll development increased the CGR value by 40.3 per cent over the control respectively. Hence, the foliar feeding of growth regulators at boll development stage created a major impact in CGR.

The Relative Growth Rate (RGR) was increased due to foliar feeding of nutrients at squaring and boll development stages. However, the plants were able to recover from this at later stages. The higher RGR ranged from flowering to boll development stages were 0.026 g $g^{-1}day^{-1}$in PGR formulation-III (T_9), when 0.021 g $g^{-1}day^{-1}$in control (NAA @ 40ppm-T_1) respectively. The foliar feeding of nutrients at boll development increased the RGR value by 23.8 per cent over the control respectively. Hence, the foliar feeding of growth regulators at boll development stage created a major impact in RGR. The major determinant of RGR is the development and maintenance of photosynthetically active LA. This fact was supported by the report of Matusura *et al.* (1996) in four graminaceous crops.

The Net Assimilation Rate (NAR) was increased due to foliar feeding of nutrients at squaring and boll development stages. The higher NAR ranged from flowering to boll development stages were 0.37 g m^{-2} LA day^{-1}in PGR formulation-III (T_9), when 0.16 g m^{-2} LA day^{-1}in control (NAA @ 40ppm-T_1) respectively. The foliar feeding of nutrients at boll development increased the NAR value by 13.2 per cent over the control respectively. Hence, the foliar feeding of growth regulators at boll development stage created a major impact in NAR. This fact was supported by the report of Hay and Walker (1989).

The Total Dry Matter Production (TDMP) was found to be increased in almost all stages due to foliar application of plant nutrients. However, foliar application given at boll

development stages was found to be more detrimental compared to squaring stage. Again, the beneficial effects of foliar feeding of nutrients were found to be much more pronounced in PGR formulation-III (T_9).

Total Dry Matter Production has a direct relationship with crop productivity. Bhatt (1982) reported that TDMP observed in the vegetative growth stage was directly correlated with the final yield. Dastur (1960) emphasized that for a better yield capacity, the rainfed crop of cotton should produce adequate quantities of dry matter. Higher grain and dry matter production of maize crop foliar application of boron fertilization may be attributed to low available B content of the experimental soil (Sakal *et al.,* 1988).

5.7. Biochemical parameters

The total chlorophyll, chlorophyll 'a' and a/b ratio were found increasing from square formation to boll development stages. This indicated that the chlorophyll synthesis as well as the photosynthetic activity was more at flowering stage in cotton. This is in accordance with the observation made by Rhoads and McIntosh (1991).

The component of total chlorophyll, chlorophyll 'a' and a/b ratio were also found to increase when there was a foliar nutrients applications. Increasing of chlorophyll pigment of the plant had influenced the photosynthetic rate and thereby the efficiency of the plant for increased biomass production was obtained was earlier reported by Chandrababu, 1990 and Sujatha, 2001. Increasing in chlorophyll biosynthesis due to foliar feeding of growth regulators was evidenced in the present experiment. Again the PGR formulation-III (T_9) possessed higher chlorophyll content when compared to control (NAA @ 40ppm-T_1) as evidenced by higher content at boll development stage. The total chlorophyll content recorded at the flower formation stage, the PGR formulation-III (T_9) showed a higher value in the range from 2.05 mg g^{-1} to 2.23 mg g^{-1} at boll development stage. The per cent increase of foliar formulation over control was observed as 28.9 in the

case of flowering stage and in boll development stage it was 22.5. The increasing in chlorophyll pigments due to foliar application of growth regulators was evident at flowering and boll development stages also.

Soluble protein is an indirect measure of photosynthetic rate and it showed a increasing trend due to foliar nutrition respectively of all treatments. PGR formulation-III (T_9) followed by

PGR formulation-IV (T_{10}) showed a sustained accumulation of soluble protein even under foliar feeding of nutrients indicating the higher vigour in nature. It was seen that effect of foliar nutrients invariably increased the soluble protein content in almost all stages of cotton. As early as Martigone *et al.,* 1981, reported that soluble proteins are the nitrogenous compounds, which usually decline during pod filling stage. Hence, spraying of 1% urea might have increased the soluble protein content.

Proline synthesis and accumulation has been a subject of debate as for as the abiotic stresses are concerned. Proline accumulation is regarded as index of tolerance mechanism. Foliar application of growth regulators may be due to the stimulation of proline synthesis from glutamate by loss of feedback inhibition, declining in proline oxidation or due to the decrease of its incorporation into protein. Osmoprotectans such as proline, glycine betaine (GB), and mannitol occurs commonly in plants. Earlier studies indicated that proline is a common compatible in many different organisms, including higher plants, and some plant species accumulate proline in response to drought. Growth regulators enhance praline content (Koheil *et al.,* 1992).

The praline content was increased due to foliar feeding of nutrients at squaring and flowering stages, when it was decline in the further stages. The higher proline ranged from flowering to boll development stages were 837 µg g^{-1} in PGR formulation-III (T_9), when 813 µg g^{-1} in control (NAA @ 40ppm-T_1) respectively. The foliar feeding of nutrients at boll development slightly declines the proline content boll development stage respectively. Hence, the foliar feeding of growth regulators at boll development stage created a major impact in praline content.

The NRase activity was increased due to foliar feeding of nutrients at squaring and flowering stages, when it was decline in the boll development stage. The higher NRase activity ranged from flowering stage were 63.0 µg NO_2^- g^{-1} hr^{-1} in |PGR formulation-III (T_9), when 41.1 µg NO_2^- g^{-1} hr^{-1} in control (NAA @ 40ppm-T_1) respectively. The foliar feeding of nutrients at flowering increased the NRase activity by 53.3 per cent over the control respectively. NRase activity was slightly decline at boll development stage it was 51.4 µg NO_2^- g^{-1} hr^{-1} in PGR formulation-III (T_9), when 36.6 µg NO_2^- g^{-1} hr^{-1} in control (T_1-NAA @ 40ppm) respectively. The foliar feeding of nutrients at boll development stage increased the NRase activity by 40.4 per cent over the

control respectively. The higher NRase activity was related to the yield of grain and grain protein content in many crops (Mishra *et al.*, 1980). The increase in enzyme NRase activity by nitrogen was also reported by Akhtar *et al.* (1991). The level of NRase was found to fluctuate in response to environmental condition (Sinha and Nicholas, 1981). These are in coincidence with present findings that foliar nutrients application enhances NRase activity than control.

The Chlorophyll Stability Index (CSI) was increased due to foliar feeding of nutrients at squaring and boll development stages. The higher CSI ranged from flowering to boll development stages were 84.56 percent in PGR formulation-III (T_9), when 70.63 percent in control (NAA @ 40ppm-T_1) at flowering stage respectively. The foliar feeding of nutrients at boll development increased the CSI value by 19.7 per cent over the control respectively. Hence, the foliar feeding of growth regulators at boll development stage created a major impact in CSI. This fact was supported by the report of Kaloyereas (1958) was the first to suggest a correlation between CSI and foliar nutrition of plant growth regulators in pine trees. Later, Sahadevan (1961) and Murthy and Majumdhar (1962) reported a similar relationship between CSI and photosynthetic efficiency in rice.

5.8. Physiological parameters

The phenotypic expression of a character is interplay of foliar application of growth regulators. These factors therefore readily alter the physiological mechanism of crop plants either singly or in combination. Understanding of this altered physiology of a crop assumes importance to formulate crop management strategies which shall be situation specific. Hence identification of best foliar feeding nutrients is a continuous process in which physiological parameters confirming best treatment need to be analyzed and interpreted.

The Relative Water Content (RWC) which is an important physiological parameter for increasing production seed cotton yield due to enhancing photosynthetic activity was found to be influenced by foliar application of nutrients. At PGR formulation -III (T_9) recorded higher RWC than others. As far as RWC is concerned, PGR formulation-III (T_9) is maintained highest RWC percent ranged from 78.6 to 61.3 in control (NAA @ 40ppm-T_1) at the boll development stage. The reports are in support of the present findings that foliar nutrients could invariably enhance the RWC. There was a increase in RWC whenever plant growth

regulators given (Begg and Turner, 1976). In cotton, increment in RWC was reported by Janagoudar *et al.* (1990). The reports are in support of the present findings that water stress could invariably lower the RWC.

The Cell Membrane Integrity (CMI) which is an important physiological parameter for increasing yield. At PGR formulation-III (T_9) recorded higher CMI than others. As far as CMI is concerned, PGR formulation-III (T_9) is maintained highest percent ranged from 83.3 to 70.2 in control at boll development stage. The reports are in support of the present findings that foliar nutrients could invariably enhance the CMI. The foliar application of plant growth regulators are induced nutrient uptake and reduced cell membrane leakage (Guo and Oosterhuis, 1995).

The Epicuticular Wax (ECW) which is an important physiological parameter for increasing yield due to reducing transpiration loss. At PGR formulation-III (T_9) recorded higher ECW than others. As far as ECW is concerned, PGR formulation-III (T_9) is maintained highest ECW value ranged from 136.9 µg cm^{-2} in PGR formulation-III (T_9) to 122.5 µg cm^{-2} in control at boll development stage. The foliar feeding of nutrients at boll development increased the ECW value by 11.7 per cent over the control respectively. The reports are in support of the present findings that foliar nutrients could invariably enhance the ECW. The foliar spray of growth regulators enhances, ECW has been shown to reduce the net radiation load of the canopy as well as cuticular transpiration and to improve stomata control over transpiration (Blum, 1979).

The SPAD chlorophyll value showed that foliar nutrients have an increasing effect respective of all foliar feeding treatments. Foliar spray given at squaring and flowering stages has more or less increased the SPAD values. With reference to the foliar formulations, PGR formulation-III (T_9) ranks first in maintaining higher SPAD value. The least value was recorded in control (NAA @ 40ppm-T_1). There is an increasingly large body of evidence that plant growth regulators may have a positive effect on photosynthetic capacity (Chaves, 2002).

The Stomatal Diffusive Resistance (SDR) was found to be lower incontrol. At boll development stage the overall treatment ranged from 16.4 in PGR formulation-III (T_9) to 11.3 in control. The per cent increase of SDR due to foliar formulation over control is 45.2 in PGR formulation-III (T_9) respectively. During flowering and boll development

stage also PGR formulation-III (T_9) showed improved SDR values over other treatments indicating under foliar application of nutrients, the SDR will show increasing trend. Exogenous application of salicylic acid (SA) may influence a range of diverse processes in plants, including stomatal closure (Larque-Saaverda, 1979). SA naturally participates in the regulation of physiological processes in plant such as stomatal closure, chlorophyll synthesis, protein synthesis, inhibition of ethylene biosynthesis, transpiration and photosynthesis (Raskin, 1992; Khan and Shimullah, 2003; Shakirova *et al.,* 2003).

Foliar application of plant growth regulators have resulted in decreased leaf temperature respectively at flowering and boll development stages. During boll development stage the PGR formulation showed a leaf temperature ranged from 31.4 ˚C in PGR formulation-III (T_9) to 35.31˚C in control. The per cent decreased due to foliar formulation over control is 12.5˚C in the PGR formulation respectively.

It was found that foliar nutrients application at square and boll development stage significantly increased the leaf temperature. In particular control has shown always higher values of leaf temperature. Mtui *el al.* (1981) reported that the leaf temperature could be reduced under foliar nutrient application of KNO_3 in corn which may be due to plant water stress and reduced stomatal conductance.

Foliar application of plant growth regulators have resulted in increase the quantum values respectively at flowering and boll development stages. During boll development stage the PGR formulation showed a quantum values ranged from 1301.6 µE m^{-2} s^{-1} in PGR formulation-III (T_9) to 1006.2 µE m^{-2} s^{-1} in control. The per cent decreased due to foliar formulation over control is 29.4 in the PGR formulation respectively.

The transpiration rate which is the indicative of the overall plant water relation at different stages was observed to be lowered when the foliar treatments were given. Among the ten treatments the PGR formulation-III (T_9) was showed that lowered values of transpiration rate, it was 1.54 µg $cm^{-2}s^{-1}$ in PGR formulation-III (T_9) to 2.96 µg $cm^{-2}s^{-1}$ in control. The transpiration rate was reduced in PGR formulations indicated that enhancing higher production of seed cotton yield. The rate of transpiration is directly related to the gradient of water vapour concentrations between intercellular spaces of the leaf and the ambient air. Rate of transpiration was positively correlated with leaf water potential (Schulze and Hall, 1982). Photosynthetic rate and transpiration rate were

influenced by growth substances in all stages. Foliar spray of NAA increased the photosynthetic rate and transpiration rate (Guinn and Brummett, 1993).

5.9 Yield and Yield components

Yield is determined by a complex chain of developmental processes. The sequences of events are definite and a disturbance in any one of the steps may have serious consequences. Yield is an outward expression of growth regulators influenced the seed cotton yield. The ultimate aim in management of a crop plant is to produce maximum yield, by tapping the entire exogenous potential as well as input energy with least external cost. Yield is contributed by different yield parameters and any change in any one parameter as influenced by extraneous condition will alter the yield significantly.

The yield components i.e. Number of flowers, Number of bolls are the deciding factors in all treatments. It is well-known that foliar application of growth regulators influences the yield components in a considerable way. It was found that number of flowers was getting increased due to foliar spray of nutrients at boll development stage. This present investigation was supported by the findings of Thandapani and Subharayalu (1986).

Number of bolls per plant was also increased due to foliar application of growth regulators at square and boll development stages. Flower production is directly associated with number of fruits and yield in any crop. Foliar application of 1% urea increased the pod number in green gram (Thandapani, 1981). Bud and boll shedding decreased significantly by combined application of NAA + DAP + topping (Venkatakrishnan, 1995). Hsu *et al.* (1974) found that application of exogenous auxin to unfertilised bolls reduced shedding and stimulated the development of young bolls. In cotton plants, larger numbers of flowers are shed in cotton and fewer numbers develop into bolls occurred under irrigated conditions. The foliar application of PGR formulations were recorded higher number of flowers and bolls when compared to control. The sustained level of salicylic acid may be a prerequisite for the synthesis of auxin and/or cytokinin (Metwally *et al*., 2003). In cotton, there was an increase in the number of bolls per plant through GA_3 application (Sawan *et al.,* 1989). Foliar application of this cytokinin product was reported to promote bud initiation and development that caused an increase in plant fruitfulness and efficiency of the plant to develop (Murry *et al.*, 1976).

The foliar application of plant growth regulators at square and boll development stage showed a significant increase in fertility coefficient than control. Foliar nutrition at boll development increased the value of 50.3 in PGR formulation-III (T_9) to 47.4 in the control. It was evident that with regard to number of flower produced, PGR formulation - III (T_9) ranked first under irrigated condition as against control which shows least number of flowers and bolls. Limitation in cotton productivity is mainly associated with climatic conditions which affect the fruiting efficiency and boll retention. The number of bolls set or shed was decided by auxin – abscisin interaction, nutrient supply and weather conditions (Bhatt, 1982). The foliar application of hormone NAA @ 10ppm on 60 and 75 days of seed crop growth enhanced the seed setting efficiency and boll weight. (Rathinavel *et al.,* 2004). Growth regulators like GA and IAA significantly increased the number of flowers per plant and improved fruit setting (Subramanian and Palaniappan, 1981).

Seed cotton yield ultimately is the result of plant population, photosynthetic ability of the plants in community, number of flowers and number of bolls. Yield was remarkably increased when foliar nutrients was imposed at squaring and boll development stages. Foliar nutrient application was recorded higher seed cotton yield than control. The PGR formulation-III (T_9) recorded 3750 kg ha^{-1} when compared to control; it was 3029 kg ha^{-1} of producing seed cotton yield. In this case PGR formulation-III (T_9) increase percent over control is 23.8.

A linear increase in lint production was observed by Reginato (1983) as the seasonal average stress index decreased. Exogenous applications of SA to different crop species have been shown to elicit effects on yield and yield components. An increase in the number of pods and yield has been found in mung bean (Singh and Kaur 1980). Application of growth regulators was found to be most effective in increasing plant height, dry weight, rate of photosynthesis and seed cotton yield (Kiran Kumar *et al.,* 2005). Lint yield is generally reduced because of reduced boll production, primarily because of fewer flowers and also due to increased boll abortions when the stress is extreme and when it occurs during reproductive growth (Pettigrew, 2004). Namken (1984) applied single and multiple foliar applications of a cytokinin product to cotton at first one-third-grown square and at first bloom; treated cotton produced a significantly higher lint cotton yield than the untreated check.

Harvest index also indicated that the efficiency of the plant to diver photosynthates to economic parts in biomass production. The present study indicated that foliar application of growth regulators increased harvest index invariably. The HI follow similar trend of increasing that foliar feeding of growth regulators. The treatments, PGR formulation III (T_9) followed by PGR formulation-IV (T_{10}) have shown higher HI than others.

5.10. Fibre quality parameters

The fibre quality is a prime factor in combination with lint yield deciding the acceptance of a commercial variety. If any one of the quality parameters are not expressed to the desired extent, the variety will not be acceptable by the farmers and textile industry. Therefore, all the fibre quality parameters have to be simultaneously considered together with the seed cotton yield.

In the present investigation foliar application of growth regulators had slightly increased the fibre length. The 2.5% Staple length, Uniformity ratio, Micronaire value, Maturity ratio, Elongation percentage and Tenacity are having no significant difference among the various foliar nutrition formulations. The variation was found to be narrow with respect to the treatments. Among these ten treatments PGR formulation-III (T_9) was recorded higher values than the control. The percent increase due to foliar formulation over control is 4.7 in the PGR formulation respectively for 2.5% Staple length, simultaneously 8.6 increases in Uniformity ratio, 14.4 in Micronaire value, 10.1 Tenacity value and 5.6 Elongation percentages.

In the present investigation the Ginning out turn has registered higher value in PGR formulations than control. The PGR formulation III (T_9) have higher value GOT was recorded 39.8 percent, when 36.8 percent in control. The percent increase due to PGR formulation-III (T_9) over control is 8.2.

In cotton foliar nutrition is by far the best method of overcoming bud and boll shedding in view of high crop response. It is obvious that, design and development of appropriate and comprehensive foliar formulation is therefore need of the hour. Field investigation conducted during investigation has resulted in the finding of a best foliar formulation. Interestingly PGR foliar formulation-III (T_9) has resulted in as much as 23.8 percent increase over control in the seed cotton yield. Similar results were obtained

from Aruppukottai and Srivilliputhur cotton growing tracts, which formed the Multi Location Trails. The advantageous influence of the PGR formulation-III (T_9) is much impressive from the yield point of cotton and therefore the Tamil Nadu Agricultural University has recommended application of TNAU formulation III, to be sprayed at stray flowering and boll development stages, across the cotton growing traits of entire Tamil Nadu, in the recently held Annual Research Meet on Cotton (2009) during 9th to 10th June, 2009.

CHAPTER VI

SUMMARY

Field experiment was conducted with a view to evaluate the effect of foliar nutrition on growth attributes, physiological, biochemical and yield related components in Bunny hybrid Bt cotton. The experiment was laid out in randomized block design with three replications. The treatment consists of T_1-NAA (40ppm), T_2-KCl (2%), T_3-KNO_3 (3%), T_4-Salicylic acid (100ppm), T_5-DAP (2%), T_6-Polyfeed+Multi-K (1.5%), T_7-PGR (Formulation-I), T_8-PGR (Formulation-II), T_9-PGR (Formulation-III) and T_{10}-PGR (Formulation-IV).Two sprays were given at stray flowering and boll formation stages as per different treatments.

The metabolic effects of hormone based nutrient formulation have indicated that the root conducting tissues may be influenced to augment transport mechanism of both water and nutrients. It is evident that the volume of xylem vessels occupied is more in the PGR Formulation-III (T_9) when compared to the control (NAA @ 40ppm- T_1), indicating the effectiveness of the treatment in the water and nutrient uptake. PGR Formulation-III (T_9) is seen that the number and size of the xylem vessels are increased. It is evident that the volume of xylem vessels occupied is more in the PGR formulation-III (T_9) when compared to the control, it indicating the effectiveness of the treatment in the water and nutrient uptake. The leaf anatomical sections of during boll development stage indicated that the PGR formulation-III (T_9) is able to increase the xylem vessels which was fifty one cells in the treated as against forty four cells in the control.

ABA is implicated in the development of abscission layer which causes flower and boll dropping. An attempt therefore made to study hormone profiles particularly the ABA levels in the boll development stages. It was interestingly seen that the maximum peak of ABA at 262 nm recorded in PGR formulation-III (T_9) than the control. It indicating that PGR formulation-III (T_9) is able to there is a six fold depressions. This may be a reason that foliar formulation is able to retain more number of flowers and

bolls when compared to control. The Cry 1Ac gene content was estimated in leaves. The Cry 1Ac endotoxin will reduces the pest attack of the crop. In the present investigation Cry 1 Ac gene is high in the foliar feeding of PGR formulation-III (T_9).

The present investigations indicate that PGR formulation-III (T_9) has increased the growth parameters of cotton when compared to control. The growth parameters such plant height, root length, leaf area are increased due to application of foliar nutrients at flowering and boll development stages. For LAI also increase over control. The CGR was increased due to foliar feeding of nutrients at squaring and boll development stages. The foliar feeding of nutrients at boll development increased the CGR value by nearly fifty percent over the control respectively. The RGR was increased due to foliar feeding of nutrients at squaring and boll development stages. The foliar feeding of nutrients at boll development increased the RGR value by one fourth percent over the control respectively. The NAR was increased due to foliar feeding of nutrients at squaring and boll development stages. The foliar feeding of nutrients at boll development increased the NAR value by 13.2 percent over the control respectively. Foliar application given at boll development stages was found to be more detrimental increase of TDMP compared to squaring stage. The beneficial effects of foliar feeding of nutrients were found to be much more pronounced in PGR formulation-III (T_9).

The physiological parameters such as; the total chlorophyll content recorded at the flower formation stage, the PGR formulation-III (T_9) showed a higher value at both flowering and boll development stages. The per cent increase of foliar formulation over control was observed as one third percent in the case of flowering stage and in boll development stages. Soluble protein is an indirect measure of photosynthetic rate and it showed an increasing trend due to foliar nutrition respectively of all treatments. PGR formulation-III (T_9) followed by PGR formulation-IV (T_{10}) showed a sustained accumulation of soluble protein even under foliar feeding of nutrients indicating the higher vigour in nature. The proline content was increased due to foliar feeding of nutrients at squaring and flowering stages, when it was decline in the further stages. The foliar feeding of nutrients at boll development slightly declines the proline content boll

development stage respectively. NRase activity was more in the PGR formulation-III (T_9) than in control plants. The percent increase of NRase with respect to foliar nutrition was found higher in PGR formulation-III (T_9) than in control.

The PGR formulation -III (T_9) recorded higher RWC than others. As far as RWC is concerned, PGR formulation-III (T_9) is maintained highest RWC percent at the boll development stage. The total chlorophyll, chl - 'a' and a/b ratio were found increasing from square formation to flowering stage and thereafter slight decline was noticed as the crop growth proceeded towards boll development stage. The component of total chlorophyll, chl - 'a' and a/b ratio were also found to increase when there was a foliar nutrients spray. The PGR formulation-III (T_9) possessed higher chlorophyll content when compared to the control.

The CMI which is an important physiological parameter for increasing membrane stability. At PGR formulation-III (T_9) recorded higher CMI than other treatments at different growth stages. CMI reduces the membrane leakage. The ECW which is an important physiological parameter for increasing yield due to reducing transpiration loss. The foliar feeding of nutrients at boll development increased the ECW, it increases cuticle wax and reduces transpiration rate. The SPAD chlorophyll value showed that foliar nutrients have an increasing effect respective of all foliar feeding treatments. Foliar spray given at squaring and flowering stages has more or less increased the SPAD values.

The per cent increase of SDR due to foliar formulation over control is nearly fifty percent in PGR formulation-III (T_9) respectively. During flowering and boll development stages also PGR formulation-III (T_9) showed improved SDR values over other treatments indicating under foliar application of nutrients, the SDR will show increasing trend. The per cent decreased due to foliar formulation over control is 29.4 in the PGR formulation respectively. Similarly PGR formulation III (T_9) increases the quantum yield also. The transpiration rate was reduced in PGR formulations indicated that enhancing higher production of seed cotton yield. The foliar application of plant growth regulators at square and boll development stage caused a significant increase in fertility coefficient

than control. It was evident that with regard to number of flower produced, PGR formulation -III (T_9) ranked first under irrigated condition as against control which shows least number of flowers and bolls.

Yield was remarkably increased when foliar nutrients was imposed at squaring and boll development stages. Foliar nutrient application was recorded higher seed cotton yield than control. In this case PGR formulation-III (T_9) increase percent over control is one fourth percent. The HI follows similar trend of increasing that foliar feeding of growth regulators.

In the present investigation foliar application of growth regulators had slightly increased the fibre length. The PGR formulation III (T_9) have higher value of GOT was recorded than in the control. The 2.5% Staple length, Uniformity ratio, Micronaire value, Maturity ratio, Elongation percentage and Tenacity are having no significant difference among the various foliar nutrition formulations. The variation was found to be narrow with respect to the treatments. The foliar application of PGR formulation III (T_9) was recorded highest net return with cost benefit ratio than the other foliar treatments.

Application of PGR formulation III (T_9) could be considered as a better foliar spray option for higher productivity and profitability of Bunny hybrid Bt cotton under winter irrigated conditions.

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RESEARCH FINDINGS

PHYSIOLOGICAL ASPECTS OF FOLIAR NUTRITION IN RELATION TO THE CONTROL OF BUD AND BOLL SHEDDING IN COTTON *(Gossypium Spp.)*

Chairperson: Student:

Dr. H. Vijayaraghavan **S. Karthik**

Field experiment was conducted with a view to evaluate the effect of foliar nutrition on growth attributes, physiological, biochemical and yield related components in Bunny hybrid Bt cotton. The trial was carried out from August 2008 to January 2009 at Field No. 73, Eastern block of Tamil Nadu Agricultural University, Coimbatore.

The treatment consists of T_1-NAA (40ppm), T_2-KCl (2%), T_3-KNO_3 (3%), T_4-Salicylic acid (100ppm), T_5-DAP (2%), T_6-Polyfeed+Multi-K (1.5%), T_7-PGR (Formulation-I), T_8-PGR (Formulation-II), T_9-PGR (Formulation-III) and T_{10}-PGR (Formulation-IV).Two sprays were given at stray flowering and boll formation stages as per different treatments. Observations were recorded on morphological, physiological and yield attributes besides attempting to study the root anatomy and ABA profiles in all treatments.

There was a significant increase in growth in terms of plant height, LA, LAI, TDMP, CGR, RGR and NAR due to foliar application of growth regulators and its impact was more when the PGR Formulation-III (T_9) is imposed at squaring and boll development stages respectively. The squaring stage is identified as a sensitive stage.

PGR Formulation-III (T_9) has reduced the leaf temperature in all stages due to reduction in rate of transpiration. The transpiration rate was reduced in PGR formulations indicated that enhancing higher production of seed cotton yield.

The magnitude of foliar nutrients increased on SPAD value, total chlorophyll content, chl-'a', chl- a/b ratio was high in PGR Formulation-III (T_9) when compared to control. Similarly CMI, CSI, ECW, NRase activity, soluble protein and proline accumulation was high in PGR Formulation-III (T_9) when compared to control (T_1-NAA @ 40ppm).

The ABA content was reduced by application of PGR formulation-III (T9) when compared to other foliar nutrients. This leads to retaining of flowers and bolls, then increasing the seed cotton yield also.

In the present investigation attempts were made to study the influence of foliar formulation on root and leaf anatomical aspects particularly the vascular bundles. Interestingly the application of PGR Formulation-III (T_9) has pronounced impact in increasing the number of xylem vessels.

Seed cotton yield, the PGR Formulation-III (T_9) consistently maintained a higher yield (23.8 percent) and HI also higher than control (T_1-NAA @ 40ppm) under irrigated situation. PGR Formulation-III (T9) slightly increases fibre quality of cotton lint than others. The variation was found to be narrow with respect to the treatments.

Similar results were obtained from Aruppukottai and Srivilliputhur cotton growing tracts, which formed the Multi Location Trails. The advantageous influence of the PGR formulation-III (T_9) is much impressive from the yield point of cotton and therefore the Tamil Nadu Agricultural University has recommended application of TNAU formulation III, to be sprayed at stray flowering and boll development stages, across the cotton growing traits of entire Tamil Nadu, in the recently held Annual Research Meet on Cotton (2009) during 9^{th} to 10^{th} June, 2009.

Table-5 Effect of Foliar Nutrition on Germination Percentage (%) in Bunny Hybrid Bt cotton

Treatment	Germination Percentage
T_1- NAA - 40 ppm	89.4
T_2- Potassium chloride - 2 %	91.3
T_3- Potassium nitrate - 3 %	93.3
T_4- Salicylic acid - 100 ppm	94.1
T_5- Diammonium Phosphate - 2 %	92.9
T_6- Polyfeed + Multi K - 1.5 %	92.6
T_7- PGR Formulation - I	93.7
T_8- PGR Formulation - II	92.4
T_9- PGR Formulation - III	95.2
T_{10}-PGR Formulation - IV	93.5
CD(P=0.05)	**9.47 (NS)**

Table-6 Effect of Foliar Nutrition on Plant Height (cm) in Bunny Hybrid Bt cotton

Treatment	Squaring	Flowering	Boll Development
T_1- NAA - 40 ppm	51.7	83.3	104.6
T_2- Potassium chloride - 2 %	54.2	99.0	121.8
T_3- Potassium nitrate - 3 %	55.8	102.9	125.1
T_4- Salicylic acid - 100 ppm	56.1	103.7	130.2
T_5- Diammonium Phosphate - 2 %	57.7	98.4	128.2
T_6- Polyfeed + Multi K - 1.5 %	53.8	101.8	133.6
T_7- PGR Formulation - I	58.3	106.8	132.9
T_8- PGR Formulation - II	59.9	105.1	130.6
T_9- PGR Formulation - III	61.0	112.8	147.3
T_{10}-PGR Formulation - IV	59.3	111.4	142.8
CD (P=0.05)	**5.78 (NS)**	**10.45**	**13.20**

Table-7 Effect of Foliar Nutrition on Root Length (cm) in Bunny Hybrid Bt cotton

Treatment	Squaring	Flowering	BollDevelopment
T_1- NAA - 40 ppm	35.8	67.2	88.4
T_2- Potassium chloride - 2 %	38.2	69.3	90.7
T_3- Potassium nitrate - 3 %	37.3	70.5	93.2
T_4- Salicylic acid - 100 ppm	38.9	70.9	94.0
T_5- Diammonium Phosphate - 2 %	39.6	72.3	100.2
T_6- Polyfeed + Multi K - 1.5 %	36.2	68.8	89.3
T_7- PGR Formulation - I	37.7	69.4	90.1
T_8- PGR Formulation - II	39.5	71.4	96.1
T_9- PGR Formulation - III	40.8	77.2	107.3
T_{10}-PGR Formulation - IV	39.6	70.6	101.4
CD(P=0.05)	**3.92 (NS)**	**2.72**	**9.69**

Table-8 Effect of Foliar Nutrition on Total Dry Matter Production (kg ha^{-1}) in Bunny Hybrid Bt cotton

Treatment	Squaring	Flowering	Boll Development	Harvest
T_1- NAA - 40 ppm	546	2874	6174	6776
T_2- Potassium chloride - 2 %	558	3045	6385	6947
T_3- Potassium nitrate - 3 %	579	3191	6533	7125
T_4- Salicylic acid - 100 ppm	565	3105	6481	7133
T_5- Diammonium Phosphate - 2 %	560	3070	6389	7109
T_6- Polyfeed + Multi K - 1.5 %	594	3657	7082	7549
T_7- PGR Formulation - I	583	3584	7006	7350
T_8- PGR Formulation - II	591	3633	7048	7420
T_9- PGR Formulation - III	648	3832	7241	7781
T_{10}-PGR Formulation - IV	588	3573	6912	7301
CD(P=0.05)	**59.24 (NS)**	**246.35**	**357.40**	**438.96**

Table-9 Effect of Foliar Nutrition on Leaf Area (LA) (cm^2 $plant^{-1}$) in Bunny Hybrid Bt cotton

Treatment	Squaring	Flowering	Boll Development
T_1- NAA - 40 ppm	4576.5	6196.5	9639.0
T_2- Potassium chloride - 2 %	4900.5	7047.0	10408.5
T_3- Potassium nitrate - 3 %	4819.2	7249.5	10894.5
T_4- Salicylic acid - 100 ppm	4617.0	8545.5	11664.0
T_5- Diammonium Phosphate - 2 %	5508.0	8424.0	11461.5
T_6- Polyfeed + Multi K - 1.5 %	4900.5	7168.5	12433.5
T_7- PGR Formulation - I	5346.0	6844.5	12028.5
T_8- PGR Formulation - II	5508.0	9072.0	12879.0
T_9- PGR Formulation - III	5710.5	10368.0	13729.5
T_{10}-PGR Formulation - IV	5508.0	8059.5	10003.5
CD(P=0.05)	**521.6**	**812.7**	**1175.4**

Table-10 Effect of Foliar Nutrition on number of days taken for First Square, Flower, Boll formation and first Boll opening (DAS) in Bunny Hybrid Bt cotton

Treatment	First Square formation	First Flower formation	First Boll formation	Boll opening
T_1- NAA - 40 ppm	38.4	58.5	69.5	123.3
T_2- Potassium chloride - 2 %	39.2	60.3	70.1	125.6
T_3- Potassium nitrate - 3 %	38.9	62.8	71.0	124.7
T_4- Salicylic acid - 100 ppm	39.5	59.6	69.2	125.5
T_5- Diammonium Phosphate - 2 %	40.1	62.3	71.6	126.3
T_6- Polyfeed + Multi K -1.5 %	39.7	61.7	69.7	126.2
T_7- PGR Formulation-I	41.7	62.4	72.3	127.8
T_8- PGR Formulation-II	42.3	63.5	72.5	127.3
T_9- PGR Formulation-III	42.5	63.8	72.8	128.7
T_{10}-PGR Formulation-IV	42.3	63.0	72.7	127.1
CD(P=0.05)	**4.12 (NS)**	**6.29 (NS)**	**1.62 (NS)**	**1.613**

Table-11 Effect of Foliar Nutrition on Leaf Area Index (LAI) in Bunny Hybrid Bt cotton

Treatment	Squaring	Flowering	Boll Development
T_1- NAA - 40 ppm	1.13	1.53	2.38
T_2- Potassium chloride - 2 %	1.21	1.74	2.57
T_3- Potassium nitrate - 3 %	1.19	1.79	2.69
T_4- Salicylic acid - 100 ppm	1.14	2.11	2.88
T_5- Diammonium Phosphate - 2 %	1.36	2.08	2.83
T_6- Polyfeed + Multi K - 1.5 %	1.21	1.77	3.07
T_7- PGR Formulation - I	1.32	1.69	2.97
T_8- PGR Formulation - II	1.36	2.24	3.18
T_9- PGR Formulation - III	1.41	2.56	3.39
T_{10}-PGR Formulation - IV	1.36	1.99	2.47
CD(P=0.05)	**0.128**	**0.201**	**0.291**

Table-12(a) Effect of Foliar Nutrition on Crop Growth Rate (CGR) (g $m^{-2}day^{-1}$) in Bunny Hybrid Bt cotton

Treatment	Squaring to Flowering	Flowering to Boll Development
T_1- NAA - 40 ppm	5.71	6.65
T_2- Potassium chloride - 2 %	5.79	6.93
T_3- Potassium nitrate - 3 %	5.67	7.17
T_4- Salicylic acid - 100 ppm	5.66	7.22
T_5- Diammonium Phosphate - 2 %	5.73	7.53
T_6- Polyfeed + Multi K - 1.5 %	5.82	7.89
T_7- PGR Formulation - I	5.86	7.74
T_8- PGR Formulation - II	5.74	8.66
T_9- PGR Formulation - III	5.79	9.33
T_{10}-PGR Formulation - IV	5.75	8.24
CD(P=0.05)	**0.58 (NS)**	**0.786**

Table-12(b) Effect of Foliar Nutrition on Relative Growth Rate (RGR) (g $g^{-1}day^{-1}$) in Bunny Hybrid Bt cotton

Treatment	Squaring to Flowering	Flowering to Boll Development
T_1- NAA - 40 ppm	0.055	0.021
T_2- Potassium chloride - 2 %	0.057	0.025
T_3- Potassium nitrate - 3 %	0.057	0.024
T_4- Salicylic acid - 100 ppm	0.057	0.025
T_5- Diammonium Phosphate - 2 %	0.057	0.024
T_6- Polyfeed + Multi K - 1.5 %	0.061	0.022
T_7- PGR Formulation - I	0.061	0.022
T_8- PGR Formulation - II	0.061	0.022
T_9- PGR Formulation - III	0.059	0.026
T_{10}-PGR Formulation - IV	0.060	0.022
CD(P=0.05)	**0.0059 (NS)**	**0.002**

Table-12(c) Effect of Foliar Nutrition on Net Assimilation Rate (NAR) (g m^{-2}LA day^{-1}) in Bunny Hybrid Bt cotton

Treatment	Squaring to Flowering	Flowering to Boll Development
T_1- NAA - 40 ppm	0.68	0.16
T_2- Potassium chloride - 2 %	0.8	0.18
T_3- Potassium nitrate - 3 %	0.87	0.28
T_4- Salicylic acid - 100 ppm	0.79	0.23
T_5- Diammonium Phosphate - 2 %	0.95	0.21
T_6- Polyfeed + Multi K - 1.5 %	0.84	0.27
T_7- PGR Formulation - I	0.81	0.35
T_8- PGR Formulation - II	0.93	0.31
T_9- PGR Formulation - III	1.18	0.37
T_{10}-PGR Formulation - IV	0.89	0.29
CD(P=0.05)	**0.090**	**0.028**

Table-13 Effect of Foliar Nutrition on SPAD values in Bunny Hybrid Bt cotton

Treatment	Squring	Flowering	Boll development
T_1- NAA - 40 ppm	39.73	38.33	41.03
T_2- Potassium chloride - 2 %	43.95	42.14	46.22
T_3- Potassium nitrate - 3 %	44.64	42.88	47.42
T_4- Salicylic acid - 100 ppm	46.39	45.27	47.92
T_5- Diammonium Phosphate - 2 %	47.23	44.91	48.98
T_6- Polyfeed + Multi K - 1.5 %	44.87	39.85	46.41
T_7- PGR Formulation - I	47.46	45.44	48.34
T_8- PGR Formulation - II	46.8	42.3	46.93
T_9- PGR Formulation - III	49.94	48.33	51.14
T_{10}-PGR Formulation - IV	47.88	43.63	48.78
CD(P=0.05)	**4.671**	**4.425**	**4.823**

Table-14 Effect of Foliar Nutrition on Total Chlorophyll (mg g^{-1}) in Bunny Hybrid Bt cotton

Treatment	Squaring	Flowering	Boll Development
T_1- NAA - 40 ppm	1.47	1.59	1.82
T_2- Potassium chloride - 2 %	1.56	1.71	1.84
T_3- Potassium nitrate - 3 %	1.59	1.69	1.87
T_4- Salicylic acid - 100 ppm	1.50	1.79	1.93
T_5- Diammonium Phosphate - 2 %	1.60	1.96	2.19
T_6- Polyfeed + Multi K - 1.5 %	1.77	1.99	2.06
T_7- PGR Formulation - I	1.59	1.77	2.00
T_8- PGR Formulation - II	1.57	1.90	2.13
T_9- PGR Formulation - III	1.79	2.05	2.23
T_{10}-PGR Formulation - IV	1.65	1.93	2.07
CD(P=0.05)	**0.164**	**0.186**	**0.204**

Table-15 Effect of Foliar Nutrition on Chlorophyll 'a'content (mg g^{-1}) in Bunny Hybrid Bt cotton

Treatment	Squaring	Flowering	Boll Development
T_1- NAA - 40 ppm	1.01	1.04	1.30
T_2- Potassium chloride - 2 %	1.11	1.14	1.34
T_3- Potassium nitrate . 3 %	1.09	1.19	1.38
T_4- Salicylic acid - 100 ppm	1.09	1.16	1.36
T_5- Diammonium Phosphate - 2 %	1.15	1.24	1.57
T_6- Polyfeed + Multi K - 1.5 %	1.20	1.33	1.43
T_7- PGR Formulation - I	1.08	1.1	1.40
T_8- PGR Formulation - II	1.13	1.27	1.57
T_9- PGR Formulation - III	1.29	1.36	1.60
T_{10}-PGR Formulation - IV	1.19	1.31	1.47
CD(P=0.05)	**0.115**	**0.124**	**0.147**

Table-16 Effect of Foliar Nutrition on Chlorophyll 'b' content (mg g^{-1}) in Bunny Hybrid Bt cotton

Treatment	Squaring	Flowering	Boll Development
T_1- NAA - 40 ppm	0.45	0.46	0.56
T_2- Potassium chloride - 2 %	0.40	0.41	0.55
T_3- Potassium nitrate . 3 %	0.45	0.45	0.54
T_4- Salicylic acid - 100 ppm	0.36	0.44	0.54
T_5- Diammonium Phosphate - 2 %	0.38	0.46	0.52
T_6- Polyfeed + Multi K - 1.5 %	0.39	0.43	0.43
T_7- PGR Formulation - I	0.40	0.41	0.42
T_8- PGR Formulation - II	0.39	0.4	0.48
T_9- PGR Formulation - III	0.37	0.39	0.44
T_{10}-PGR Formulation - IV	0.37	0.39	0.49
CD(P=0.05)	**0.041**	**0.044**	**0.052**

Table-17 Effect of Foliar Nutrition on Chlorophyll– a/b ratio at different stages of Bt cotton

Treatment	Squaring	Flowering	Boll Development
T_1- NAA - 40 ppm	2.24	2.26	2.32
T_2- Potassium chloride - 2 %	2.77	2.78	2.43
T_3- Potassium nitrate - 3 %	2.42	2.64	2.55
T_4- Salicylic acid - 100 ppm	3.03	2.63	2.51
T_5- Diammonium Phosphate - 2 %	3.02	2.69	3.01
T_6- Polyfeed + Multi K - 1.5 %	3.07	3.09	3.32
T_7- PGR Formulation - I	2.70	2.68	3.33
T_8- PGR Formulation - II	2.90	3.17	3.27
T_9- PGR Formulation - III	3.48	3.48	3.63
T_{10}-PGR Formulation - IV	3.21	3.27	3.00
CD(P=0.05)	**0.294**	**0.292**	**0.297**

Table-18 Effect of Foliar Nutrition on Soluble Protein (mg g^{-1}) in Bunny Hybrid Bt cotton

Treatment	Squaring	Flowering	Boll Formation
T_1- NAA - 40 ppm	34.5	42.6	57.2
T_2- Potassium chloride - 2 %	36.5	45.1	59.0
T_3- Potassium nitrate - 3 %	39.6	48.6	64.3
T_4- Salicylic acid - 100 ppm	37.9	44.5	64.0
T_5- Diammonium Phosphate - 2 %	40.3	46.7	63.5
T_6- Polyfeed + Multi K - 1.5 %	39.2	44.2	65.5
T_7- PGR Formulation - I	41.4	45.7	66.0
T_8- PGR Formulation - II	43.6	49.1	65.0
T_9- PGR Formulation - III	52.5	57.3	72.5
T_{10}-PGR Formulation - IV	46.5	49.7	68.1
CD(P=0.05)	**4.199**	**4.838**	**6.566**

Table-19 Effect of Foliar Nutrition on Proline content (µg g^{-1}) in Bunny Hybrid Bt cotton

Treatment	Squaring	Flowering	Boll Development
T_1- NAA - 40 ppm	447	593	526
T_2- Potassium chloride - 2 %	461	692	572
T_3- Potassium nitrate - 3 %	517	697	603
T_4- Salicylic acid - 100 ppm	622	712	669
T_5- Diammonium Phosphate - 2 %	594	685	638
T_6- Polyfeed + Multi K - 1.5 %	648	736	685
T_7- PGR Formulation - I	683	773	721
T_8- PGR Formulation - II	661	759	705
T_9- PGR Formulation - III	779	837	813
T_{10}-PGR Formulation - IV	688	761	726
CD(P=0.05)	**62.01**	**73.74**	**67.67**

Table-20 Effect of Foliar Nutrition on NRase activity (µg NO_2^- g^{-1} hr^{-1}) in Bunny Hybrid Bt cotton

Treatment	Squaring	Flowering	Boll Formation
T_1- NAA - 40 ppm	34.2	41.1	36.6
T_2- Potassium chloride - 2 %	36.1	44.6	39.3
T_3- Potassium nitrate - 3 %	38.9	47.2	41.9
T_4- Salicylic acid - 100 ppm	41.0	48.3	43.2
T_5- Diammonium Phosphate - 2 %	45.5	55.1	49.1
T_6- Polyfeed + Multi K - 1.5 %	34.4	42.5	37.2
T_7- PGR Formulation - I	41.7	49.4	45.7
T_8- PGR Formulation - II	43.6	58.4	47.7
T_9- PGR Formulation - III	46.6	63.0	51.4
T_{10}-PGR Formulation - IV	44.8	52.5	47.1
CD(P=0.05)	**4.151**	**5.133**	**4.479**

Table-21 Effect of Foliar Nutrition on Chlorophyll Stability Index (%) in Bunny Hybrid Bt cotton

Treatment	Squaring	Flowering	Boll Development
T_1- NAA - 40 ppm	61.33	67.94	70.63
T_2- Potassium chloride - 2 %	63.41	69.90	72.90
T_3- Potassium nitrate . 3 %	66.84	73.93	73.82
T_4- Salicylic acid - 100 ppm	67.32	76.44	76.93
T_5- Diammonium Phosphate - 2 %	69.29	78.22	78.25
T_6- Polyfeed + Multi K - 1.5 %	67.82	78.63	79.89
T_7- PGR Formulation - I	70.73	79.61	80.33
T_8- PGR Formulation - II	73.26	80.06	79.31
T_9- PGR Formulation - III	78.12	83.14	84.56
T_{10}-PGR Formulation - IV	72.64	79.11	80.28
CD(P=0.05)	**7.023**	**7.795**	**7.897**

Table-22 Effect of Foliar Nutrition on Relative Water Content (RWC) (%) in Bunny Hybrid Bt cotton

Treatment	Squaring	Flowering	Boll Development
T_1- NAA - 40 ppm	52.6	56.7	61.3
T_2- Potassium chloride - 2 %	67.3	71.9	73.2
T_3- Potassium nitrate . 3 %	53.3	58.6	65.7
T_4- Salicylic acid - 100 ppm	62.9	69.5	72.2
T_5- Diammonium Phosphate - 2 %	54.2	60.3	68.7
T_6- Polyfeed + Multi K - 1.5 %	63.9	68.4	70.3
T_7- PGR Formulation - I	67.5	70.2	73.1
T_8- PGR Formulation - II	66.2	67.9	70.8
T_9- PGR Formulation - III	72.0	74.5	78.6
T_{10}-PGR Formulation - IV	70.3	72.4	73.3
CD(P=0.05)	**1.71**	**2.39**	**2.53**

Table-23 Effect of Foliar Nutrition on Cell Membrane Integrity (CMI) (%) in Bunny Hybrid Bt cotton

Treatment	Squaring	Flowering	Boll Development
T_1- NAA - 40 ppm	69.4	68.1	70.2
T_2- Potassium chloride - 2 %	72.1	70.6	72.9
T_3- Potassium nitrate . 3 %	74.8	73.3	76.2
T_4- Salicylic acid - 100 ppm	74.7	72.6	74.8
T_5- Diammonium Phosphate - 2 %	76.3	75.8	78.3
T_6- Polyfeed + Multi K - 1.5 %	75.1	73.9	76.5
T_7- PGR Formulation - I	72.9	70.7	73.4
T_8- PGR Formulation - II	80.3	78.5	80.7
T_9- PGR Formulation - III	82.4	81.1	83.3
T_{10}-PGR Formulation - IV	78.8	77.9	79.1
CD(P=0.05)	**0.474**	**0.487**	**0.472**

Table-24 Effect of Foliar Nutrition on Epicuticular Wax content (µg cm^{-2}) in Bunny hybrid Bt cotton

Treatment	Squaring	Flowering	Boll Development
T_1- NAA - 40 ppm	116.4	119.3	122.5
T_2- Potassium chloride - 2 %	121.3	126.2	127.4
T_3- Potassium nitrate . 3 %	128.0	129.4	130.2
T_4- Salicylic acid - 100 ppm	125.8	124.5	126.3
T_5- Diammonium Phosphate - 2 %	134.2	134.9	135.0
T_6- Polyfeed + Multi K - 1.5 %	129.3	130.2	131.5
T_7- PGR Formulation - I	132.6	132.8	132.9
T_8- PGR Formulation - II	130.5	131.6	133.2
T_9- PGR Formulation - III	135.8	136.3	136.9
T_{10}-PGR Formulation - IV	132.4	133.7	132.8
CD(P=0.05)	**2.626**	**3.463**	**3.180**

Table-25 Effect of Foliar Nutrition on Stomatal Diffusive Resistance (SDR) (s cm^{-1}) in Bunny Hybrid Bt cotton

Treatment	Squaring	Flowering	Boll Development
T_1- NAA - 40 ppm	10.1	10.9	11.3
T_2- Potassium chloride - 2 %	10.6	11.4	11.9
T_3- Potassium nitrate - 3 %	11.3	12.2	13.5
T_4- Salicylic acid - 100 ppm	11.2	11.9	12.7
T_5- Diammonium Phosphate - 2 %	12.4	13.1	14
T_6- Polyfeed + Multi K - 1.5 %	11.9	12.7	13.9
T_7- PGR Formulation - I	13.5	14	14.6
T_8- PGR Formulation - II	14.1	14.7	15.3
T_9- PGR Formulation - III	14.9	15.3	16.4
T_{10}-PGR Formulation - IV	13.8	14.2	15.1
CD(P=0.05)	**1.255**	**1.322**	**1.407**

Table-26 Effect of Foliar Nutrition on Leaf Temperature (°C) in Bunny Hybrid Bt cotton

Treatment	Squaring	Flowering	Boll Development
T_1- NAA - 40 ppm	33.96	33.24	35.31
T_2- Potassium chloride - 2 %	32.51	32.83	34.46
T_3- Potassium nitrate - 3 %	32.36	31.49	33.53
T_4- Salicylic acid - 100 ppm	32.79	31.98	33.75
T_5- Diammonium Phosphate - 2 %	31.66	32.11	34.25
T_6- Polyfeed + Multi K - 1.5 %	32.37	31.56	32.58
T_7- PGR Formulation - I	31.42	31.93	33.96
T_8- PGR Formulation - II	32.48	31.62	32.90
T_9- PGR Formulation - III	29.33	30.41	31.40
T_{10}-PGR Formulation - IV	31.69	31.21	32.55
CD(P=0.05)	**1.291**	**1.202**	**0.845**

Table-27 Effect of Foliar Nutrition on Quantum measurements (µE m^{-2} s^{-1}) in Bunny Hybrid Bt cotton

Treatment	Squaring	Flowering	Boll Development
T_1- NAA - 40 ppm	897.4	968.2	1006.2
T_2- Potassium chloride - 2 %	906.3	982.3	1049.3
T_3- Potassium nitrate - 3 %	918.8	995.4	1037.8
T_4- Salicylic acid - 100 ppm	943.9	1024.6	1094.1
T_5- Diammonium Phosphate - 2 %	980.6	1130.3	1179.3
T_6- Polyfeed + Multi K - 1.5 %	971.8	1107.0	1170.5
T_7- PGR Formulation - I	963.5	1083.7	1128.0
T_8- PGR Formulation - II	990.2	1162.5	1238.6
T_9- PGR Formulation - III	1159.3	1209.4	1301.6
T_{10}-PGR Formulation - IV	1042.8	1179.3	1276.4
CD(P=0.05)	**99.483**	**109.948**	**116.489**

Table-28 Effect of Foliar Nutrition on Transpiration Rate (µg cm^{-2} s^{-1}) in Bunny Hybrid Bt cotton

Treatment	Squaring	Flowering	Boll Development
T_1- NAA - 40 ppm	2.84	3.05	2.96
T_2- Potassium chloride - 2 %	2.81	2.94	2.88
T_3- Potassium nitrate - 3 %	2.66	2.82	2.74
T_4- Salicylic acid - 100 ppm	2.09	2.47	2.28
T_5- Diammonium Phosphate - 2 %	1.98	2.17	2.06
T_6- Polyfeed + Multi K - 1.5 %	2.70	3.01	2.83
T_7- PGR Formulation - I	2.26	2.56	2.33
T_8- PGR Formulation - II	1.45	2.03	1.66
T_9- PGR Formulation - III	1.32	1.93	1.54
T_{10}-PGR Formulation - IV	1.68	2.10	1.86
CD(P=0.05)	**0.236**	**0.264**	**0.248**

Table-29 Effect of Foliar Nutrition on ABA quantification (ppm) in Bunny hybrid Bt cotton

Treatment	Boll Development	Harvest
T_1- NAA - 40 ppm	6.79	17.89
T_2- Potassium chloride - 2 %	2.26	3.61
T_3- Potassium nitrate - 3 %	0.81	1.23
T_4- Salicylic acid - 100 ppm	1.57	1.14
T_5- Diammonium Phosphate - 2 %	0.92	2.34
T_6- Polyfeed + Multi K - 1.5 %	0.26	1.97
T_7- PGR Formulation - I	0.24	0.91
T_8- PGR Formulation - II	0.48	0.77
T_9- PGR Formulation - III	0.23	0.52
T_{10}-PGR Formulation - IV	0.35	0.72
CD(P=0.05)	**0.265**	**0.688**

Table-30 Effect of Foliar Nutrition on Cry 1 AC (µg g^{-1}) in Bunny hybrid Bt cotton

Treatment	Cry 1 AC (µg g-1)
T_1- NAA - 40 ppm	2.933
T_2- Potassium chloride - 2 %	3.027
T_3- Potassium nitrate - 3 %	3.016
T_4- Salicylic acid - 100 ppm	3.158
T_5- Diammonium Phosphate - 2 %	3.001
T_6- Polyfeed + Multi K - 1.5 %	3.157
T_7- PGR Formulation - I	3.360
T_8- PGR Formulation - II	4.012
T_9- PGR Formulation - III	4.650
T_{10}-PGR Formulation - IV	3.684
CD(P=0.05)	**0.349**

Table-31 Effect of Foliar Nutrition on No. of Monopodia and No. of Sympodia in Bunny Hybrid Bt cotton

Treatments	No. of Monopodia	No. of Sympodia
T_1- NAA - 40 ppm	1.3	16.6
T_2- Potassium chloride - 2 %	1.6	17.7
T_3- Potassium nitrate - 3 %	1.4	18.0
T_4- Salicylic acid - 100 ppm	1.9	16.3
T_5- Diammonium Phosphate - 2 %	1.5	17.3
T_6- Polyfeed + Multi K - 1.5 %	1.9	21.6
T_7- PGR Formulation - I	1.3	19.0
T_8- PGR Formulation - II	1.6	20.5
T_9- PGR Formulation - III	2.0	22.3
T_{10}-PGR Formulation - IV	1.7	18.8
CD(P=0.05)	**0.168**	**1.915**

Table-32 Effect of Foliar Nutrition on Boll weight per boll (g boll^{-1}) and Fertility Co -efficient (%) in Bunny Hybrid Bt cotton

Treatments	Boll Weight (g boll^{-1})	Fertility Co-efficient (%)
T_1- NAA - 40 ppm	3.3	47.4
T_2- Potassium chloride - 2 %	3.7	49.5
T_3- Potassium nitrate - 3 %	4.8	49.4
T_4- Salicylic acid - 100 ppm	4.7	49.6
T_5- Diammonium Phosphate - 2 %	4.4	47.3
T_6- Polyfeed + Multi K - 1.5 %	4.6	46.9
T_7- PGR Formulation - I	4.5	47.6
T_8- PGR Formulation - II	4.4	46.4
T_9- PGR Formulation - III	5.1	50.3
T_{10}-PGR Formulation - IV	4.6	45.2
CD(P=0.05)	**0.1781**	**2.059**

Table-33 Effect of Foliar Nutrition on Number of Squares, Flowers, Bolls and opened bolls per plant in Bunny Hybrid Bt cotton

Treatment	No. of. Squares plant $^{-1}$	Number of Flowers plant $^{-1}$	No. of Bolls plant $^{-1}$	No. of. opened Bolls plant $^{-1}$
T_1- NAA - 40 ppm	124.3	67.9	32.2	30.8
T_2- Potassium chloride - 2 %	118.9	68.9	34.1	33.0
T_3- Potassium nitrate - 3 %	119.3	67.6	33.4	32.6
T_4- Salicylic acid - 100 ppm	119.8	69.7	34.6	33.1
T_5- Diammonium Phosphate - 2 %	120.3	72.1	34.1	32.9
T_6- Polyfeed + Multi K - 1.5 %	122.6	72.4	34.0	32.5
T_7- PGR Formulation - I	121.5	74.6	35.5	34.4
T_8- PGR Formulation - II	122.7	76.3	35.4	34.9
T_9- PGR Formulation - III	122.9	77.6	39.0	38.6
T_{10}-PGR Formulation - IV	123.4	77.5	35.0	34.7
CD(P=0.05)	**12.41 (NS)**	**7.364**	**1.249**	**3.439**

Table-34 Effect of Foliar Nutrition on Seed Cotton Yield (kg ha^{-1}) and Harvest Index (%) in Bunny Hybrid Bt cotton

Treatments	Yield(kg/ha)	Harvest Index (%)
T_1- NAA - 40 ppm	3029	44.7
T_2- Potassium chloride - 2 %	3147	45.3
T_3- Potassium nitrate - 3 %	3270	45.9
T_4- Salicylic acid - 100 ppm	3338	46.8
T_5- Diammonium Phosphate - 2 %	3377	47.5
T_6- Polyfeed + Multi K - 1.5 %	3556	47.1
T_7- PGR Formulation - I	3425	46.6
T_8- PGR Formulation - II	3510	47.3
T_9- PGR Formulation - III	3750	48.2
T_{10}-PGR Formulation - IV	3497	47.9
CD(P=0.05)	**343.6**	**4.76 (NS)**

Table-35(a) Effect of Foliar Nutrition on 2.5% Staple Length, Uniformity Ratio, Micronaire Value and Ginning Out Turn (GOT) (%) in Bunny Hybrid Bt cotton

Treatment	2.5% Staple Length (mm)	Uniformity Ratio (%)	Micronaire Value (µg/inch)	GOT (%)
T_1- NAA - 40 ppm	30.80	45.0	3.80	36.8
T_2- Potassium chloride - 2 %	31.20	45.9	4.20	37.7
T_3- Potassium nitrate - 3 %	31.05	47.5	3.90	37.2
T_4- Salicylic acid - 100 ppm	31.15	47.0	4.10	37.5
T_5- Diammonium Phosphate - 2 %	31.45	46.7	4.05	37.3
T_6- Polyfeed + Multi K - 1.5 %	31.25	48.5	3.95	38.1
T_7- PGR Formulation - I	31.80	46.5	4.25	38.0
T_8- PGR Formulation - II	31.50	47.0	4.15	37.6
T_9- PGR Formulation - III	32.25	48.9	4.35	39.8
T_{10}-PGR Formulation - IV	31.35	46.0	4.05	37.5
CD(P=0.05)	**3.21 (NS)**	**4.78 (NS)**	**0.42 (NS)**	**1.194**

Table-35(b) Effect of Foliar Nutrition on Maturity Ratio, Tenacity, and Elongation (%) in Bunny Hybrid Bt cotton

Treatment	Maturity Ratio	Tenacity (g tex^{-1})	Elongation (%)
T_1- NAA - 40 ppm	0.73	21.30	5.80
T_2- Potassium chloride - 2 %	0.74	22.85	6.05
T_3- Potassium nitrate - 3 %	0.76	23.25	5.90
T_4- Salicylic acid - 100 ppm	0.74	22.70	6.10
T_5- Diammonium Phosphate - 2 %	0.76	22.40	6.00
T_6- Polyfeed + Multi K - 1.5 %	0.75	22.35	6.05
T_7- PGR Formulation - I	0.75	21.50	5.95
T_8- PGR Formulation - II	0.74	23.00	5.96
T_9- PGR Formulation - III	0.76	23.45	6.13
T_{10}-PGR Formulation - IV	0.73	23.00	5.90
CD(P=0.05)	**0.076 (NS)**	**2.308 (NS)**	**0.612 (NS)**

Table-36 Effect of Foliar Nutrition on gross income, net income and B:C ratio on Bt cotton

Treatment	Gross income (Rs. ha^{-1})	Cost of cultivation (Rs. ha^{-1})	Net income (Rs. ha^{-1})	B:C ratio
T_1- NAA - 40 ppm	72696	26891	45805	1.69
T_2- Potassium chloride - 2 %	75528	27833	47695	1.71
T_3- Potassium nitrate - 3 %	78480	28712	49768	1.73
T_4- Salicylic acid - 100 ppm	80112	28694	51418	1.79
T_5- Diammonium Phosphate - 2 %	81048	28932	52116	1.81
T_6- Polyfeed + Multi K - 1.5 %	85344	29122	56222	1.93
T_7- PGR Formulation - I	82200	29649	52551	1.77
T_8- PGR Formulation - II	84240	29897	54343	1.81
T_9- PGR Formulation - III	90000	29233	60767	2.07
T_{10}-PGR Formulation - IV	83928	29687	54241	1.82

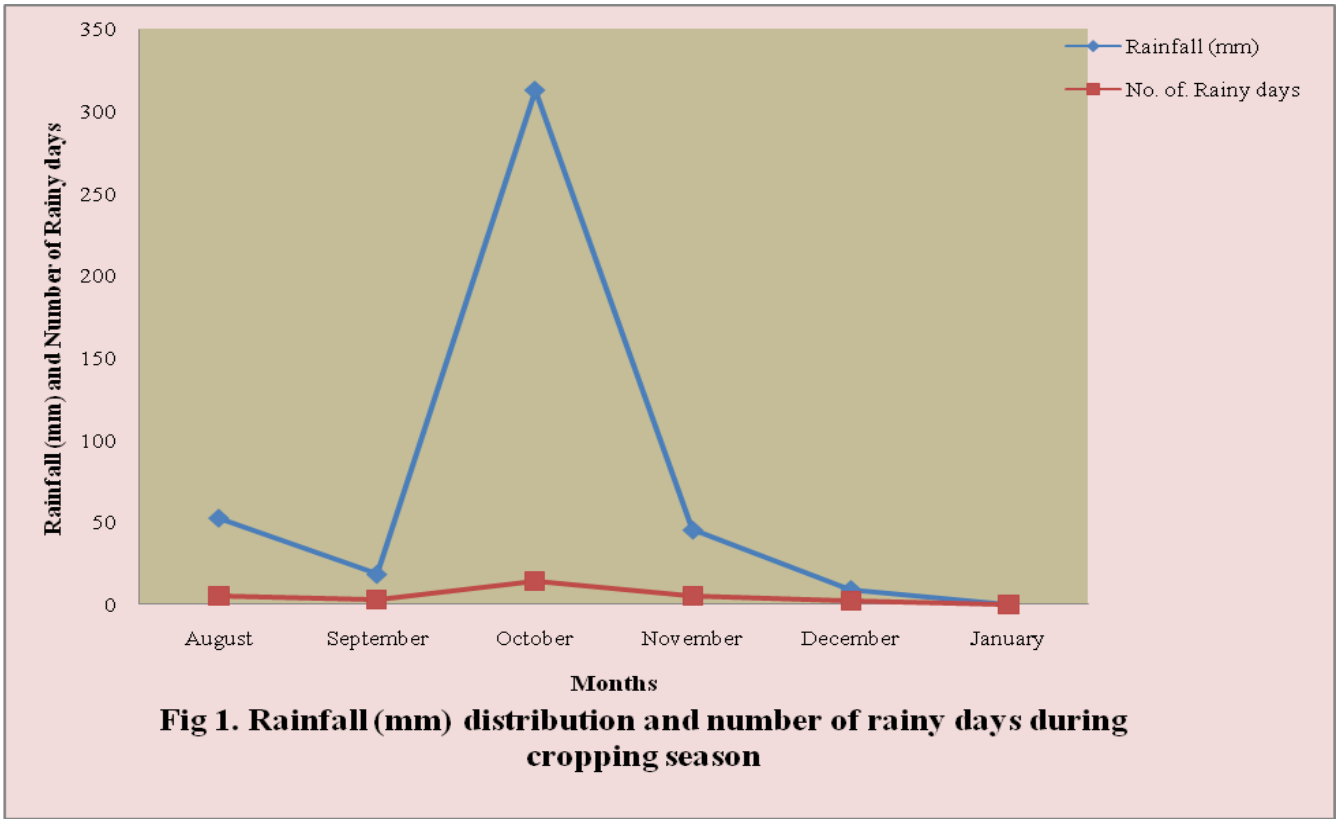


Fig 1. Rainfall (mm) distribution and number of rainy days during cropping season

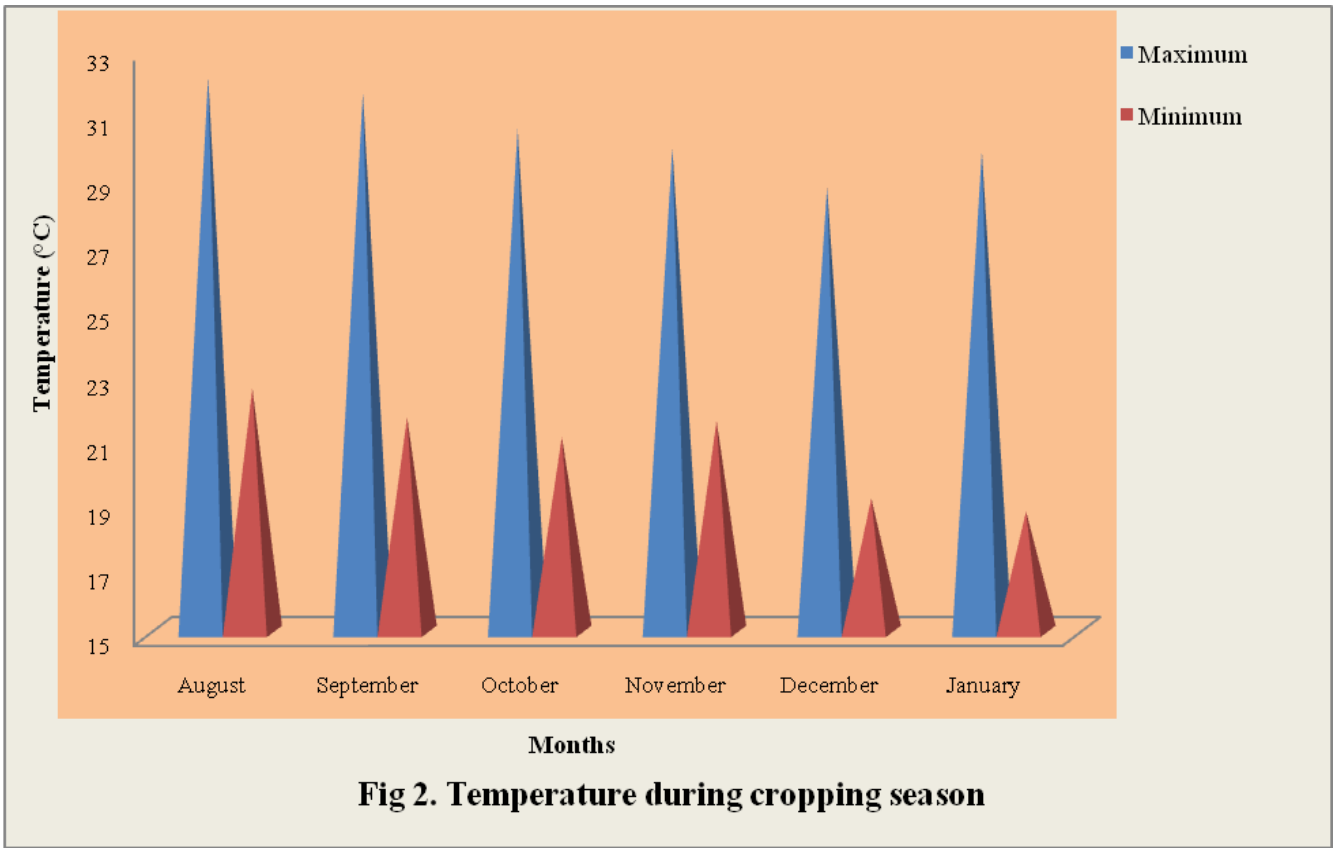


Fig 2. Temperature during cropping season

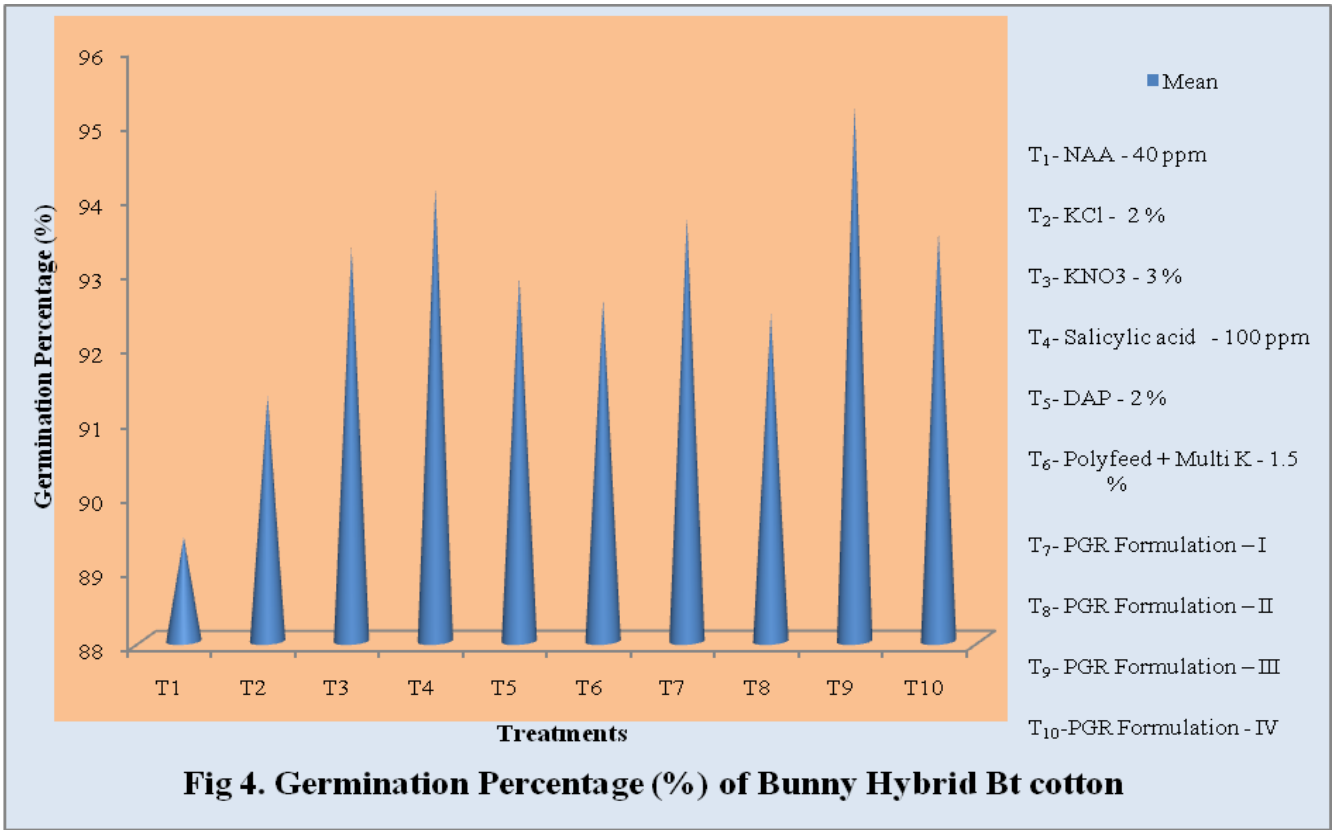


Fig 4. Germination Percentage (%) of Bunny Hybrid Bt cotton

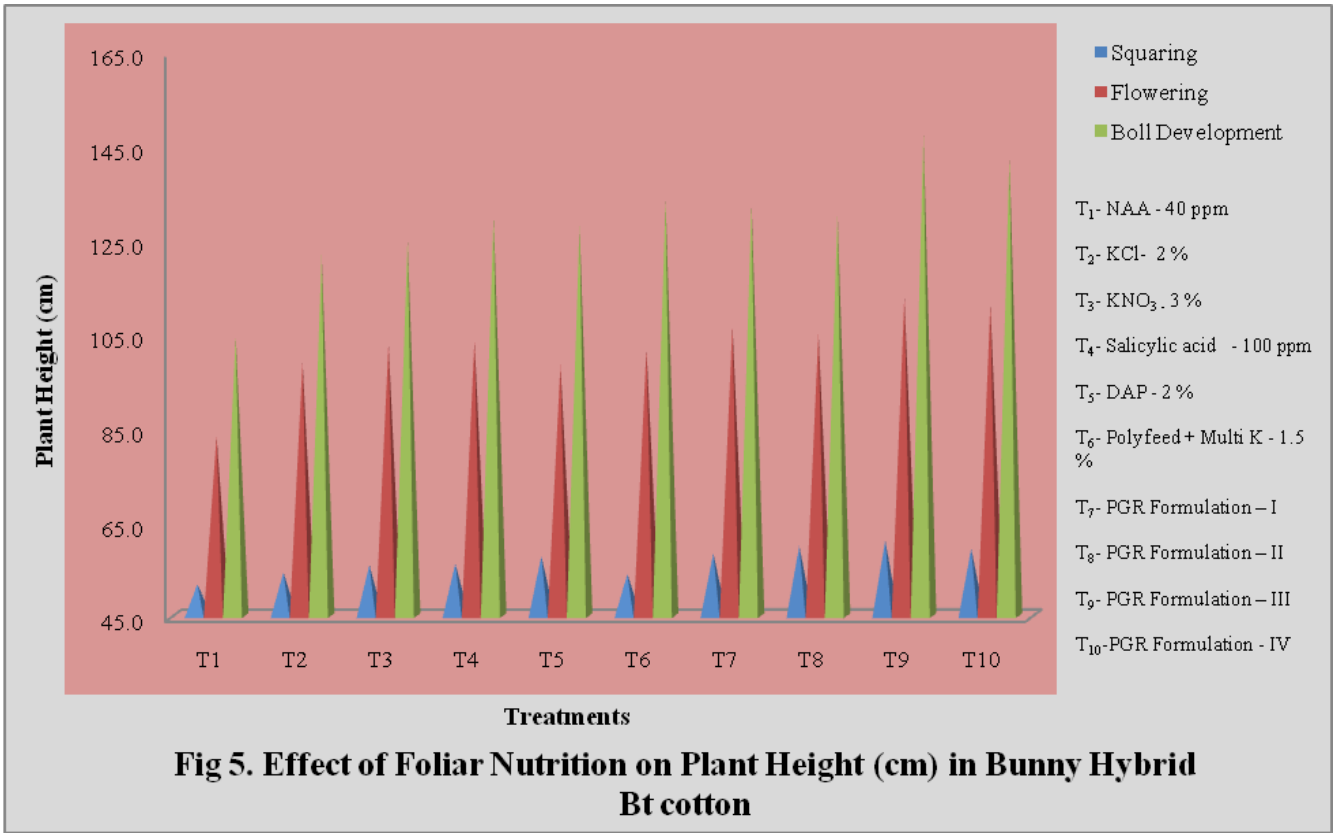


Fig 5. Effect of Foliar Nutrition on Plant Height (cm) in Bunny Hybrid Bt cotton

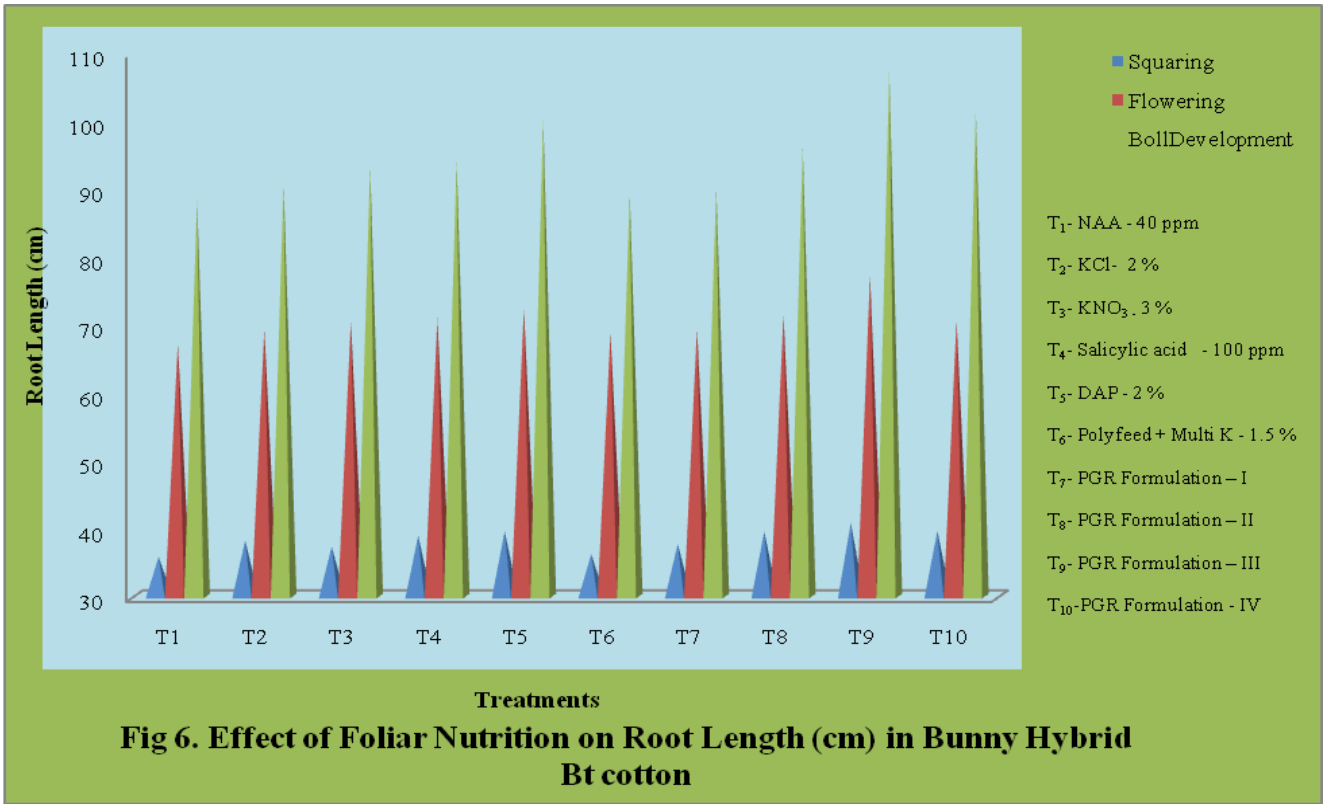


Fig 6. Effect of Foliar Nutrition on Root Length (cm) in Bunny Hybrid Bt cotton

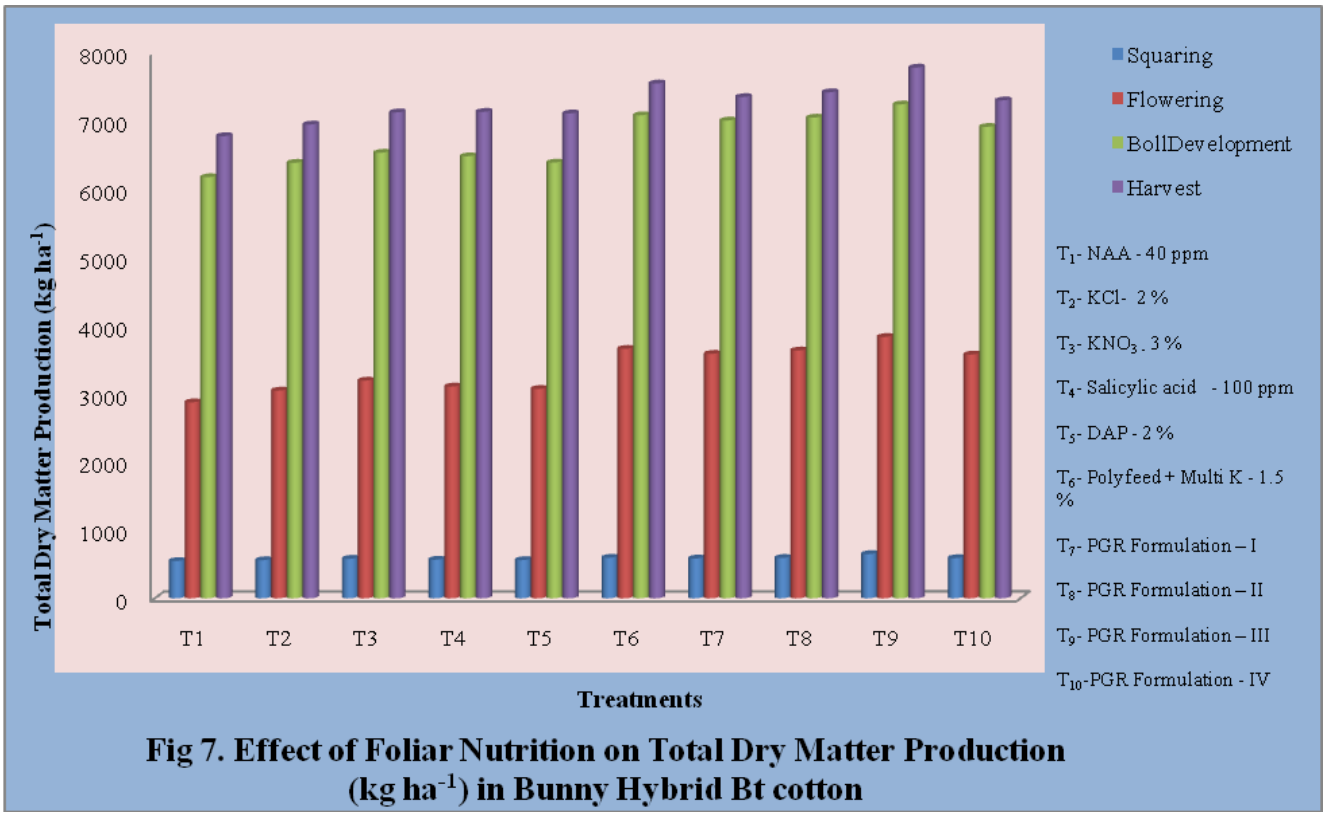


Fig 7. Effect of Foliar Nutrition on Total Dry Matter Production (kg ha^{-1}) in Bunny Hybrid Bt cotton

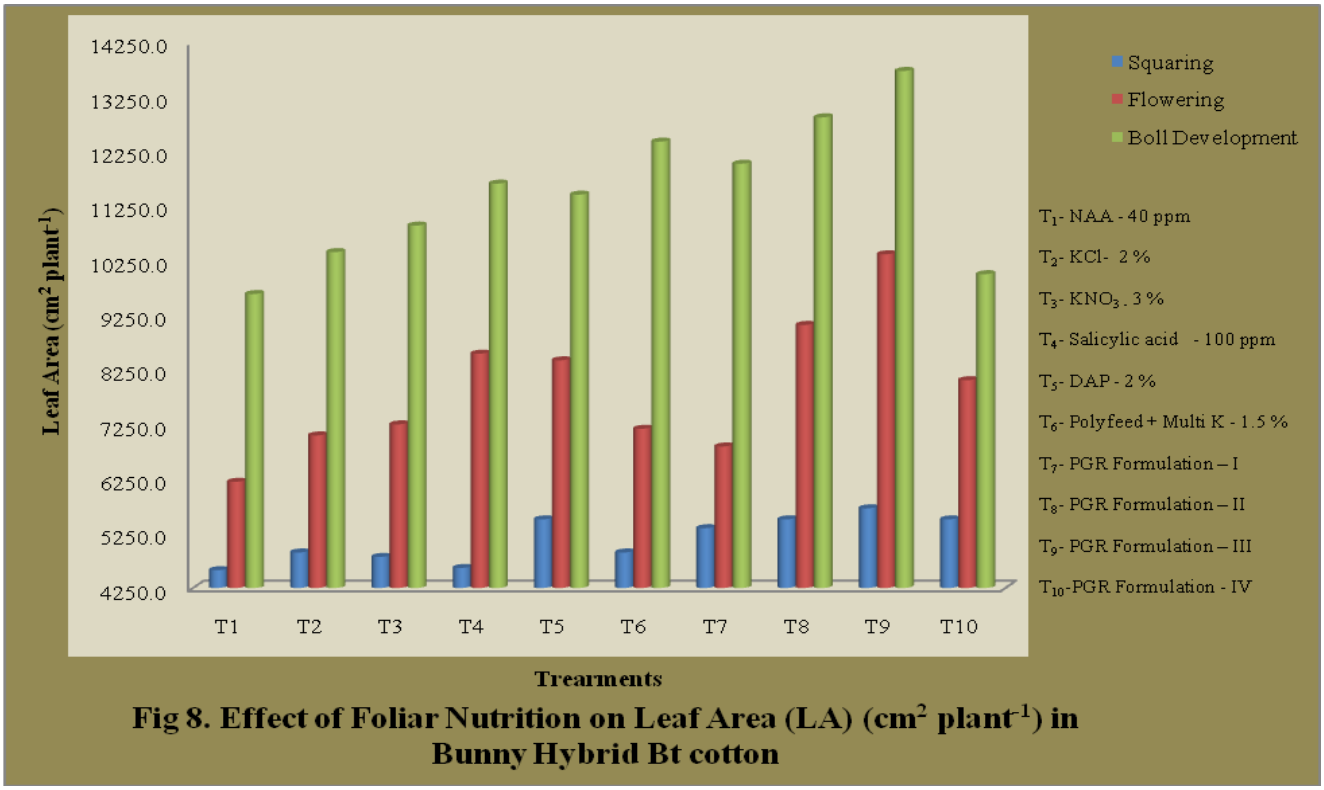


Fig 8. Effect of Foliar Nutrition on Leaf Area (LA) (cm^2 $plant^{-1}$) in Bunny Hybrid Bt cotton

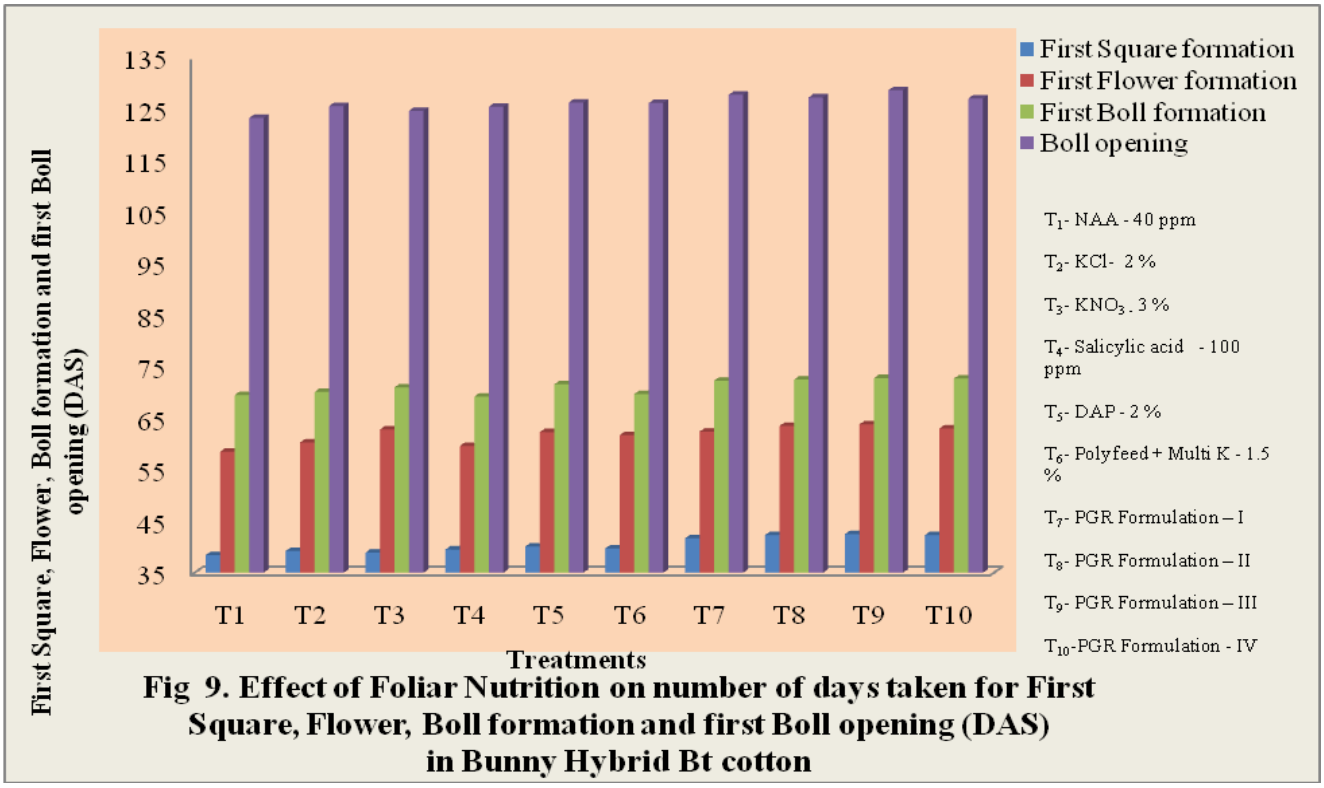


Fig 9. Effect of Foliar Nutrition on number of days taken for First Square, Flower, Boll formation and first Boll opening (DAS) in Bunny Hybrid Bt cotton

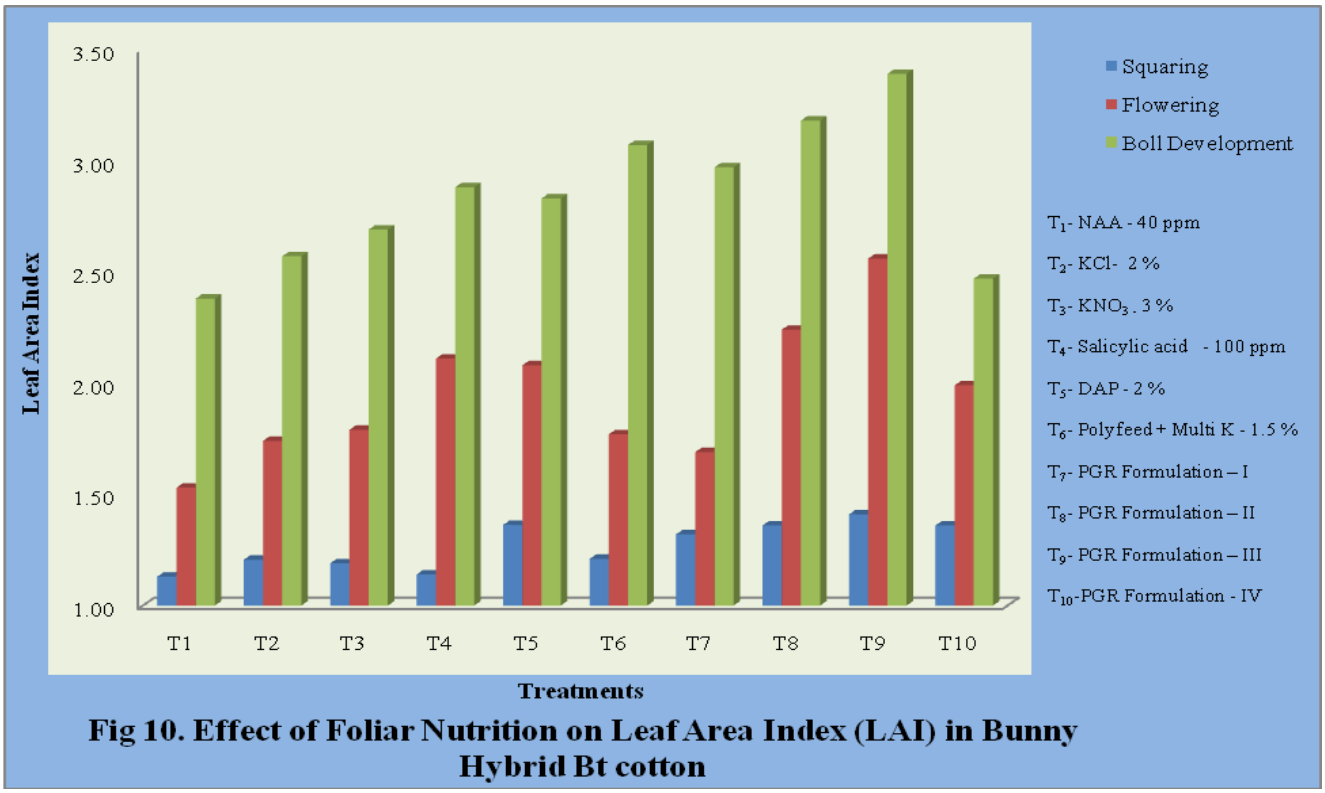


Fig 10. Effect of Foliar Nutrition on Leaf Area Index (LAI) in Bunny Hybrid Bt cotton

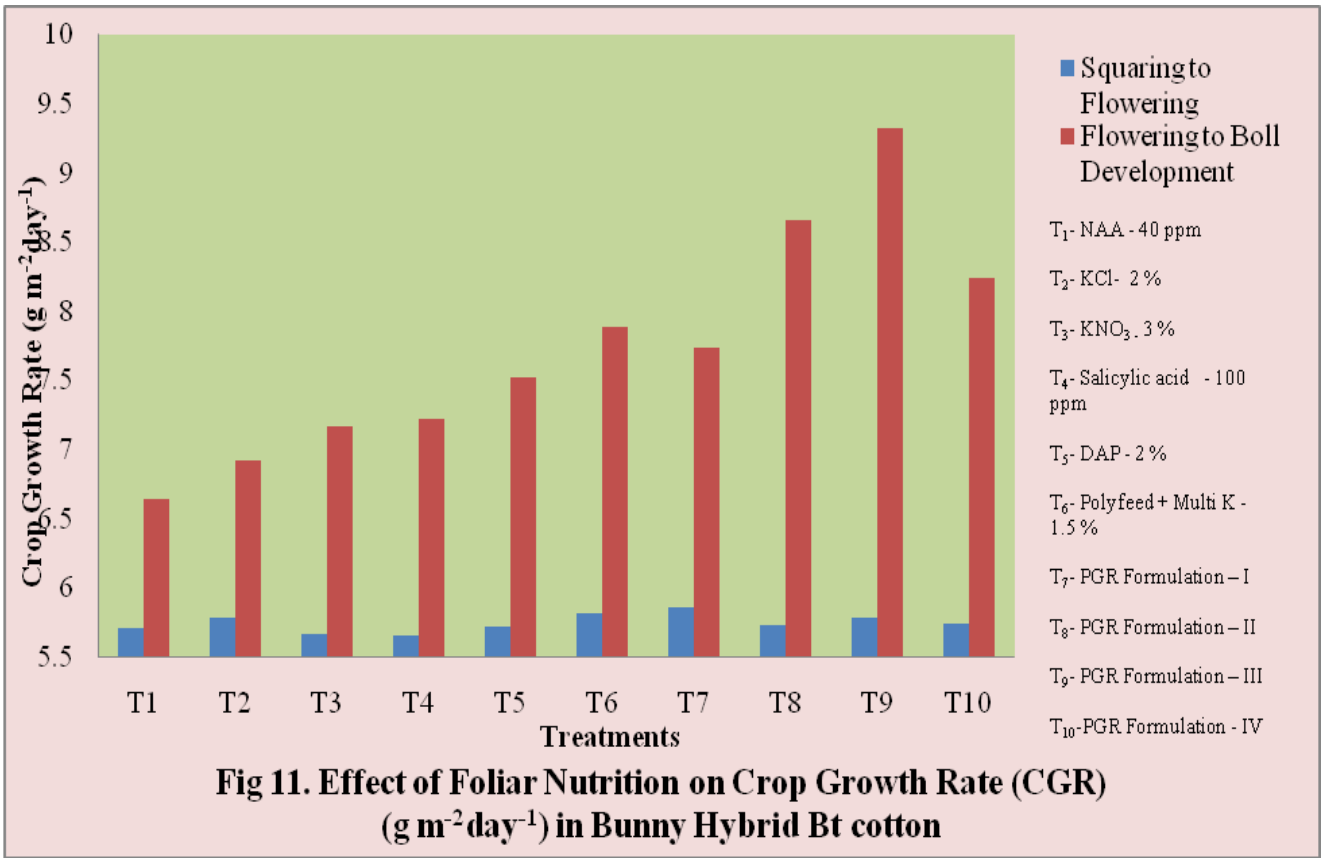


Fig 11. Effect of Foliar Nutrition on Crop Growth Rate (CGR) ($g\ m^{-2} day^{-1}$) in Bunny Hybrid Bt cotton

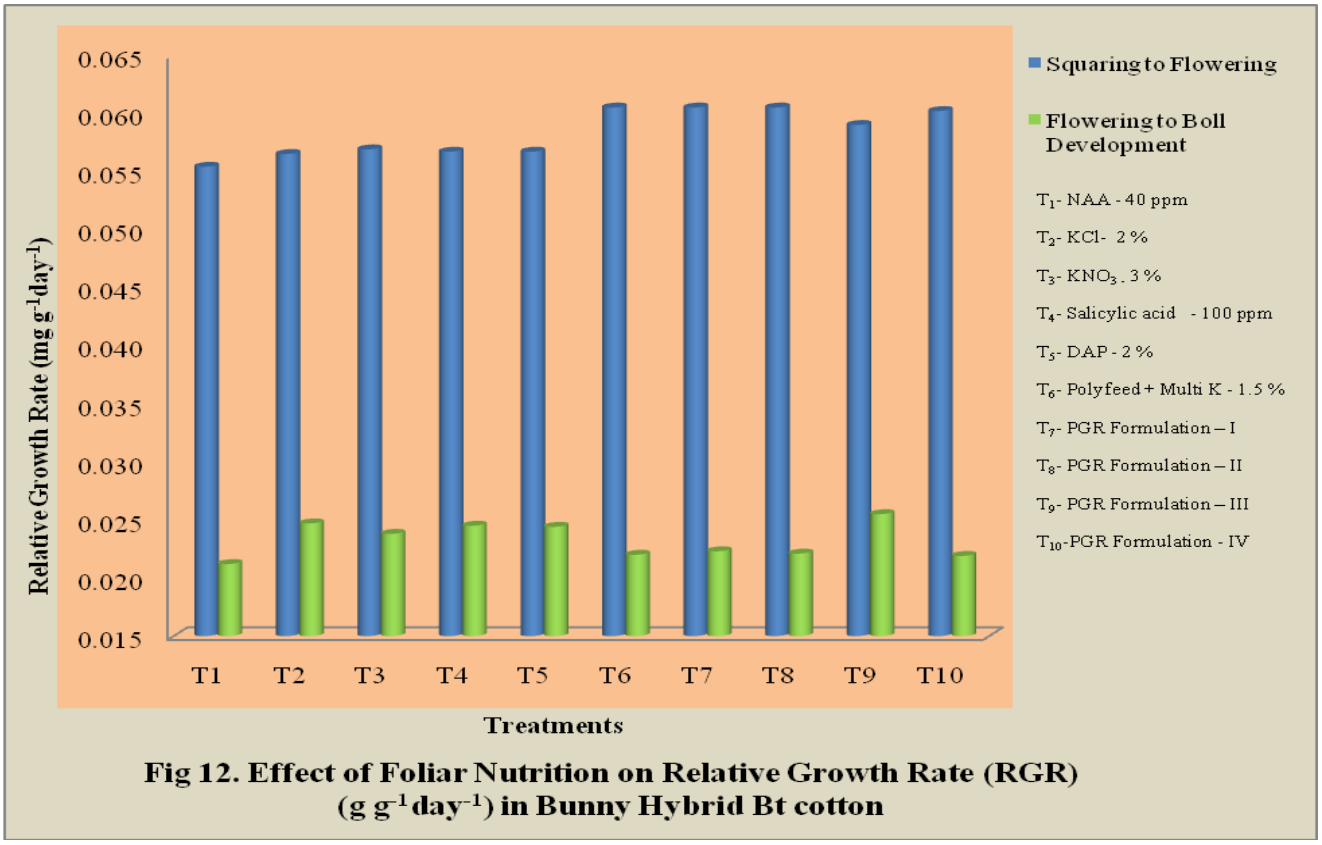


Fig 12. Effect of Foliar Nutrition on Relative Growth Rate (RGR) (g g^{-1}day^{-1}) in Bunny Hybrid Bt cotton

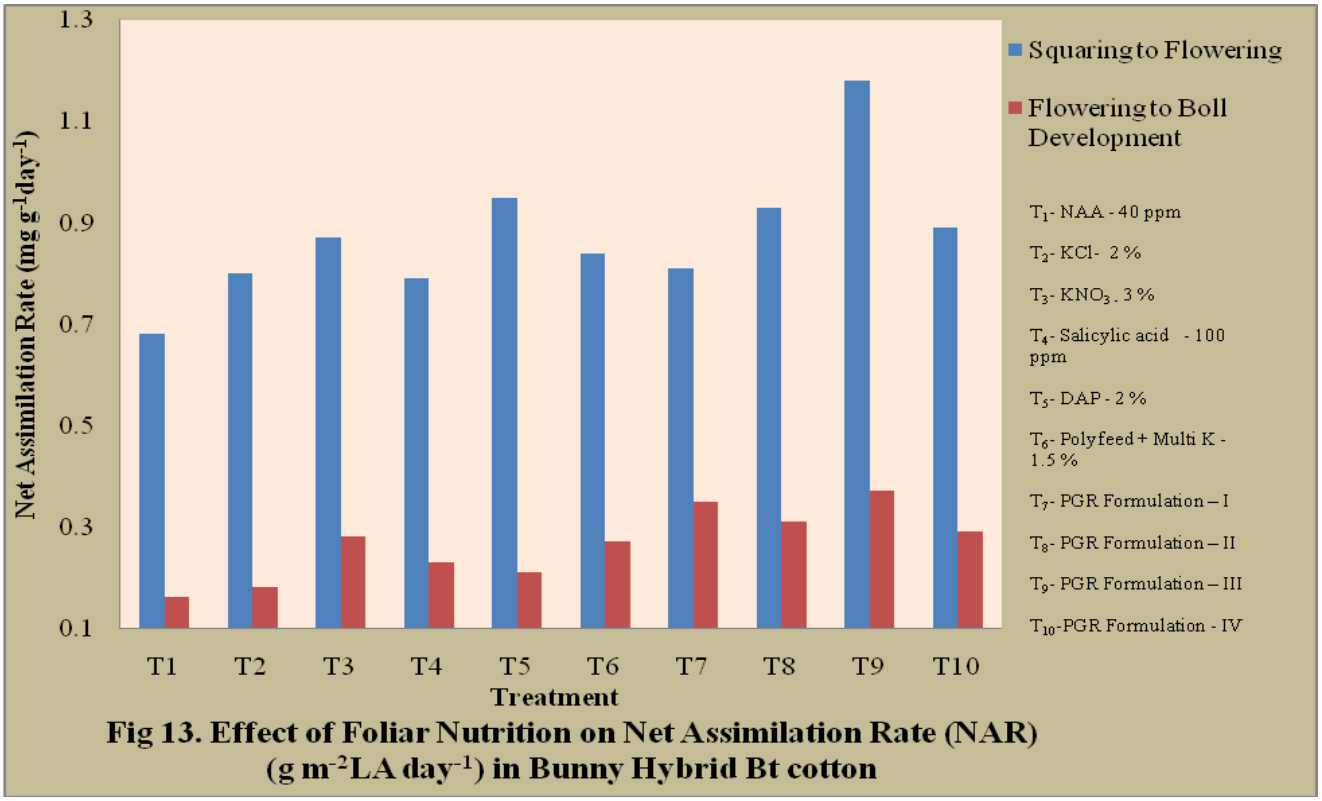


Fig 13. Effect of Foliar Nutrition on Net Assimilation Rate (NAR) (g m^{-2}LA day^{-1}) in Bunny Hybrid Bt cotton

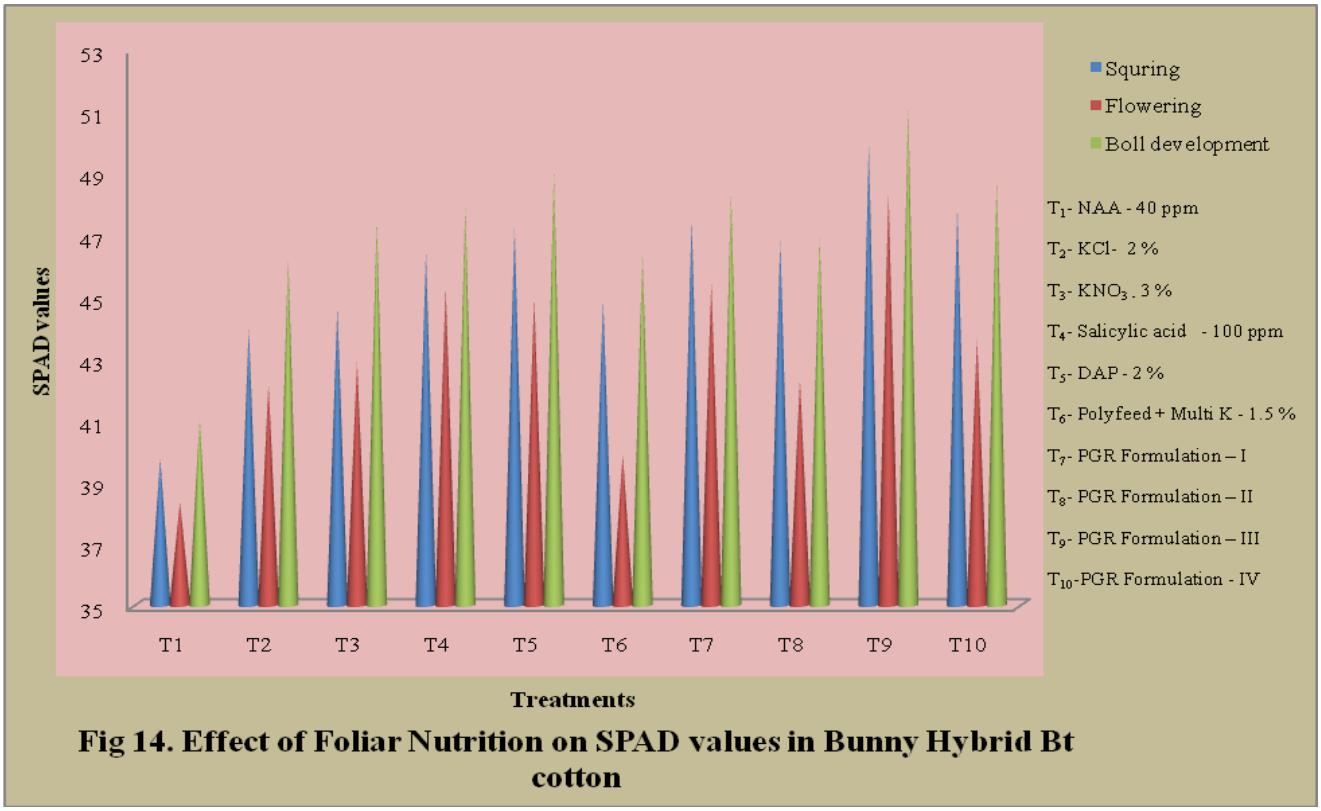


Fig 14. Effect of Foliar Nutrition on SPAD values in Bunny Hybrid Bt cotton

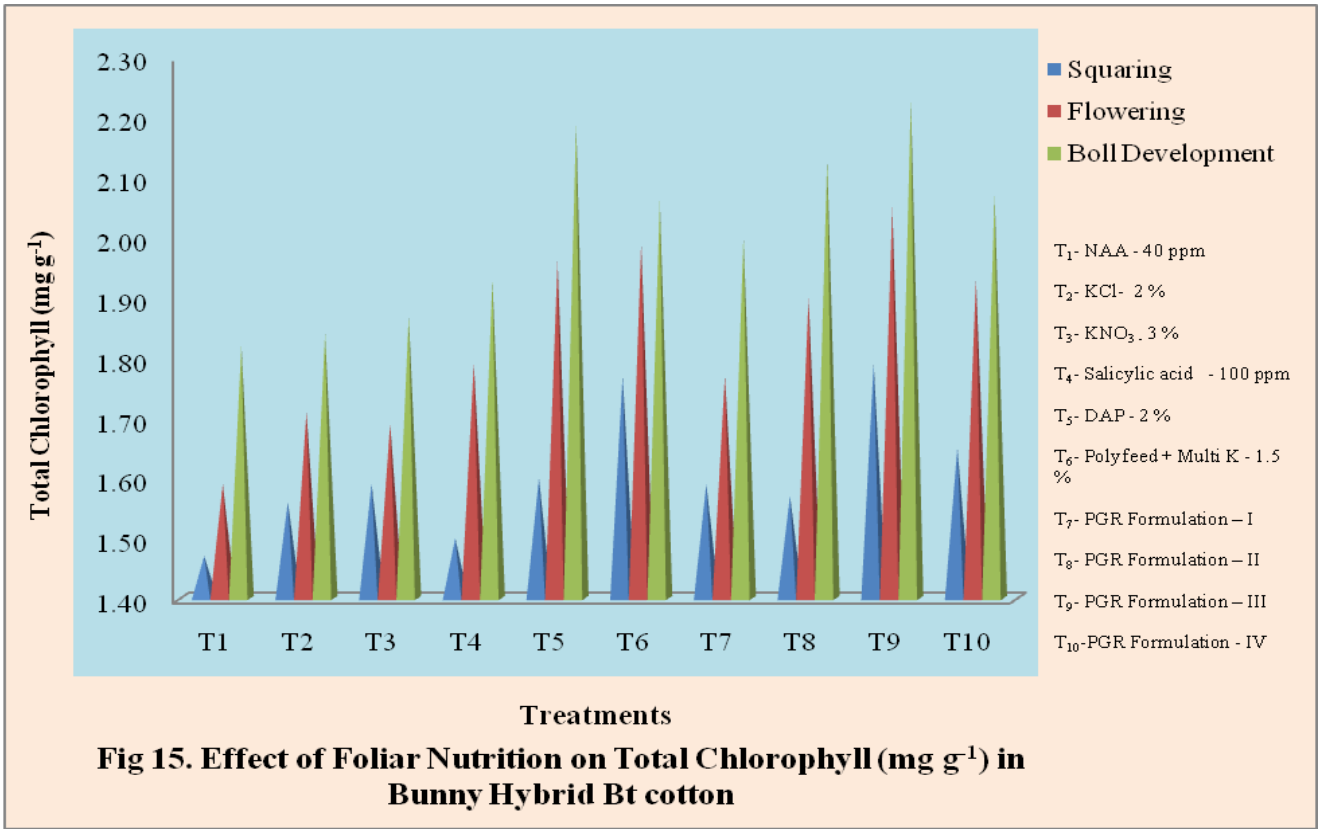


Fig 15. Effect of Foliar Nutrition on Total Chlorophyll (mg g^{-1}) in Bunny Hybrid Bt cotton

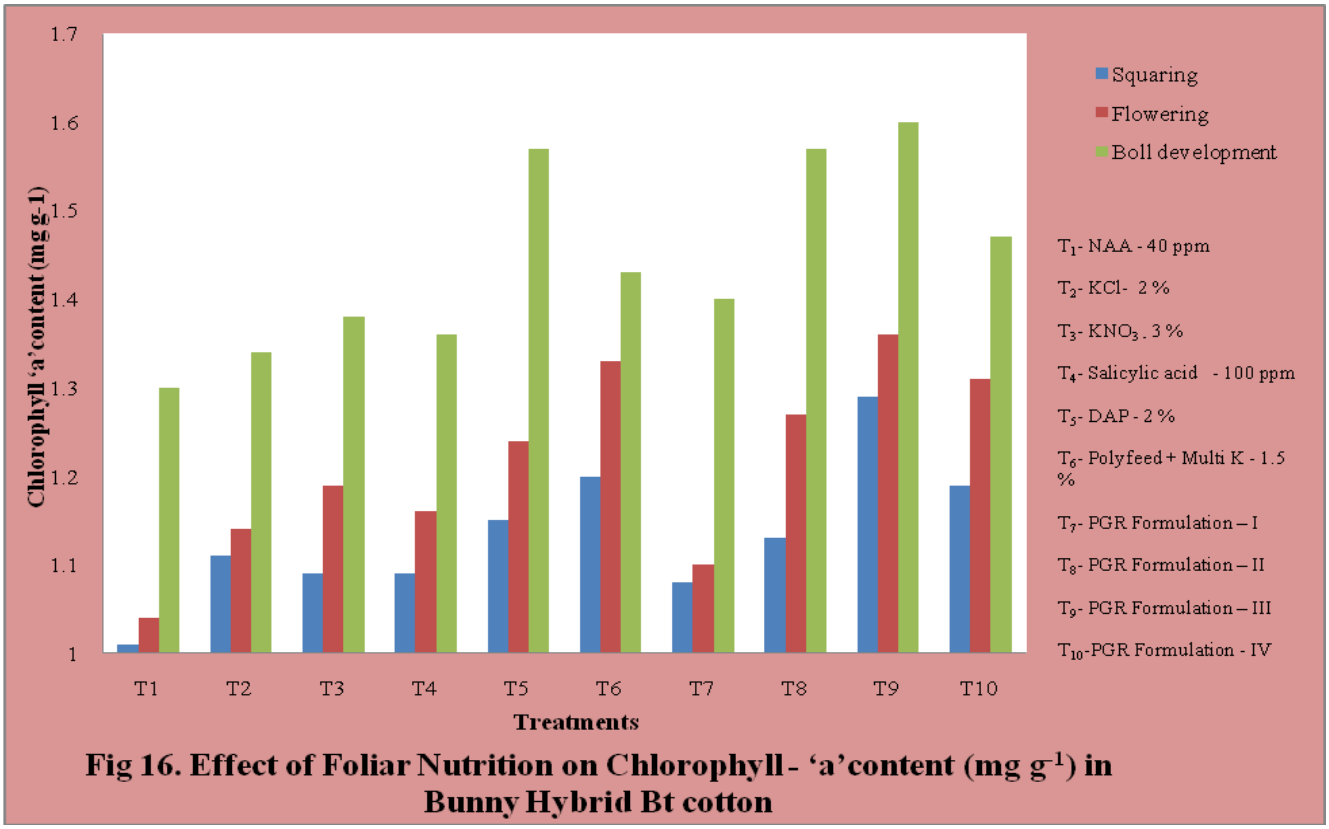


Fig 16. Effect of Foliar Nutrition on Chlorophyll - 'a' content (mg g^{-1}) in Bunny Hybrid Bt cotton

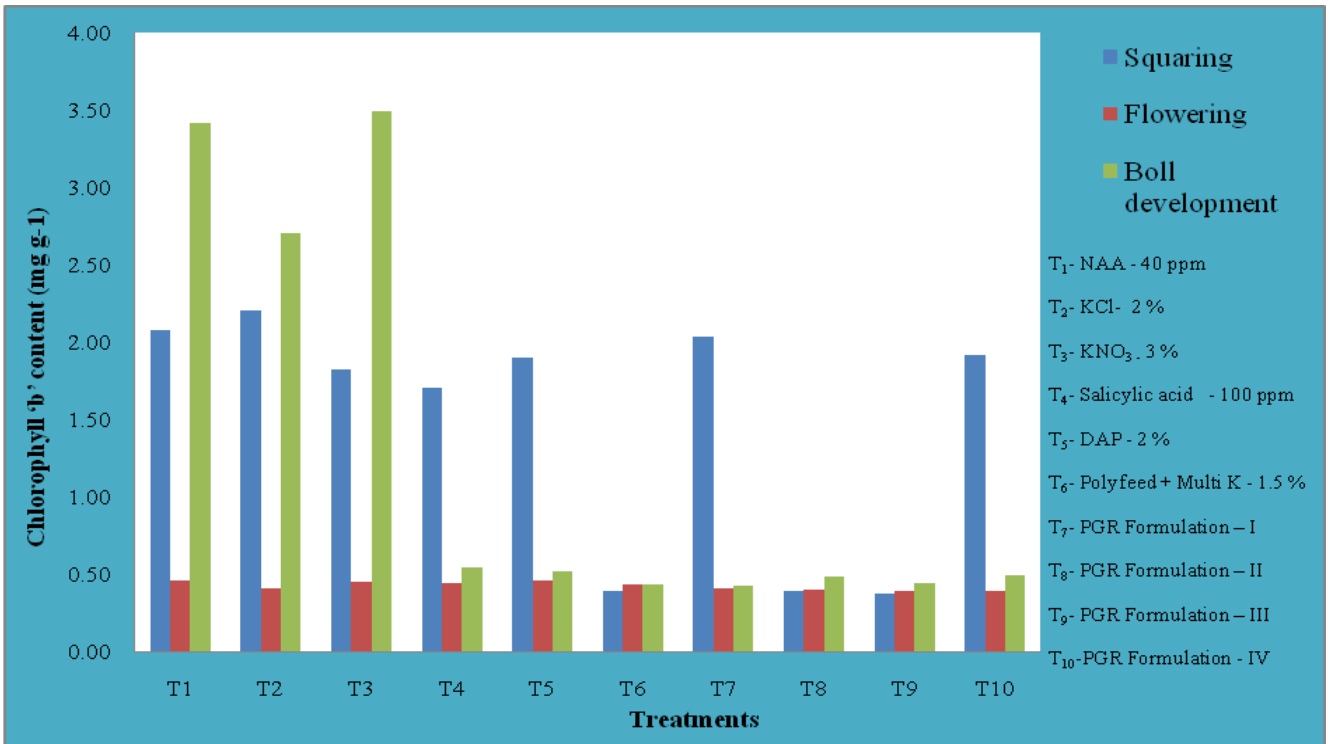


Fig 17. Effect of Foliar Nutrition on Chlorophyll 'b' content (mg g^{-1}) in Bunny Hybrid Bt cotton

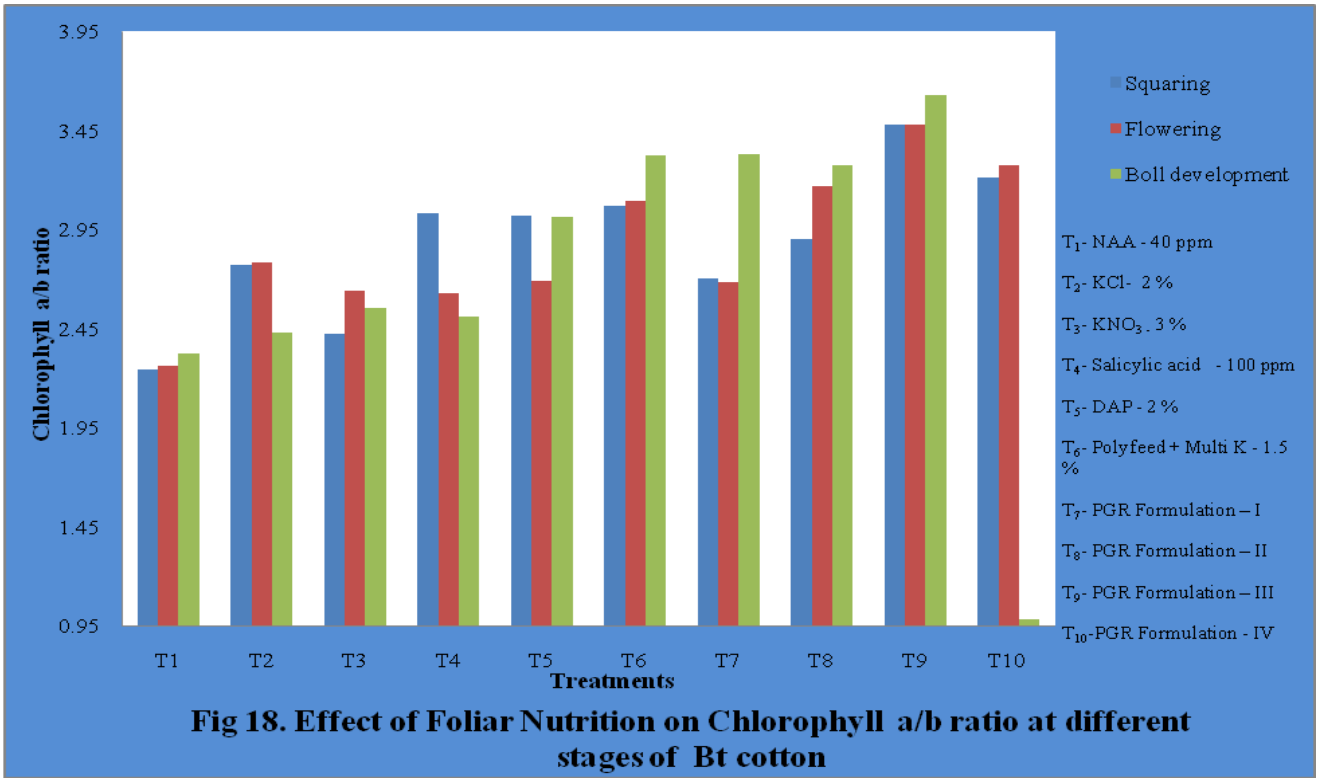


Fig 18. Effect of Foliar Nutrition on Chlorophyll a/b ratio at different stages of Bt cotton

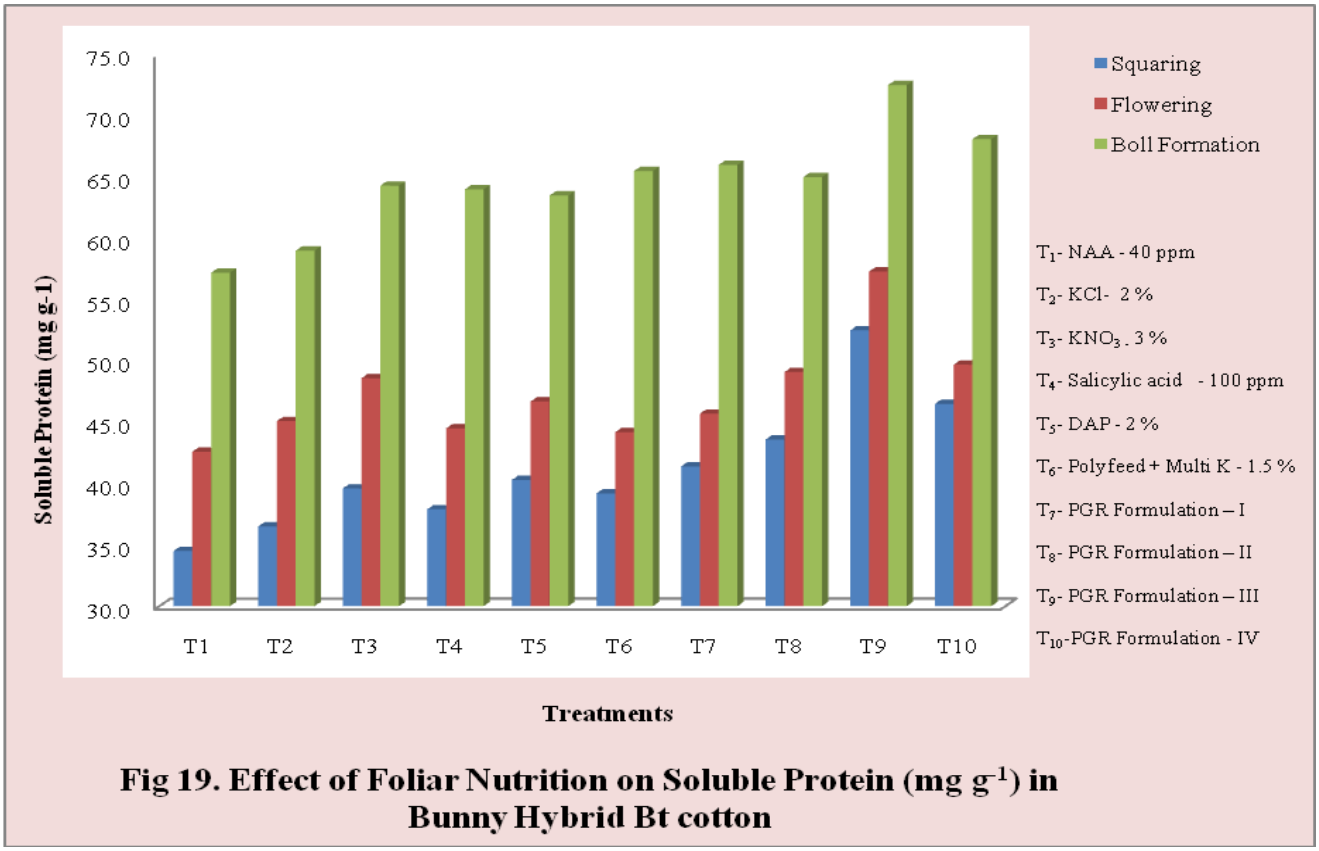


Fig 19. Effect of Foliar Nutrition on Soluble Protein (mg g^{-1}) in Bunny Hybrid Bt cotton

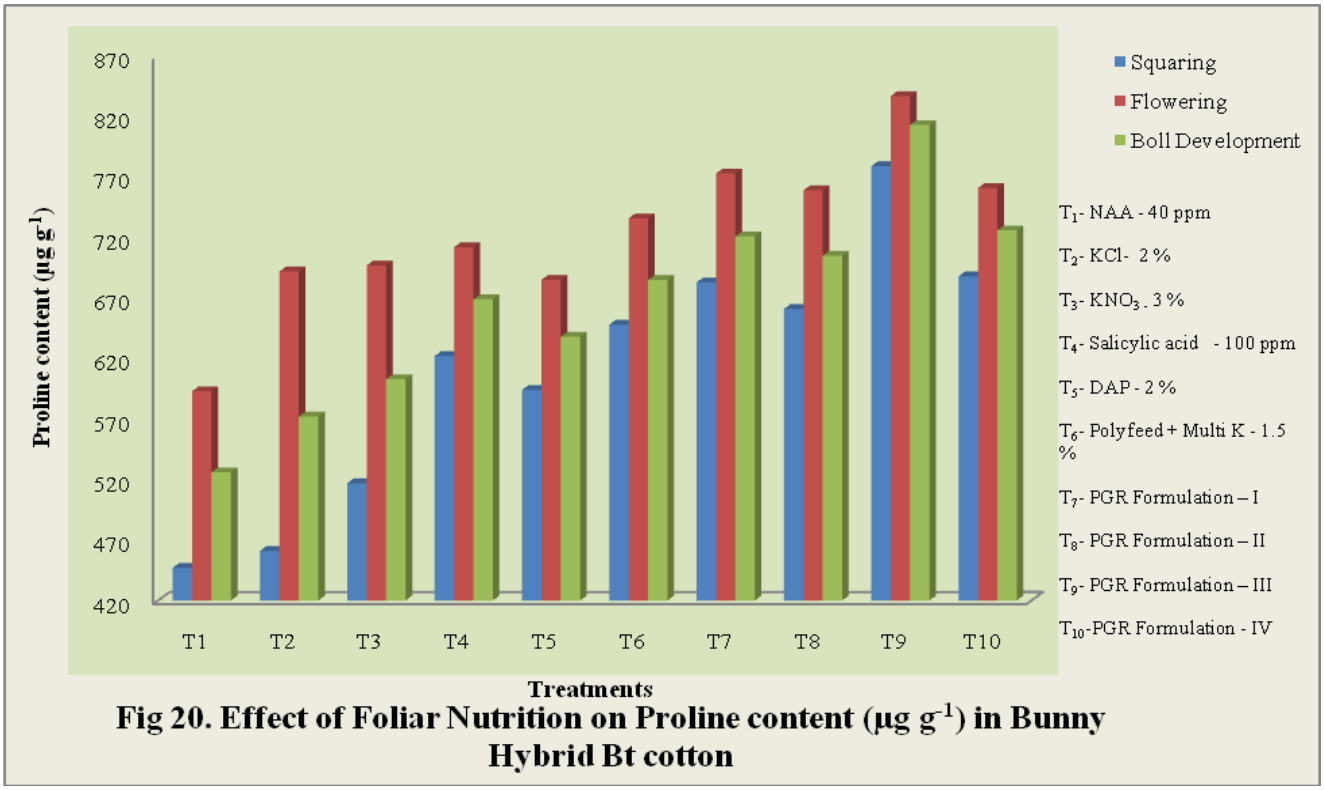


Fig 20. Effect of Foliar Nutrition on Proline content (µg g^{-1}) in Bunny Hybrid Bt cotton

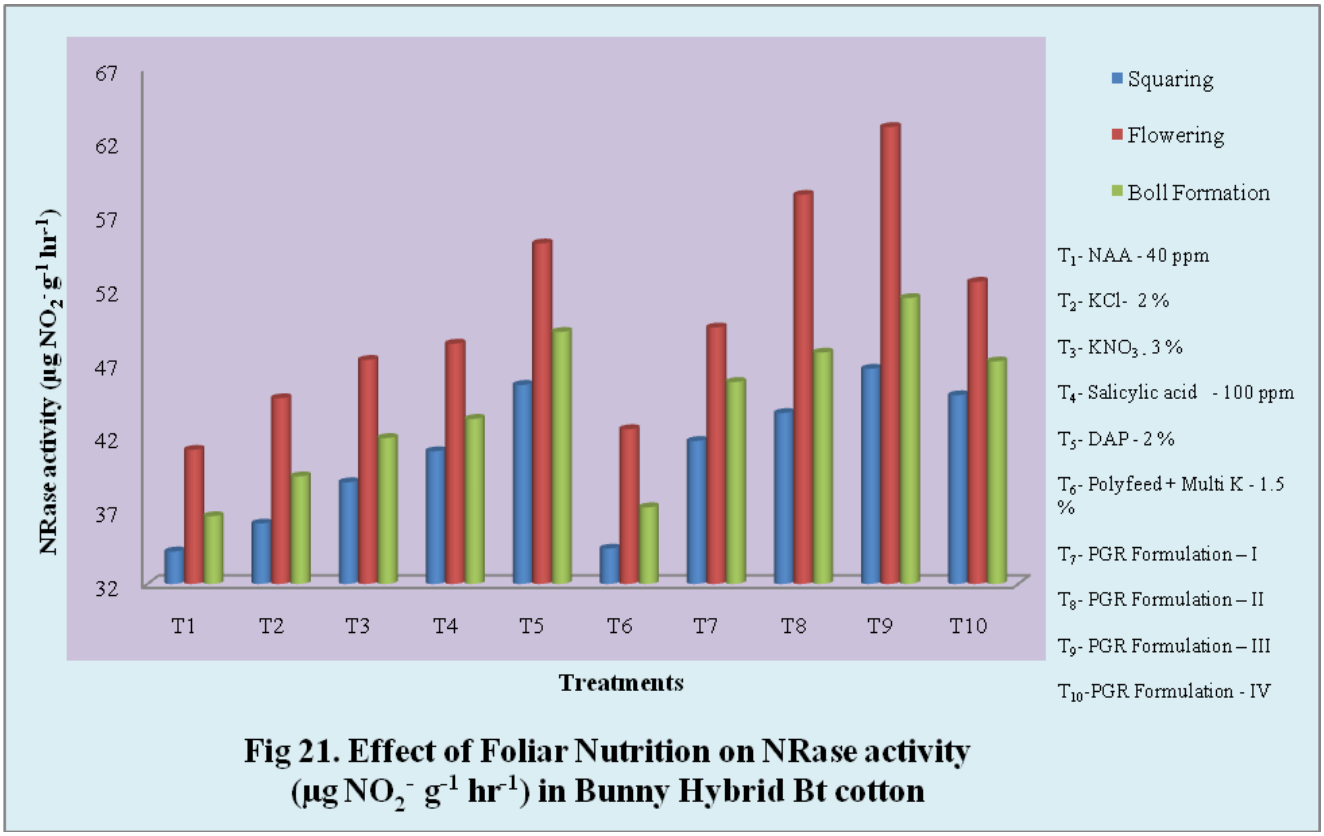


Fig 21. Effect of Foliar Nutrition on NRase activity (µg NO_2^- g^{-1} hr^{-1}) in Bunny Hybrid Bt cotton

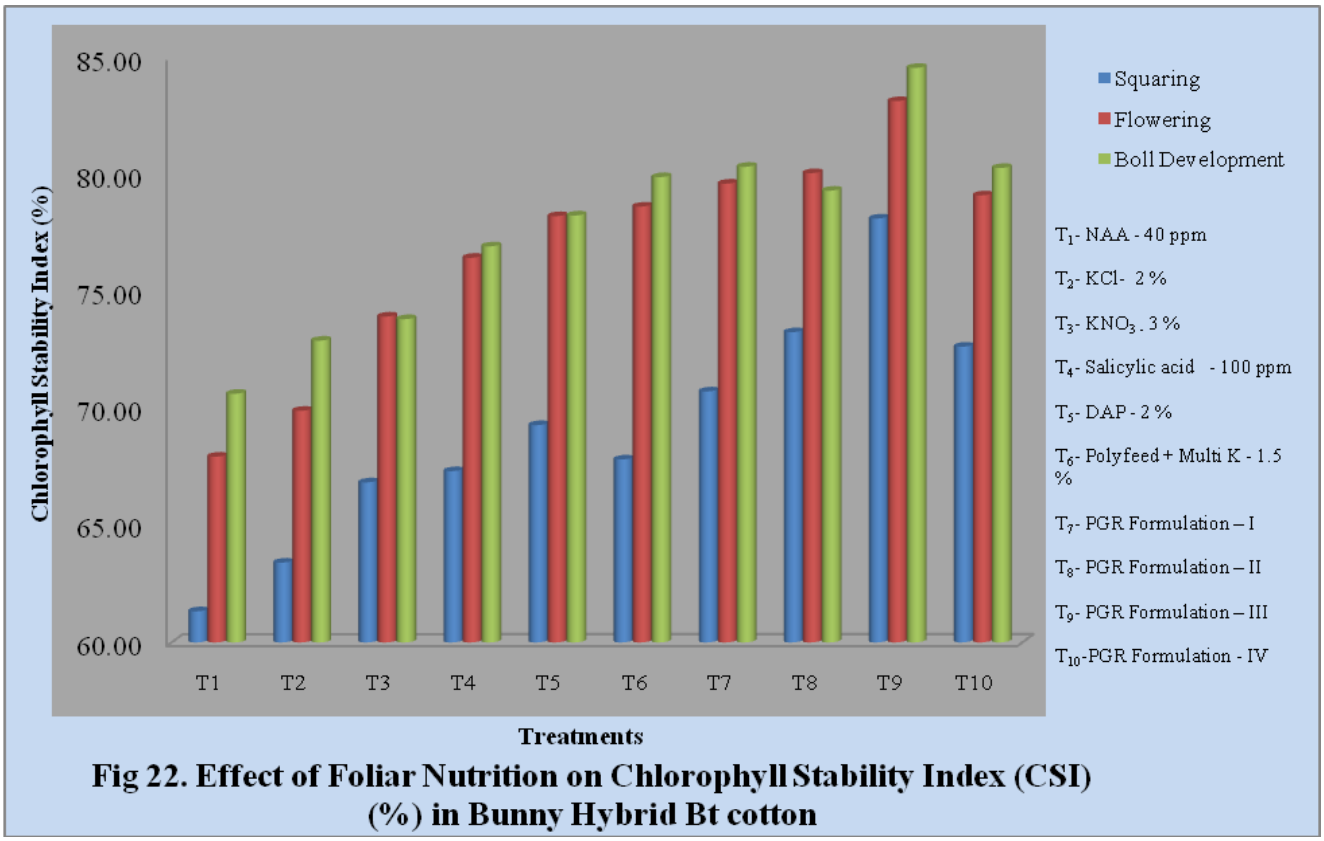


Fig 22. Effect of Foliar Nutrition on Chlorophyll Stability Index (CSI) (%) in Bunny Hybrid Bt cotton

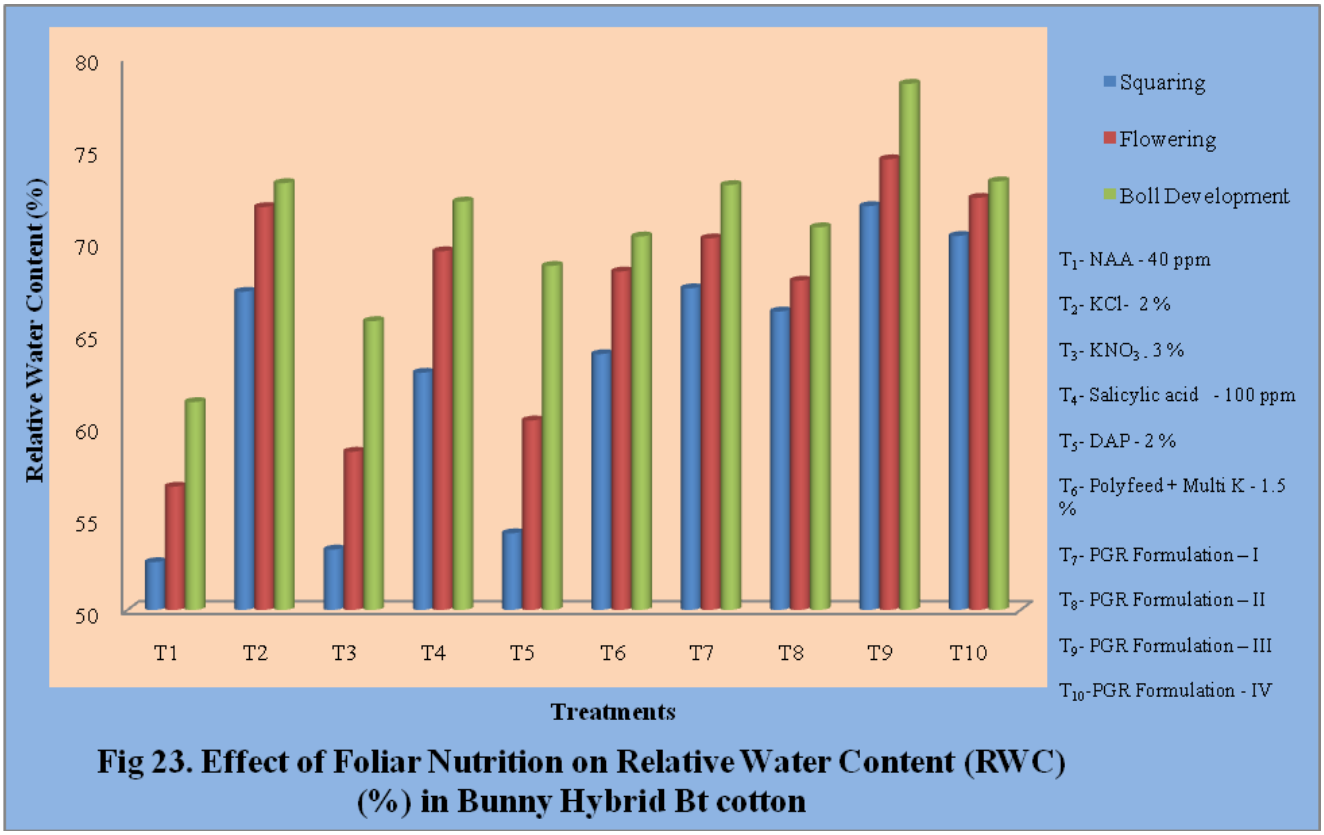


Fig 23. Effect of Foliar Nutrition on Relative Water Content (RWC) (%) in Bunny Hybrid Bt cotton

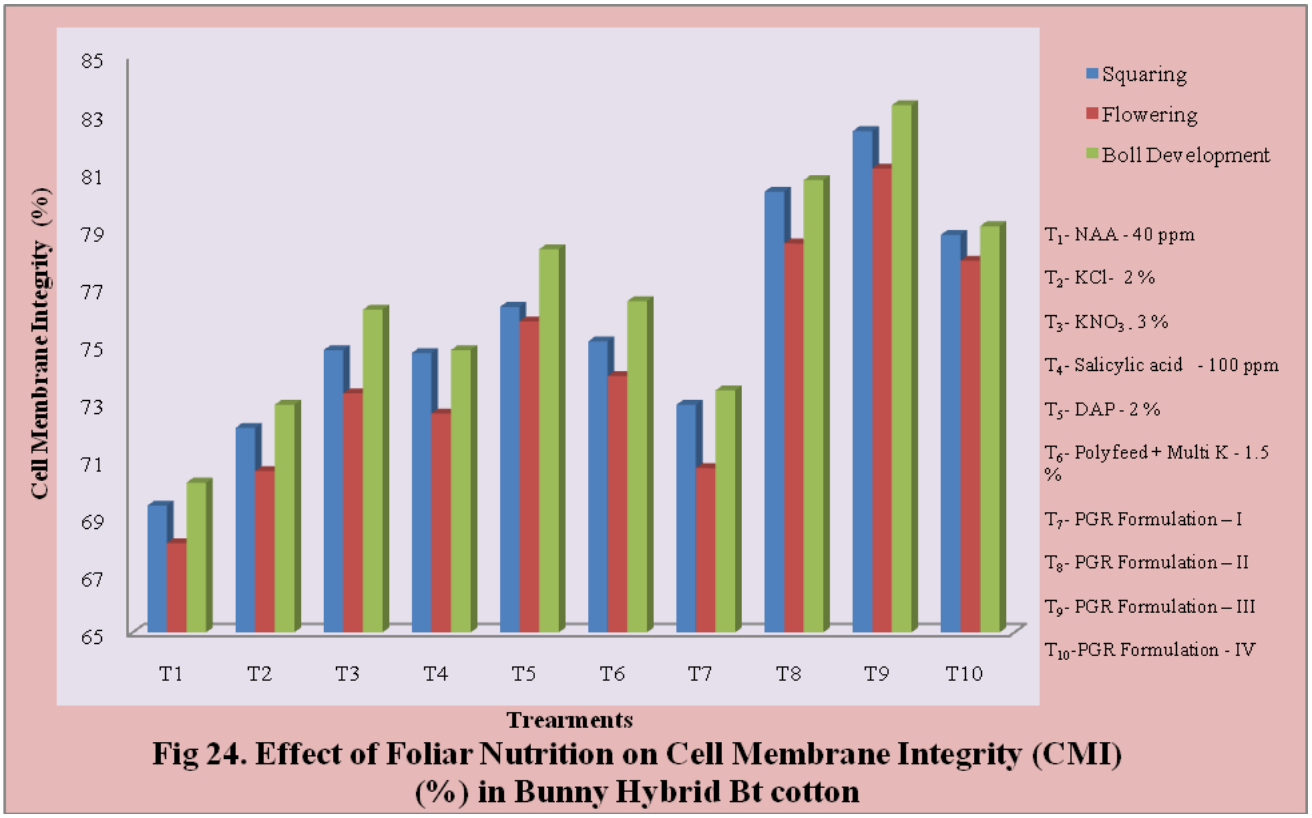


Fig 24. Effect of Foliar Nutrition on Cell Membrane Integrity (CMI) (%) in Bunny Hybrid Bt cotton

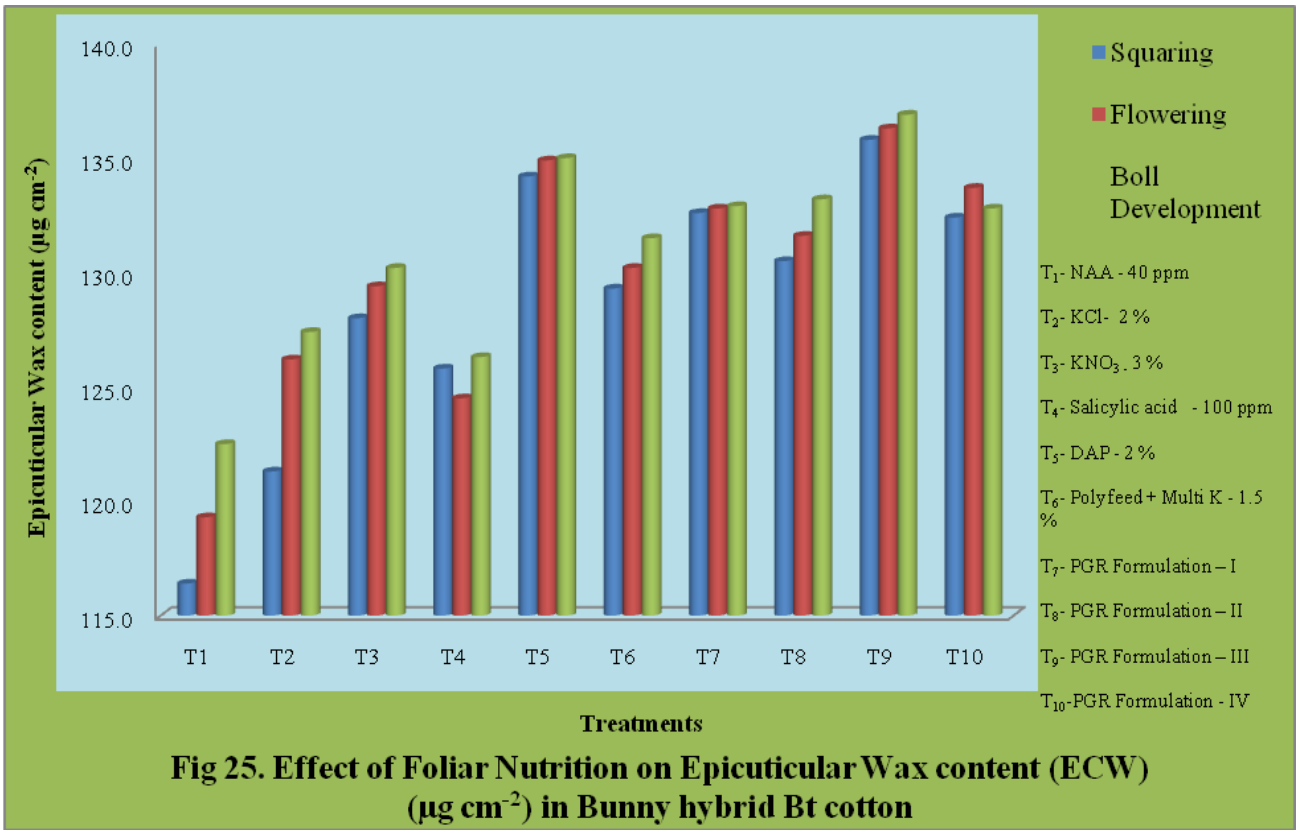


Fig 25. Effect of Foliar Nutrition on Epicuticular Wax content (ECW) (µg cm^{-2}) in Bunny hybrid Bt cotton

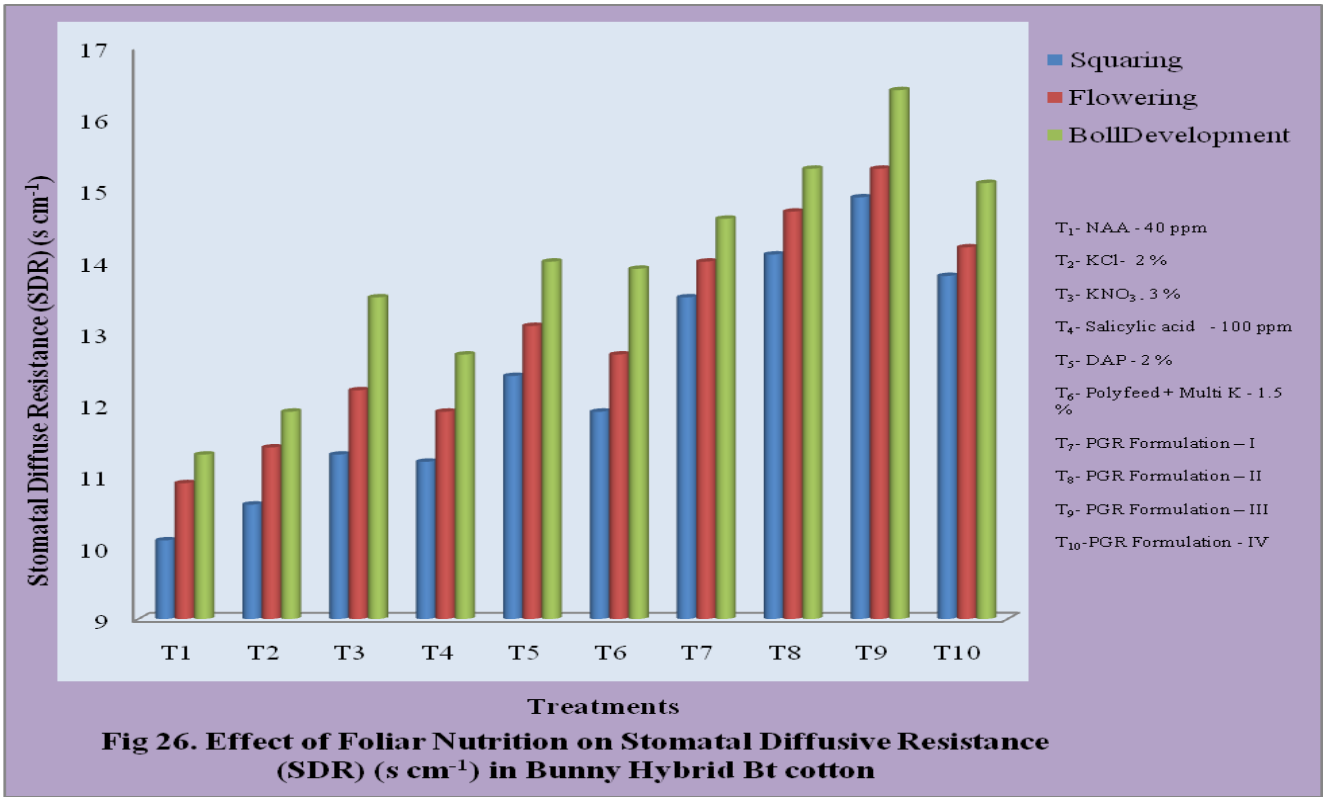


Fig 26. Effect of Foliar Nutrition on Stomatal Diffusive Resistance (SDR) (s cm^{-1}) in Bunny Hybrid Bt cotton

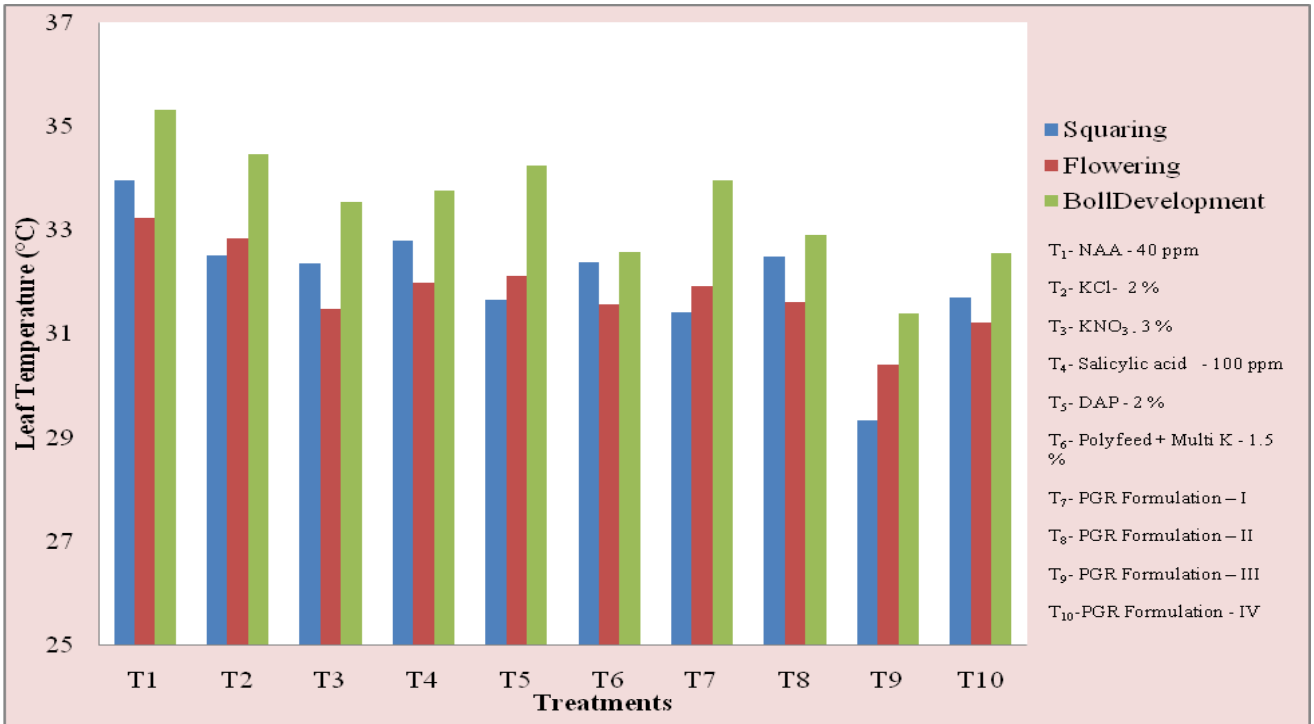


Fig 27. Effect of Foliar Nutrition on Leaf Temperature (°C) in Bunny Hybrid Bt cotton

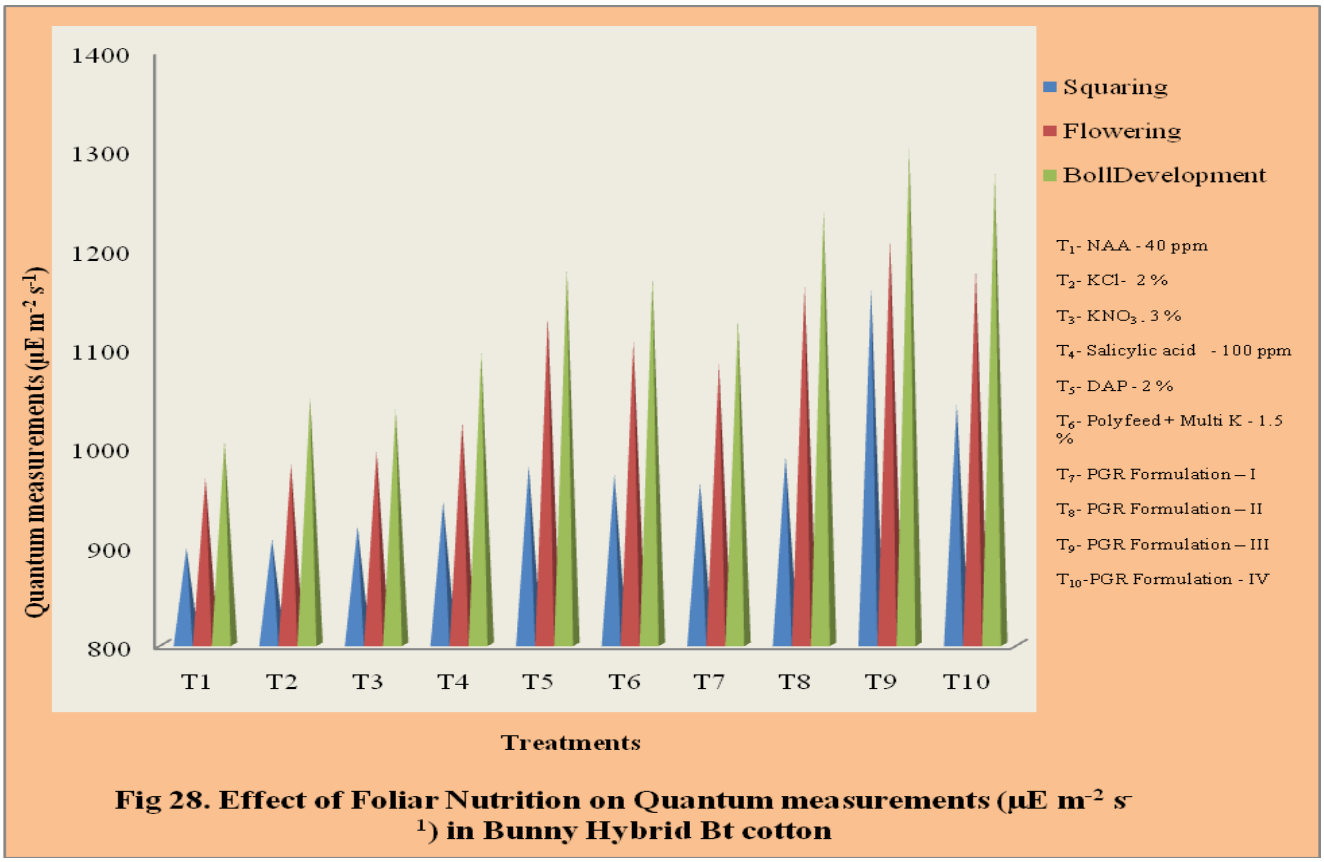


Fig 28. Effect of Foliar Nutrition on Quantum measurements (µE m^{-2} s^{-1}) in Bunny Hybrid Bt cotton

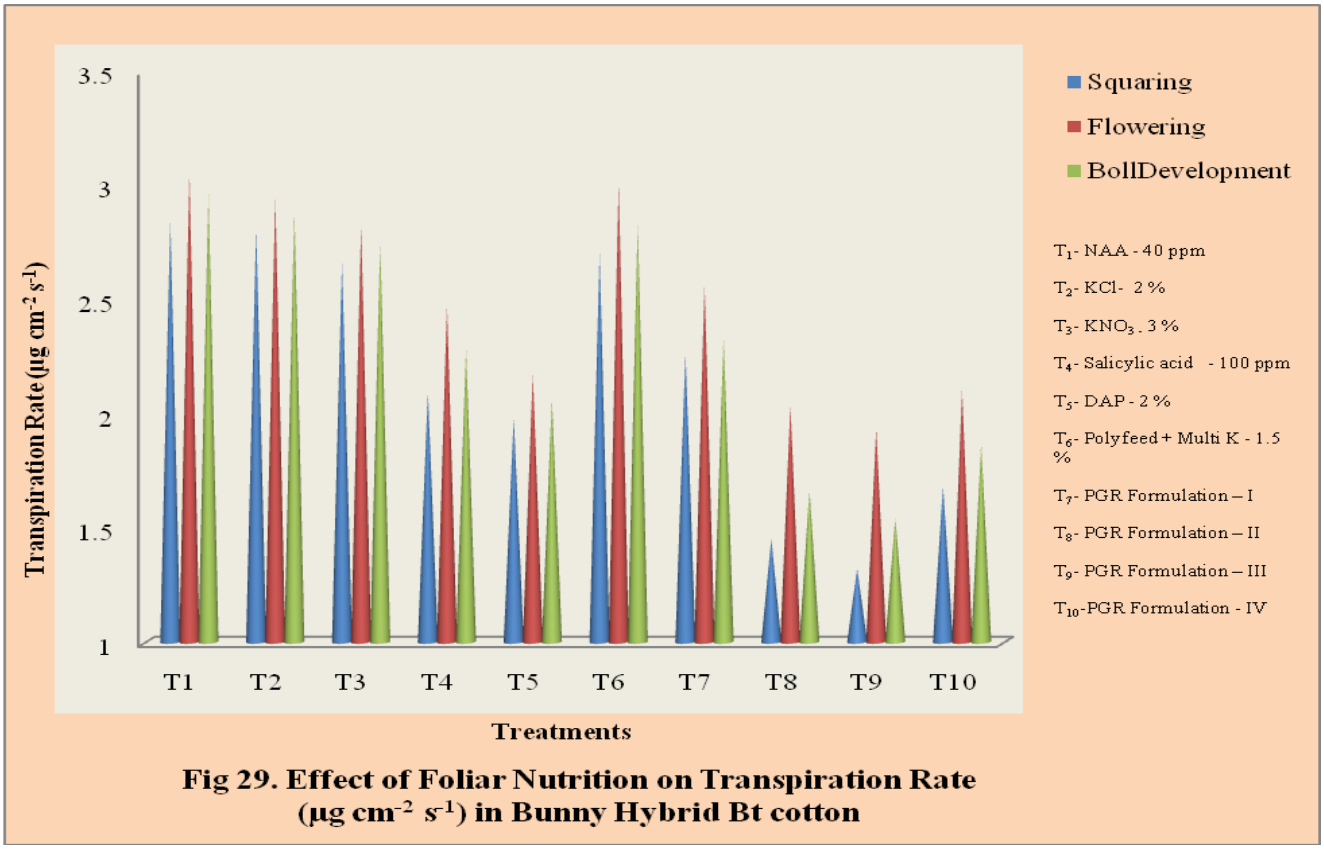
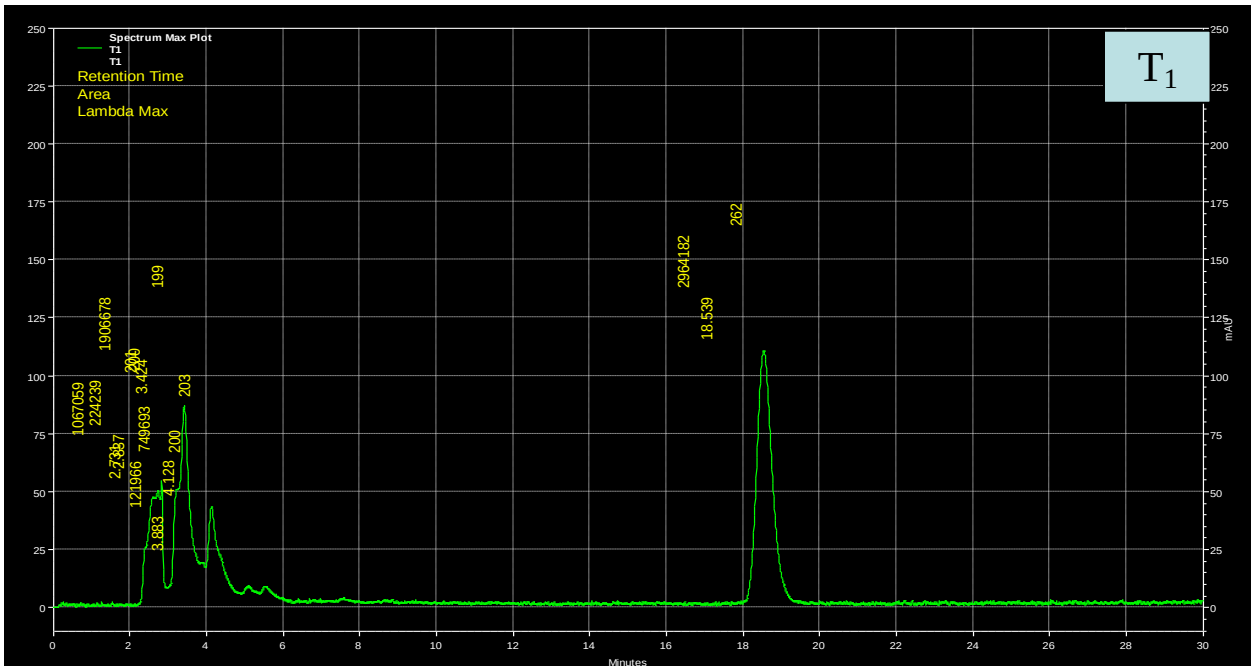
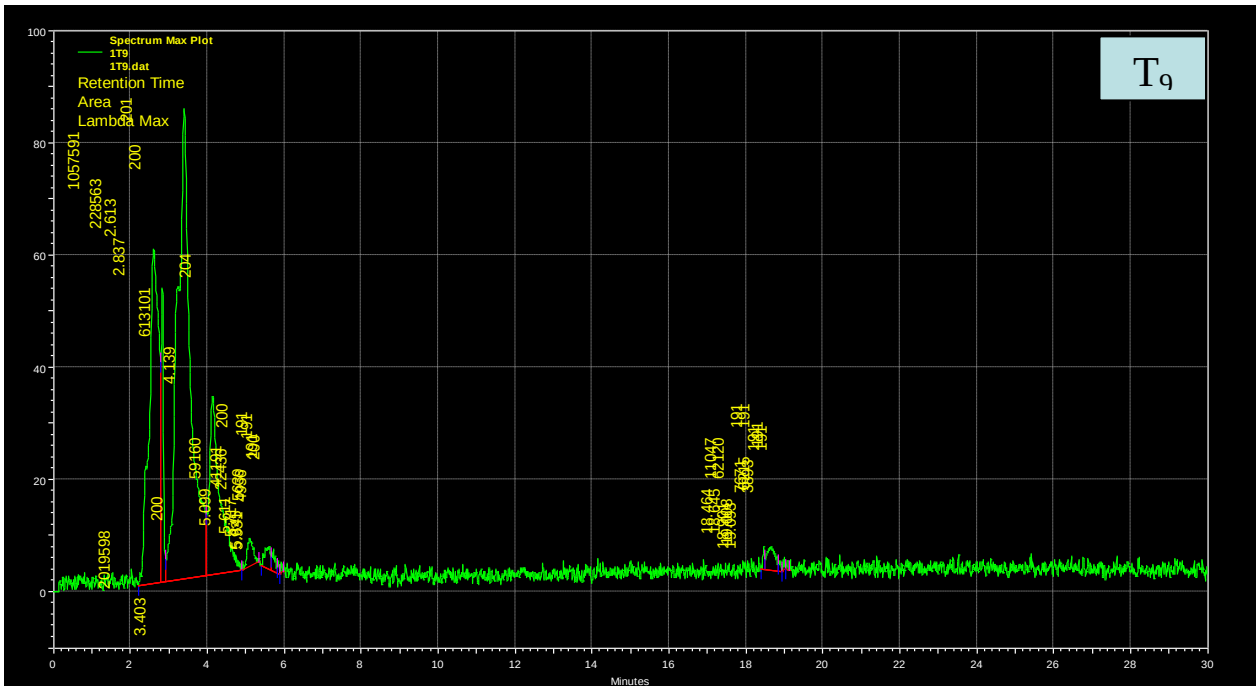


Fig 29. Effect of Foliar Nutrition on Transpiration Rate (µg cm^{-2} s^{-1}) in Bunny Hybrid Bt cotton

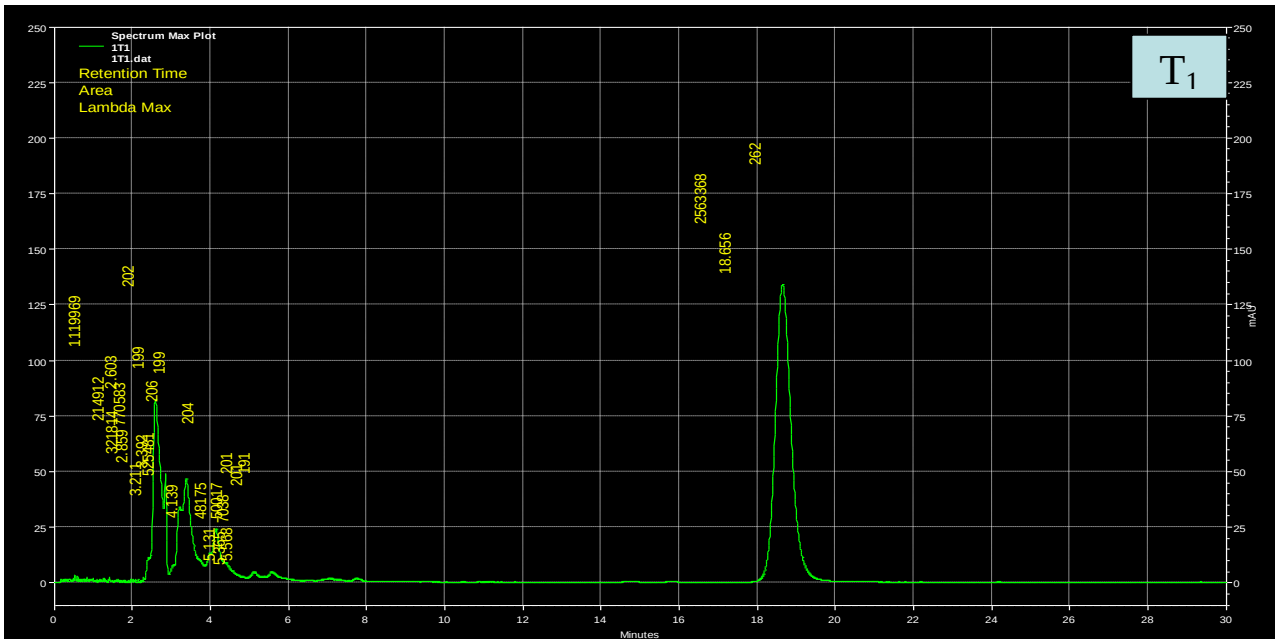


T1- NAA @ 40 ppm

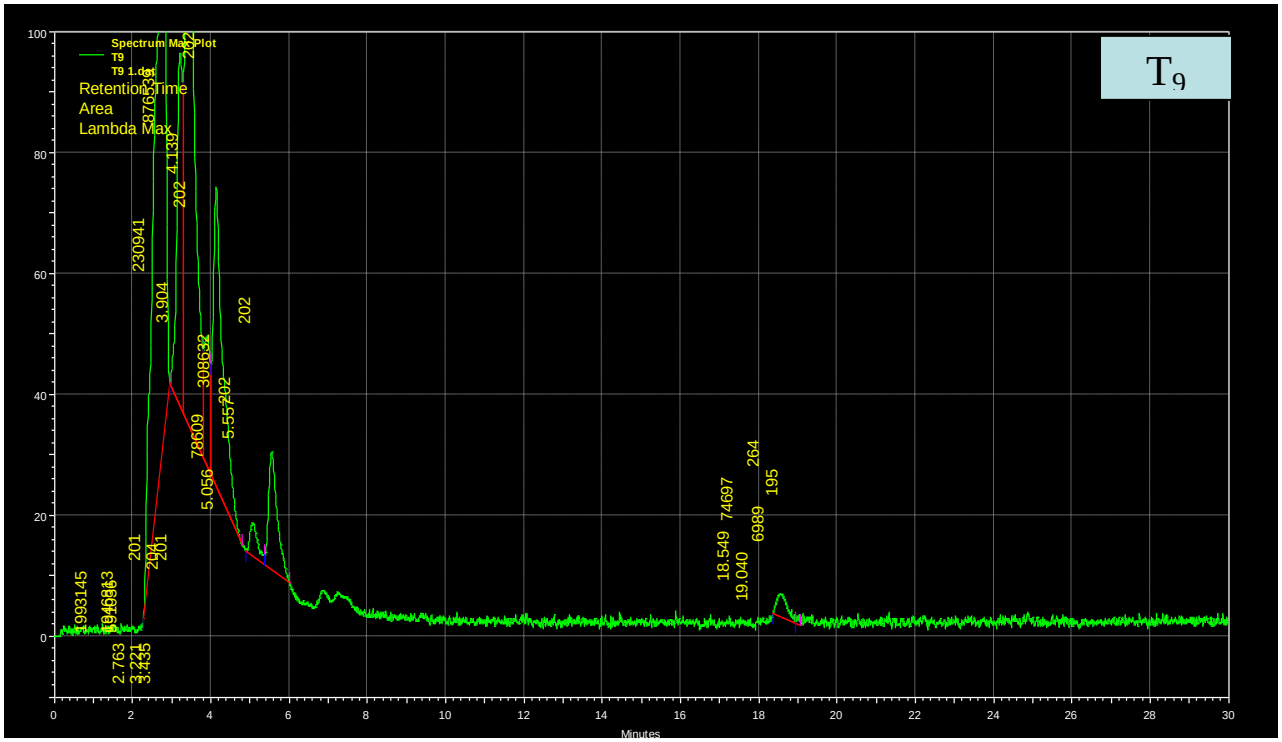


T9- PGR consortia (Formulation-III)

Fig 30(a). Effect of Foliar Nutrition on ABA (ppm) at Boll development stage in Bunny hybrid Bt cotton

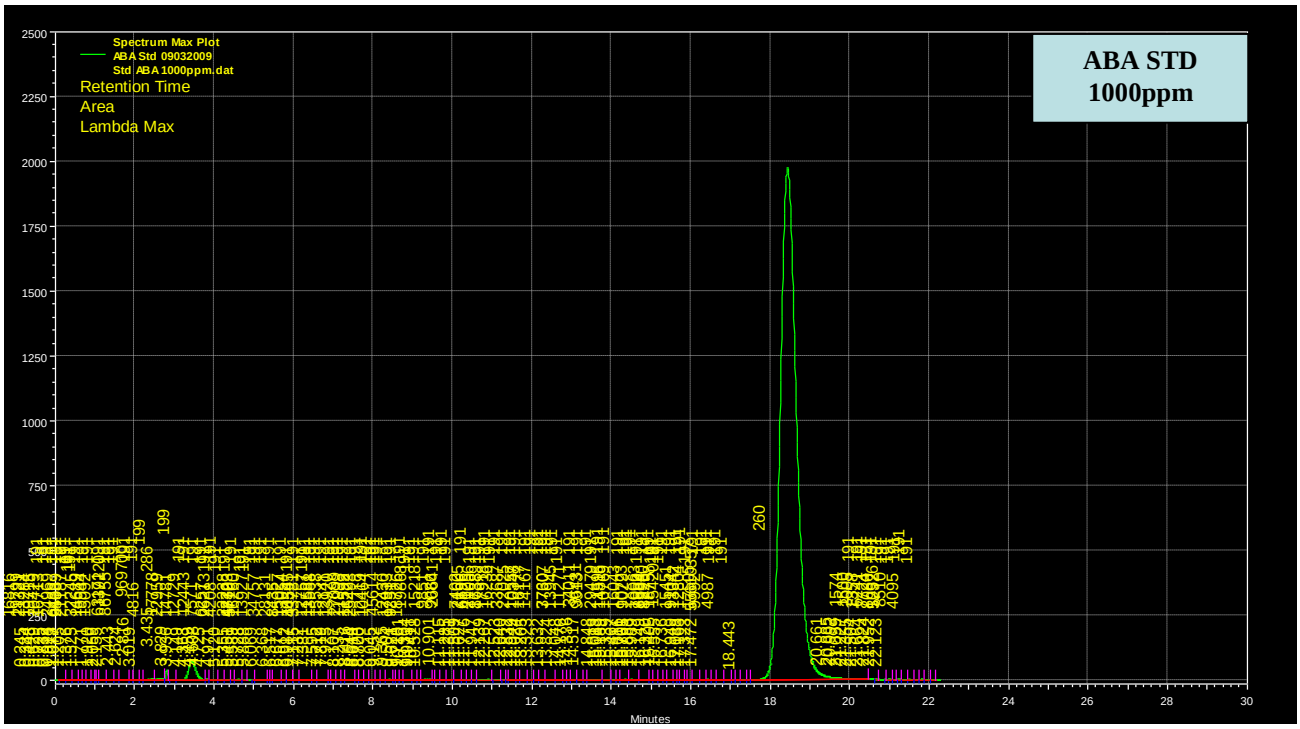


T1- NAA @ 40 ppm

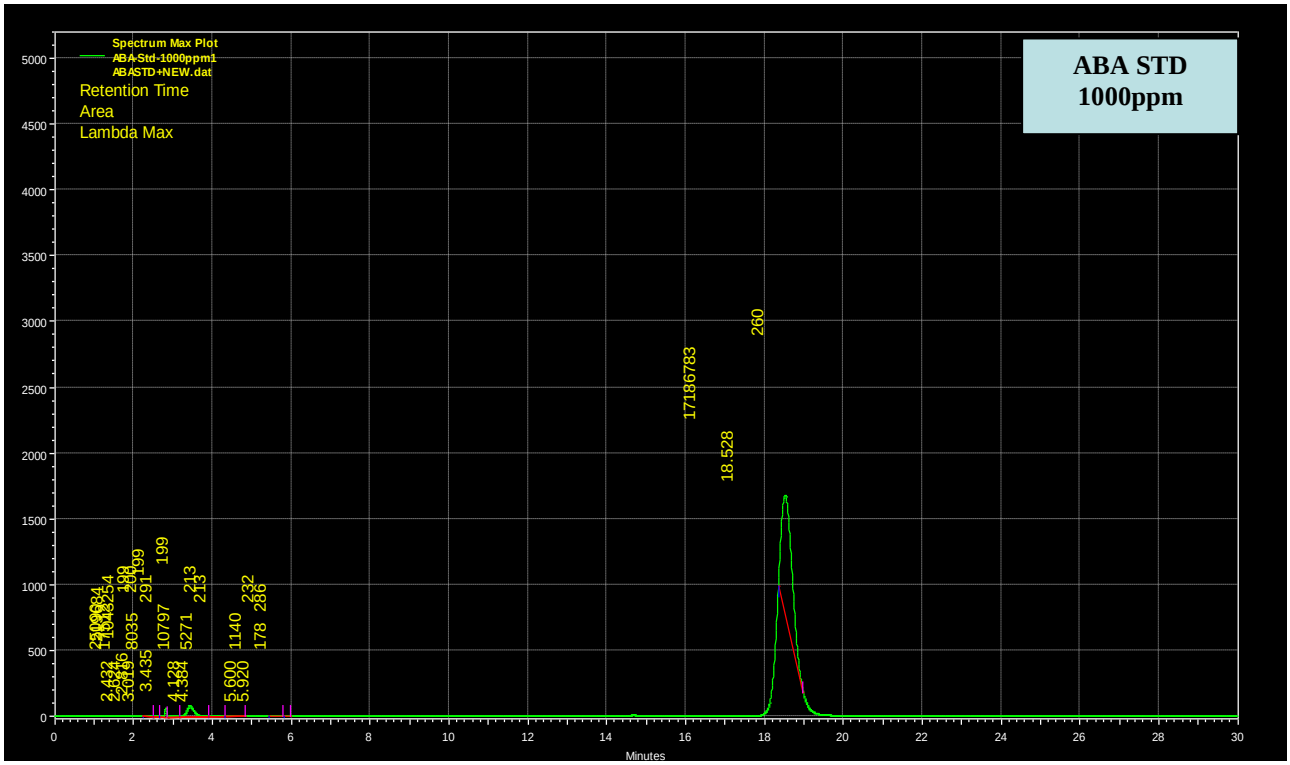


T9- PGR consortia (Formulation-III)

Fig 30(b) Effect of Foliar Nutrition on ABA (ppm) at Harvest stage in Bunny hybrid Bt cotton



(i) Boll development stage



(ii) Harvest stage

Fig 30(c) ABA Standard (1000ppm)

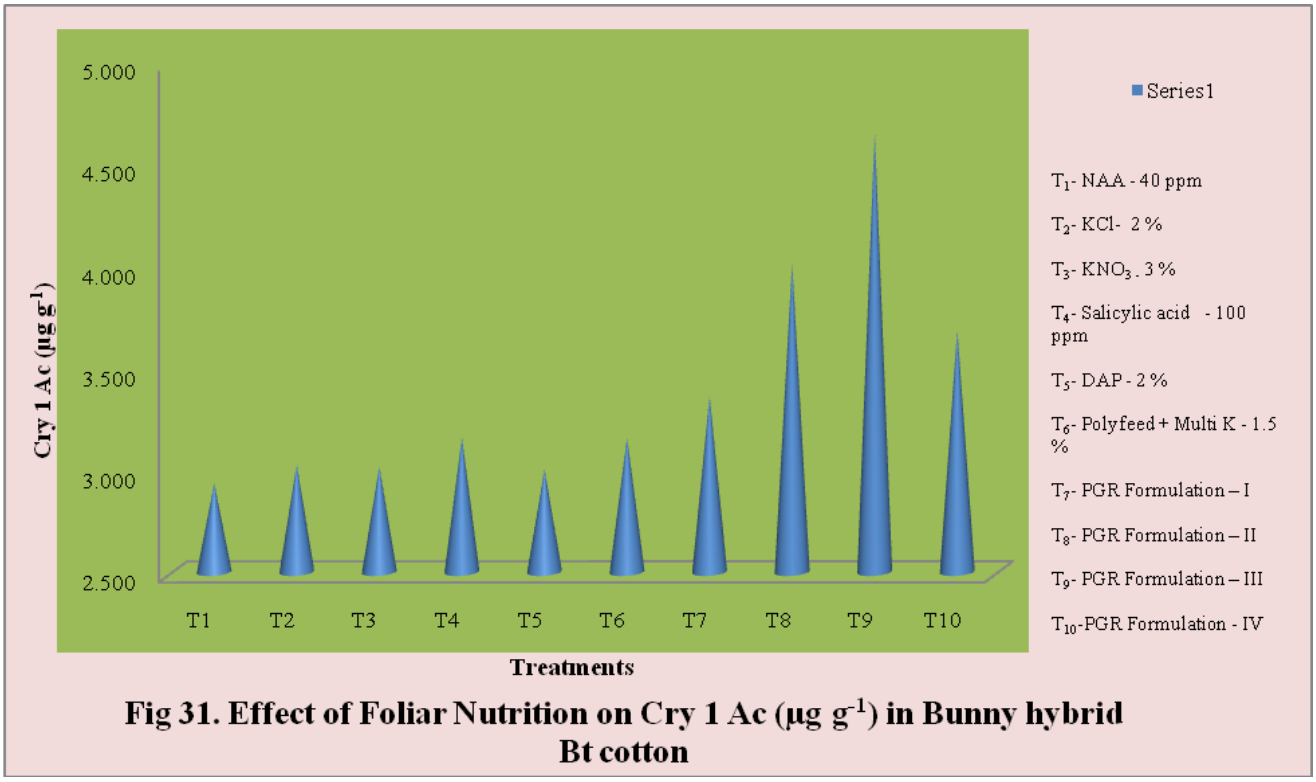


Fig 31. Effect of Foliar Nutrition on Cry 1 Ac (µg g^{-1}) in Bunny hybrid Bt cotton

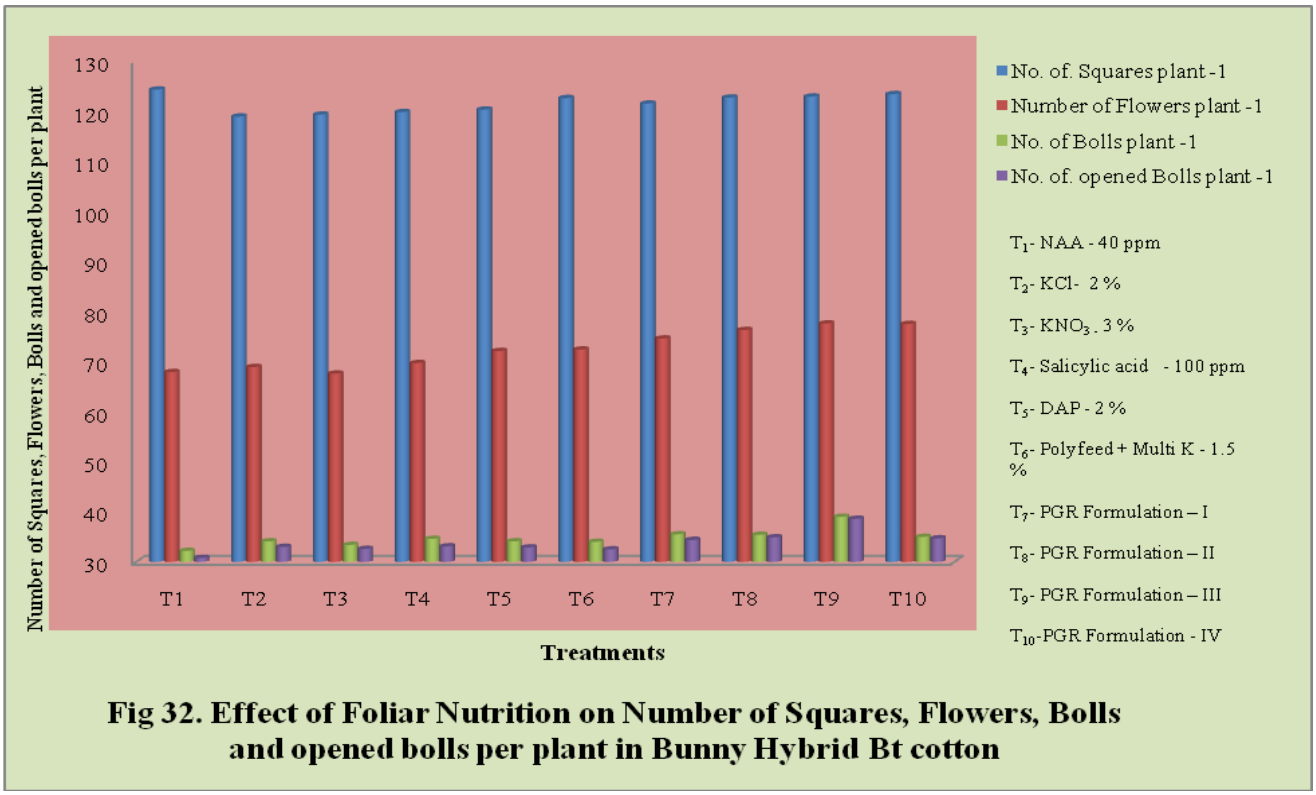


Fig 32. Effect of Foliar Nutrition on Number of Squares, Flowers, Bolls and opened bolls per plant in Bunny Hybrid Bt cotton

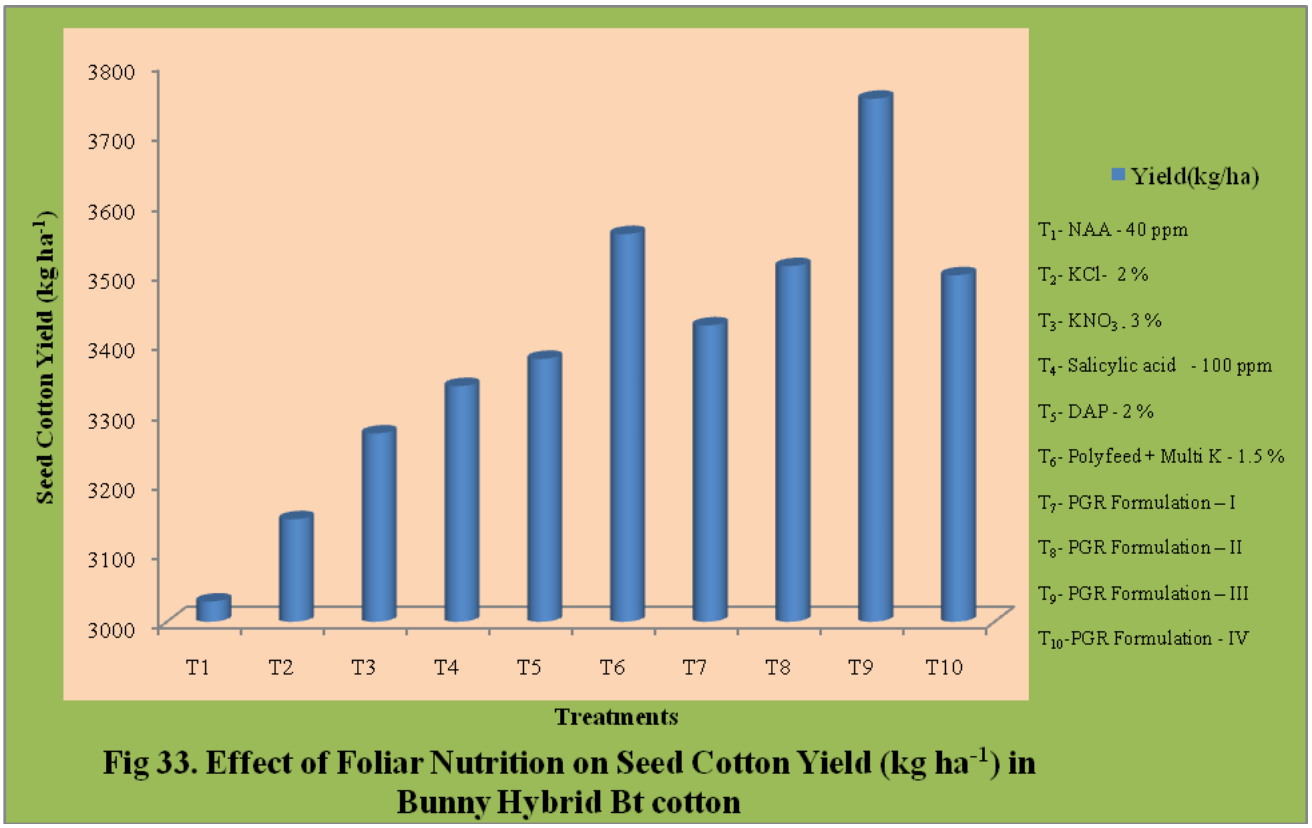


Fig 33. Effect of Foliar Nutrition on Seed Cotton Yield (kg ha^{-1}) in Bunny Hybrid Bt cotton

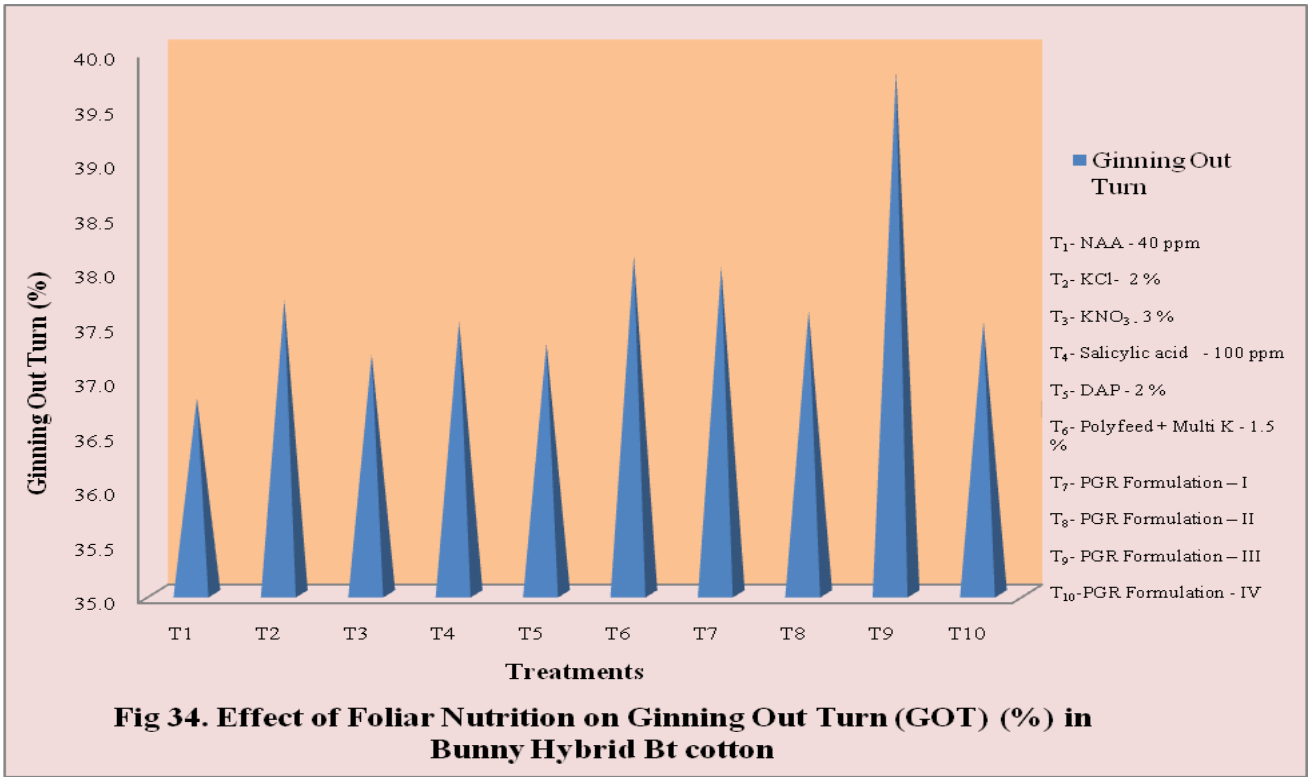
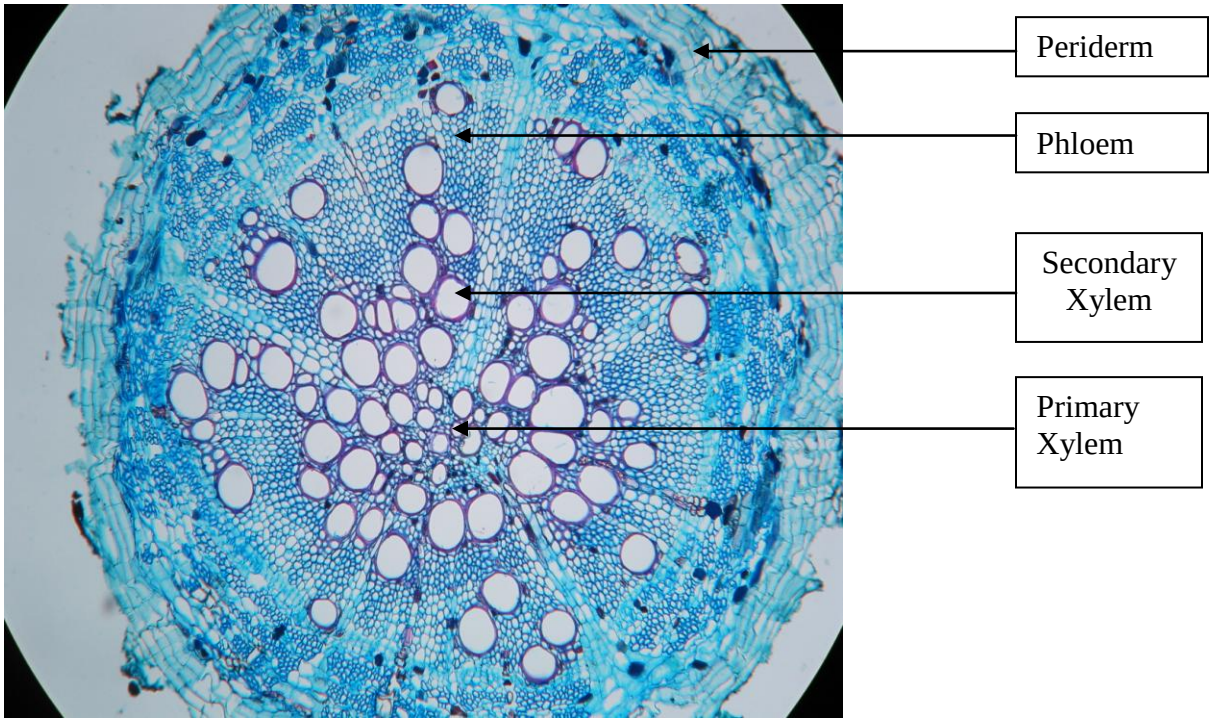
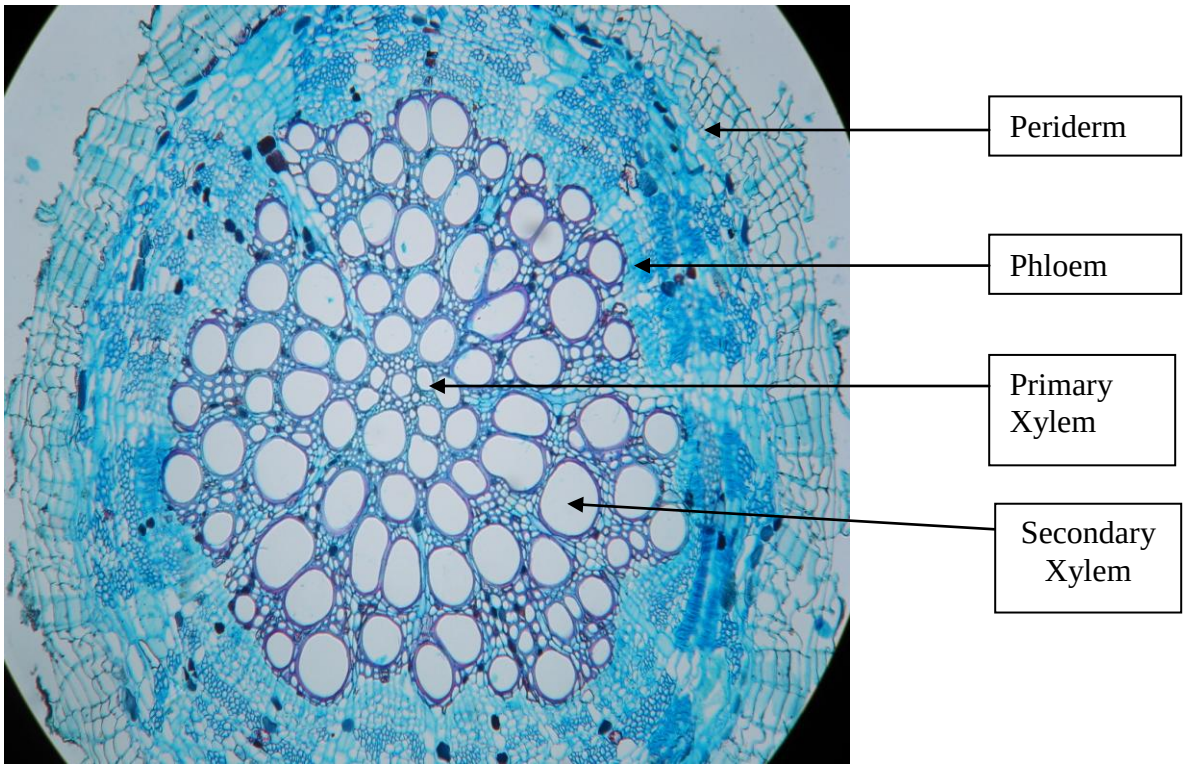


Fig 34. Effect of Foliar Nutrition on Ginning Out Turn (GOT) (%) in Bunny Hybrid Bt cotton

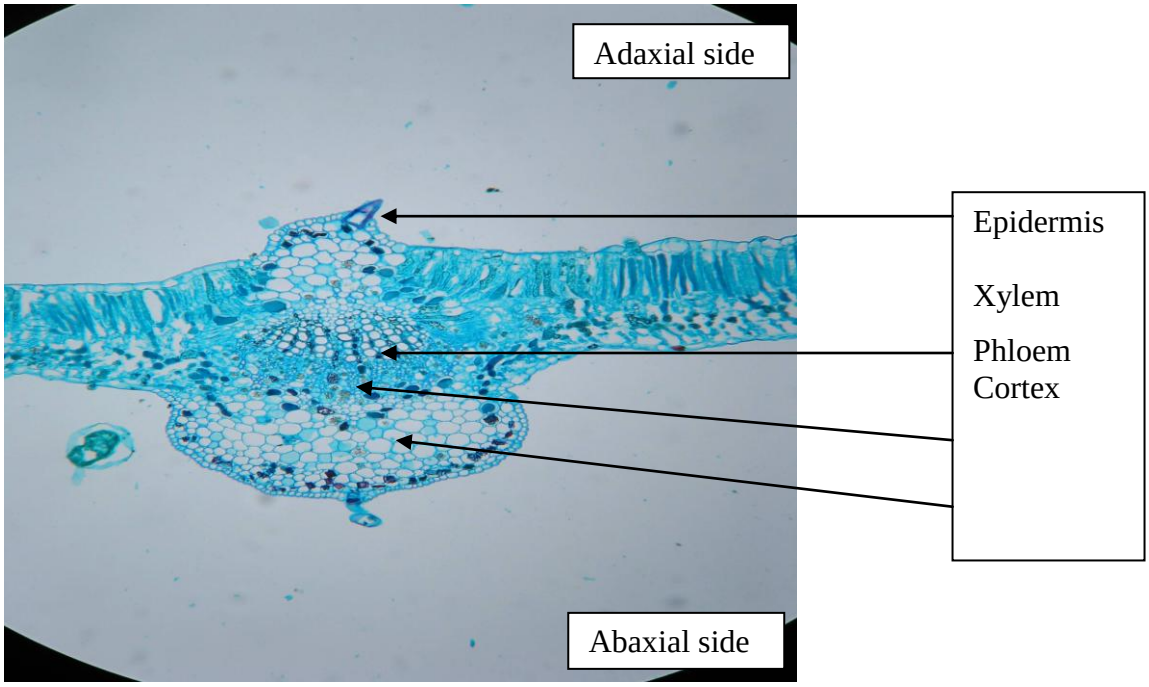


T1- NAA @ 40 ppm

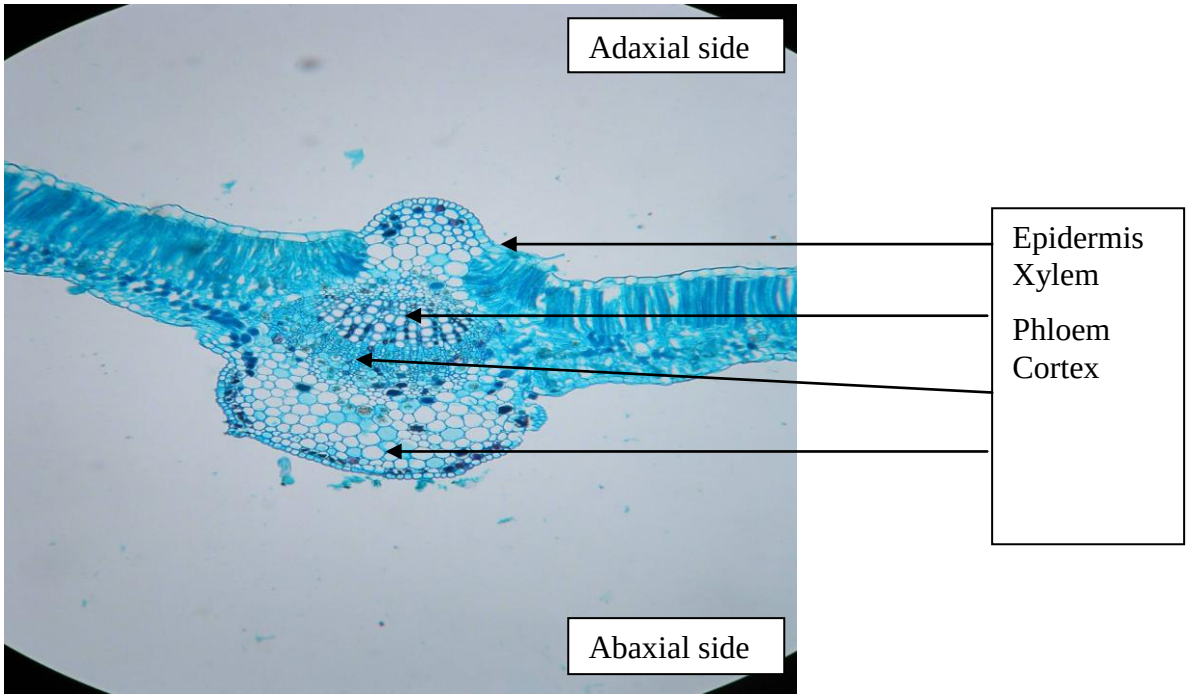


T9- PGR consortia (Formulation-III)

Fig 35. Effect of Foliar Nutrition on Root anatomy at Boll development stage in Bunny hybrid Bt cotton

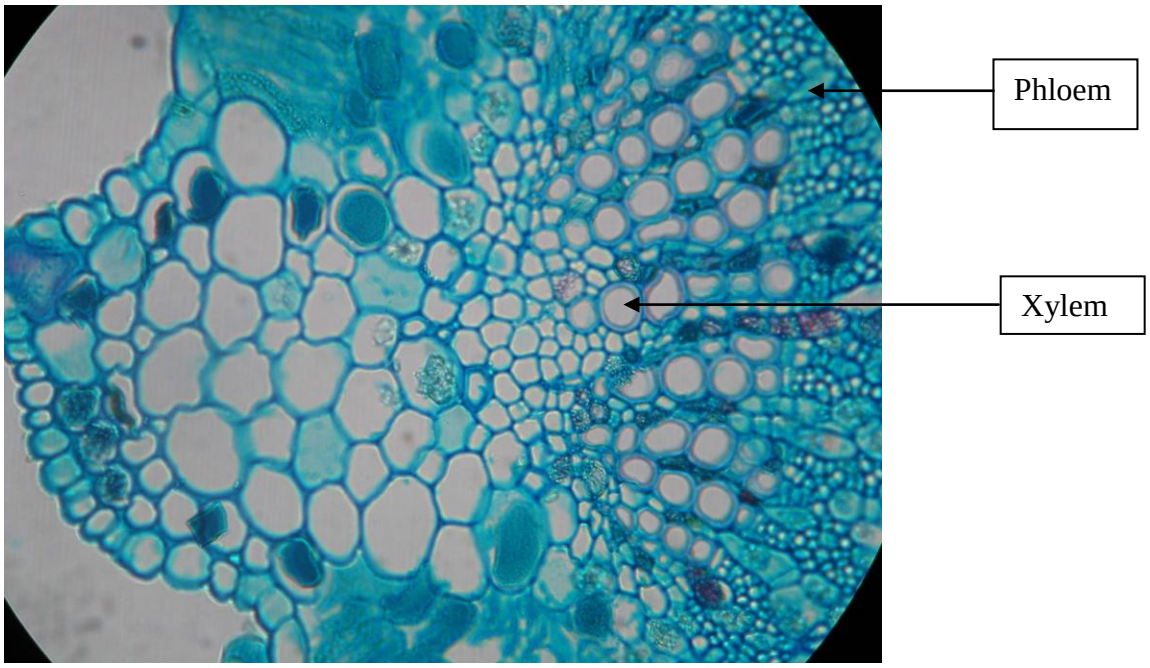


T1- NAA @ 40 ppm

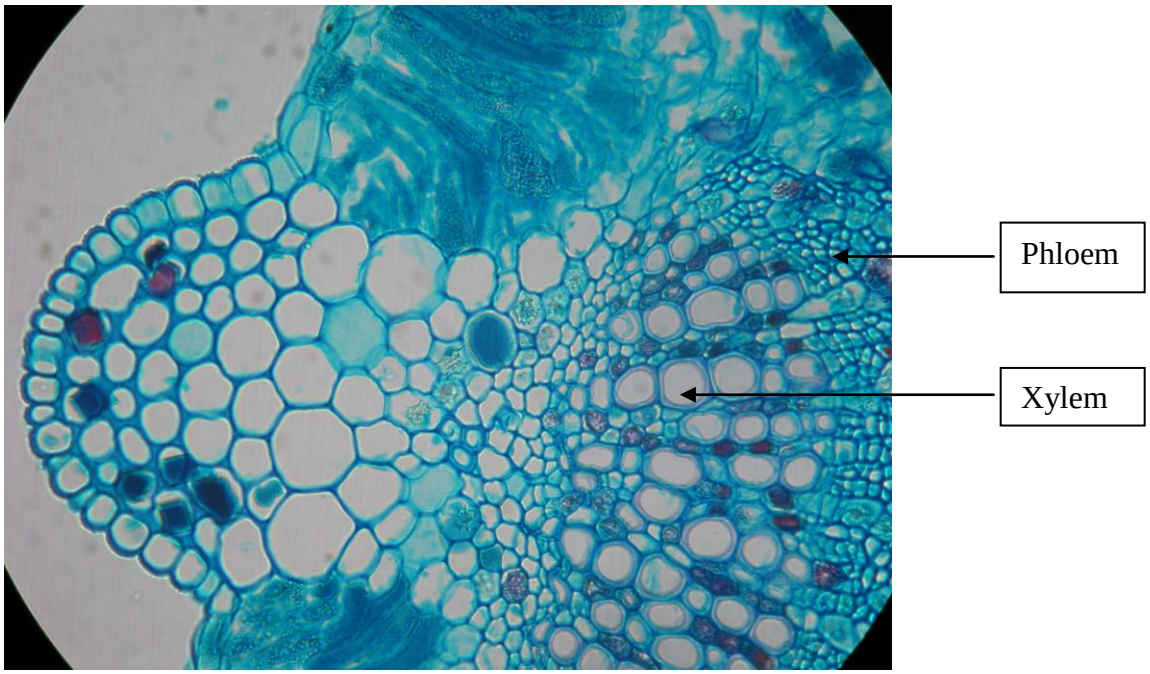


T9- PGR consortia (Formulation-III)

Fig 36(a). Effect of Foliar Nutrition on Leaf anatomy at Boll development stage in Bunny hybrid Bt cotton



T1- NAA @ 40 ppm



T9- PGR consortia (Formulation-III)

Fig 36(b). Effect of Foliar Nutrition on adaxial sides of the leaf at Boll development stage in Bunny hybrid Bt cotton

Plate 4 - Performance of PGR Formulation III

Plate 3. Impact of foliar nutrition on Roots

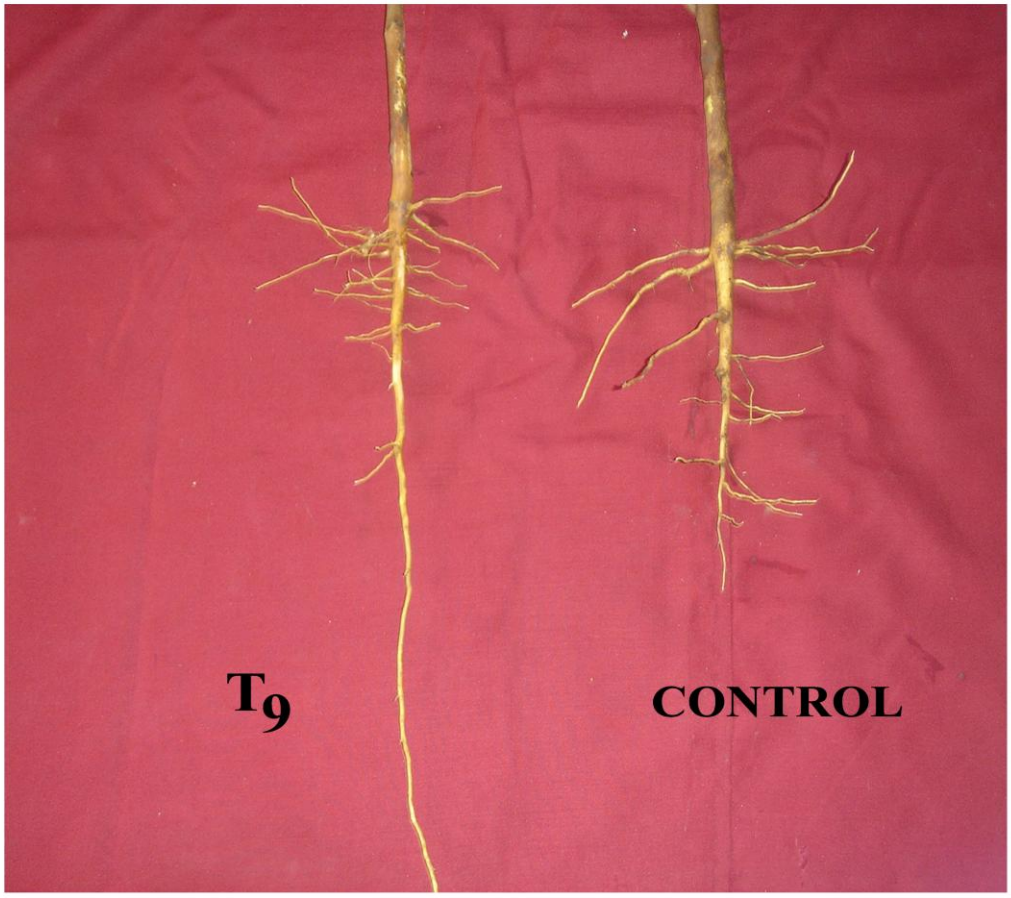


Plate -2. Best Treatment PGR Formulation III

Plate 1. General view of Experimental plot

Plate 5. Impact of foliar nutrition on Plants

CONTROL T_9