INFLUENCE OF PLANT GROWTH REGULATORS ON GROWTH, PHYSIOLOGY, YIELD AND QUALITY IN SOYBEAN [*Glycine max* (L.) Merrill]

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By

RAKSHA V. SHINDE

DEPARTMENT OF CROP PHYSIOLOGY
COLLEGE OF AGRICULTURE, DHARWAD
UNIVERSITY OF AGRICULTURAL SCIENCES,
DHARWAD – 580 005

JUNE, 2010

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1. INTRODUCTION

Soybean (*Glycine max* (L.) Merrill) belonging to family Papilionaceae is one of the most important protein and oilseed crops throughout the world. Its oil is the largest component of the world's edible oils. It is native of China and was introduced to India in 1968 (Bragg cv.) from USA (Nagata, 1970). It has emerged as one of the important commercial crops in many countries. Soybean is also known as the "Golden bean" or "Miracle crop" because of its multiple uses. Soybean seed contains 18-20 per cent oil, 40 per cent protein, 30 per cent carbohydrates, 4 per cent saponins and 5 per cent fiber. The oil contains about 0.5-1.0 per cent lecithin which is essential for building up of human nerve tissues. Due to high protein content, soybean is known as `poor man's meat'. Its oil is also used as raw material in manufacturing antibiotics, paints, varnishes, adhesives, lubricants *etc.* The bulk of the crop is solvent extracted for vegetable oil and then defatted soya meal which is used for animal feed. A very small proportion of the crop is consumed directly as food by humans. Soybean products, however, appear in large variety of processed foods. Several countries like Japan, China, Indonesia, Phillipines and European countries are importing soybean to supplement their domestic requirement for human consumption and cattle feed.

At present, soybean occupies an area of 91.4 m ha in the world with a production of 204 m tons and productivity of 2233 kg/ha (Anon., 2008). Of all the soybean producing countries, the United States occupies the first place contributing nearly 40 per cent of total world production followed by Brazil and Argentina. The production from these three countries together account for about 80 per cent of total world production. In India, soybean is grown over an area of 8.87 m ha with production of 9.46 m tons and productivity of 1069 kg/ha.

Madhya Pradesh is the soybean bowl of India, contributing 65-70 per cent of country's soybean production, followed by Maharashtra, Rajasthan and Karnataka (Anon., 2008). In Karnataka, soybean is cultivated in an area of 2.31 lakh hectares with a production of 2.37 lakh tons and productivity potential of 1025 kg per ha (Anon., 2008) which is much below the average national and world productivity.

The reasons for low productivity of this crop are large scale cultivation under rainfed and low input conditions. The major physiological constraints which limit productivity are lack of seedling vigour, slow development of leaf area during first eight weeks after planting, profuse flowering but poor seed set, limitation of source at the time of seed development due to early leaf senescence, inefficient mobilization of carbon and nitrogen etc (Renukhanna *et al*., 1988). Despite of high yielding potential and various advantages of soybean, the yield per unit area of the crop is low which indicates that there is great scope in improving the productivity potential by using suitable measures particularly, the use of plant growth regulators.

Plant growth regulators so far have emerged as "magic chemicals" that could increase agricultural production at an unprecedented rate and help in removing and circumventing many of the barriers imposed by genetics and environment. Plant growth regulators when added in small amounts; modify the natural growth regulatory system right from seed germination to senescence in several crop plants. Some examples are the use of GA_3 for increasing berry size in grapes, increase of latex flow in rubber trees by ethylene, ripening of sugarcane, control of sprouting in onion and potato, dwarfing in cereals to prevent lodging, preventing premature ripening and deterioration of fruits, *etc.* A little spray of Progibb (which contains GA_3) giving ½ - 2 inches of elongation could be beneficial in garden mums that might be finishing a little short or the flowers may be staying too tightly bunched (Barrett, 2002). In view of their wide spectrum effectiveness on every aspect of plant growth even a modest increase of ten percent in yield is considered as good chemical in the field (Sharma, 1992).

Plant growth regulators (promoters, inhibitors or retardants) play key role in contributing internal mechanisms of plant growth by interacting with key metabolic processes such as, nucleic acid metabolism and protein synthesis. Growth retardants are known to reduce inter-nodal distance, thereby enhancing source-sink relationship and stimulate the translocation of photo-asssimilates to the seeds (Luib *et al*., 1987).

Growth regulators exert their influence on foliar transport in a number of ways. These could enhance the absorption by the leaf at the site of application, increase the migration

within the leaf and/or stimulate the transport out of leaf in the acropetal and basipetal direction.

With this background, the present study involving two contrasting soybean varieties *viz*. JS-335 and KHSb-2 distinct in their growth habit were taken to study the influence of both growth promoters and retardants on growth, yield and quality attributes with following objectives;

1. To find out the influence of plant growth regulators on growth and development in soybean.
2. To find out the influence of plant growth regulators on physiological parameters and productivity potential in soybean.
3. To find out the influence of plant growth regulators on quality in soybean.

2. REVIEW OF LITERATURE

The growth and development of plant is a complex process and is under the control of three main factors *viz*., genetics, environment and endogenous growth substances. The genetic factors determine the potentiality of a plant for growth and the fullest expression of this potential in turn is under the control of various environmental factors. The enhanced productivity of crop through physiological approaches is chiefly achieved by coordinating plant processes to synthesize maximum dry matter production and partitioning major quantum of this increased dry matter into effective yield contributing factors.

One of the reasons for new varieties giving increased yields is mainly because of the partitioning of larger proportion of their dry matter in economic parts of the plant. It may also be attributed to their better adaption to the environment. These effects can also be achieved by certain growth regulators. The success in using these growth regulators depends on several factors such as, the choice of plant growth substances, the purpose for which it is being used, the appropriate concentration and the right time of application.

Since the work on the influence of plant growth regulators on soybean is scanty, an attempt has therefore been made to review the work on soybean and related crops.

2.1 Morpho-physiological characters

Soybean is an annual plant; its vegetative structure consists of an erect, branched stem that normally attains a height of 75-125 cm and possess 14-26 nodes. Lowest node bears cotyledons, the two opposite primary leaves and all other leaves on stem and lateral branches are alternate, trifoliate and borne on long petiole.

2.1.1 Plant height and number of branches

Plant height reflects overall plant growth which is influenced by the interaction between the environmental variables and the genetic make-up of the plant. Chailakhyan *et al*. (1973) reported that soil application of 0.5 to 2 per cent CCC or foliar application of 0.01 to 0.5 per cent CCC decreased the plant height of soybean. Similarly, Hurde and Parjosavulecs (1981) treated soybean seeds at various rates with Atonik, Ame-Chen T6AS63, TIBA and CCC and noticed decrease in plant height with an increase in concentration of these growth retardants.

Baz *et al*. (1984) treated soybean cv. Clark with foliar sprays of 50, 100 and 150 ppm GA_3, CCC and IBA at 45 and 70 to 110 days and found an increase in plant height. GA_3 was found to be more effective than CCC. Castro and Crocomo (1984) studied the action of TIBA and CCC on the development of soybean in green house trial and reported reduction in plant height with application of these chemicals.

Nigam *et al*. (1984) applied GA_3, B-9 and CCC to the groundnut leaves and reported that except GA_3, others increased the number of primary and secondary branches. Reddy and Singh (1985) reported a significant increase in the number of branches per plant in ground nut with the foliar application of Alar (2000-4000 ppm), CCC or TIBA (1000-2000 ppm).

Results of the experiment conducted by Vello and Castro (1987) in soybean cv. Davis revealed that pre-flowering foliar spray of GA_3 (100 ppm) significantly increased the plant height (119.7 cm); while, CCC (2000 ppm) reduced it to the extent of 94.8 cm. Bruce (1990) treated determinate soybean with GA_3 and ethephon, GA_3 treatment mainly produced positive effects on number of pods, height and nodes/branch: while, ethephon decreased yield and 100-seed weight.

Shimano and Matsumoto (1991) conducted pot trials to study the effect of 0.01 to 1000 ppm GA_3 applied at different growth stage on internodal elongation of soybean and found that GA_3 (10-100 ppm) increased the 4^{th} internodal length compared with the control, GA_3 was most effective in promoting internodal elongation when applied at floral initiation stage.

Deotale *et al*. (1995) found that growth retardants like TIBA and B-9 (50-250 ppm) had stimulatory effects on number of leaves, branches, leaf area, dry weight and seed yield

per plant except plant height. TIBA @ 100 ppm and B-9 @ 250 ppm were found to be most effective as they reduced plant height to a greater extent.

Leite *et al*. (2003) observed that foliar application of GA_3 increased the plant height, first nodal elongation and stem diameter in soybean. Leaf area and dry matter production also increased; however, there was no effect on number of leaves, stem branches and root dry matter.

Kothule *et al*. (2003) reported that plant growth substances of different concentrations i.e. GA, NAA, CCC and salicylic acid each @ 100 and 200 ppm and urea @ 1 and 2% when applied exogenously as foliar spray improved morphological characters *viz*. plant height, number of branches, leaf area, total dry matter of plant and reduced the number of days to 50 per cent flowering in soybean. GA @ 200 ppm was found most effective in increasing plant height. While, Cato *et al*. (2006) revealed that TIBA (30, 40 or 50 gm/l) application at V_5 phenological stage in soybean (cv. Pintado) was effective in reducing plant height without affecting parameters related to productivity.

Emongor (2007) revealed that exogenous application of GA_3; 7 days after emergence at 30, 60 and 90 mg/l significantly increased plant height, first nodal height, leaf area and number of leaves per plant without significant effect on plant senescence in cowpea. Thus exogenous application of GA_3 can be used to modify growth and development of some cowpea varieties. Vasudevan *et al*. (2008) reported that GA_3 (100 ppm) foliar spray at 50 per cent flowering resulted in production of significantly higher plant height, number of productive branches (6.68) and seed yield (8.53 q/ha) in fenugreek.

The results of the study conducted by Zhang *et al*. (2009) for three consecutive years revealed that CCC reduced plant height and lodging without having any effect on seed quality in alfalfa. The effectiveness of CCC was highly influenced by climatic conditions.

2.1.2 Days to initiation of flowering and 50 per cent flowering

Soybean is a quantitatively short day plant, the intensity of flowering increases if the numbers of inductive photoperiodic cycles increase. Minimum day length for flowering is 13.5 to 14 hours. Temperature and photo-period are important determinants of the time from emergence to flowering in soybean. A linear and logistic model has been developed independently for describing the development rate of flowering (a high development rate means a short time of flowering).

Castro and Vello (1981) studied the soybean cv. Davis grown in greenhouse and sprayed with CCC (2000 ppm), SADH (4000 ppm), GA_3 (100 ppm) IAA (100 ppm) or water at the 4^{th} leaf stage. SADH delayed the onset of flowering, reduced flowering in relation to the water control; GA_3 reduced the time of flowering, maximum flowering and increased stem dry weight.

Singh *et al*. (1987) revealed that foliar spray of cycocel (300 ppm) or ethrel (200 ppm) at flower initiation stage induced flowering and development of pods which increased seed yield in soybean. Similarly, Resmi and Gopalkrishnan (2004) reported that CCC (300 ppm) led to early flowering and fruit harvest in yard long bean. While, Mukhtar and Singh (2006) reported an increase in growth, flowering, pod maturity and yield in cowpea with GA_3.

2.1.3 Dry matter accumulation

Leaf is the major organ where most of the photosynthates are produced. The number of leaves and their arrangement on main stem and side branches determine the structure of crop canopy which ultimately decides the dry matter production. The dry matter production at each growth stage and its partitioning to reproductive organs during pre-flowering to maturity period has immense importance in determining the final productivity.

Tanner and Ahmed (1974) observed that in soybean, total dry matter production and rate of total dry matter production were not affected by TIBA, however, both seed yield and rate of reproductive dry matter production were greater with treated than with control plants. Similar results were obtained by Singh and Sarkar (1976).

Morandi *et al*. (1984) studied the effect of DPC and CCC in soybean and found decrease in stem dry weight; while; DPC modified the pattern of dry matter partitioning by

increasing the proportion allocated to seeds. Mishrinky *et al*. (1990) reported that both CCC and GA_3 increased dry matter of plant in peas.

Kelaiya and Jethwa (1991) studied the effect of plant growth regulators *viz*., GA_3 (20 ppm) or Triacontanol (200 ml/ha) or with water spray on groundnut. Spraying growth regulator at 25 and 50 DAS increased plant dry weight. While, Shah and Prathapsenan (1991) studied the effect of cycocel on the growth and yield of mungbean. Cycocel spray (1000 ppm) at 14 days after emergence reduced stem length, but, increased shoot dry weight, leaf area, leaf thickness and chlorophyll content.

Chetti (1991) reported that the application of growth retardants *viz*., MC, lihocin (CCC) and MH increased dry weight of stem, leaf and reproductive parts and total dry weight as compared to control in groundnut. Ravichandran and Ramaswami (1991) conducted field trials in soybean by imposing pre-flowering application of TIBA (25, 50, 75 or 100 ppm) and found that TIBA (50 ppm) increased dry matter accumulation.

Zaidi and Singh (1995) conducted an experiment where soybean seeds were soaked for 4 hours in distilled water or 100 or 200 ppm GA_3/ IAA. They were then sown in pots and exposed to salinities of 0.8, 10 or 20 dS/m. The detrimental effects of salinity on dry matter production and distribution were eliminated by pre soaking in GA_3 or IAA.

Mehetre and Jamadagni (1996) studied the biomass partitioning and plant architecture in 41 soybean cultivars and reported that the soybean plant has a tendency to deposit 19.77, 8.05, 29.42, 30.85 and 11.41 per cent assimilates into seed, pod wall, stems, leaves and roots, respectively.

Progibb (4%), a gibberelin based vegetative growth promoter increased leaf length and dry weight of leaves in cilantro. Progibb (100 µl/l) was optimum for maximizing leaf production (Ramcharan, 2000). Resmi and Gopalkrishnan (2004) reported that foliar application of CCC (300, 400 or 500 ppm) to cowpea plants increased vegetative growth, fruit set and grain yield.

Pre-soaking treatment of GA_3 and CCC (10, 100, 250, 500 and 100 µg/ml) on pea (cv. Aparna and Azad P-1) showed that GA_3 irrespective of concentration was effective in promoting shoot growth while CCC at all concentrations reduced shoot growth (Bora and Sarma, 2006). Gulluoglu *et al*. (2006) observed that the application of plant growth regulators GA_3, Atonik, Cytozyme, Maxicrop reduced the effect of heat stress on both main and double cropped soybean and increased biomass yield under extended heat and dry conditions.

Pankaj Kumar *et al*. (2006) studied the influence of plant growth regulators on determinate (JS- 335) and semi- determinate (MACS-124) soybean genotypes and revealed that the growth retardants TIBA, mepiquat chloride and cycocel increased total dry matter production and BMD in both the soybean genotypes. They were more beneficial in terms of translocation of photo-assimilates towards developing reproductive parts as compared to growth promoter, kinetin and control.

Emongor (2007) observed that GA_3 applied cowpea plants had significantly higher dry matter content in whole plant, shoot and root than control plants. The response of cowpea cv. Blacke to increasing GA_3 concentration was quadratic with respect to dry matter accumulation. Similarly, Ibrahim *et al*. (2007) revealed that GA_3 (100 ppm) application led to increase in plant height, average number of leaves, leaf area per plant and dry weight of shoot in *Vicia faba*. Kalyankar *et al*. (2008) showed that foliar spray of GA_3 (150 ppm) increased number of leaves and leaf area. NAA (100ppm) was effective in increasing total dry weight.

2.1.4 Growth parameters

Technique of growth analysis has been extensively used in recent years for better understanding of physiological basis of yield variation in crop plants. Growth analysis is a physiological probe on the development of crop in chronological sequence to elucidate and account the causes for differences in yield through the events that have occurred at different stages of growth (Krishnamurthy *et al*., 1973).

Lovett and Orchard (1978) observed in sunflower that the application of CCC at different growth phases increased leaf area in cv. Predouik. Similarly, Singh (1979) reported

that foliar spray of CCC (300 ppm) or ethrel (200 ppm) at flower initiation stage increased LAI during seed filling phase in soybean.

Gujamet *et al*. (1987) reported that gibberellins treatment during pod filling may provide a useful tool to increase soybean seed yield by delaying growth arrest and N_2 fixation decline. The decline in RGR, NAR and mean N_2 fixation from flowering to mid pod filling was attenuated by GA_3.

Balkrishnan and Natarajarathan (1987) studied the aspects of critical leaf area index in pigeonpea. They found that LAR, NAR and CGR decreased progressively from the first to third cropping season. Average LAI increased rapidly between 50 DAS and first flowering, CGR was highest between 50 DAS and first flowering and reached a peak of 6.12 at 50 per cent flowering, while NAR declined from 50 DAS until harvest. The critical LAI was considered to be 5.3, coinciding with maximum CGR and NAR.

Nawalgatti *et al.* (1991) reported that there was increase in the LAI, DM production, NAR and CGR in groundnut cv. DH-3-30 with the foliar application of 500 or 1000 ppm cytozyme, CCC, Vipul or Paras, 50-60 ppm TIBA or 10 ppm NAA at 45 days after sowing. CCC was most effective followed by cytozyme and NAA (20 ppm).

Ravichanadran and Ramaswami (1991) studied the source-sink relationship in soybean as influenced by TIBA. They found that pre-flowering application of TIBA (50 ppm) decreased LAI but increased the dry matter production, CGR and NAR. While, Bhagel and Yadav (1992) observed that NAA was superior to GA_3 and IAA in enhancing LAI, NAR, CGR at all stages except CGR at pod filling stage in black gram.

Deotale and Sorte (1996) found that among various concentrations of TIBA and B-9 (50,100,150,200 and 250 ppm), TIBA (100 ppm) showed stimulatory effect on CGR, NAR and leaf nitrogen content which ultimately increased the grain yield in soybean. While, Maske *et al*. (1998) found that GA_3 was relatively more effective than NAA in increasing CGR at 30-45 and 45-60 DAS and accelerating the yield contributing factors in soybean.

Patil and Dhomne (1998) reported that foliar application of growth retardants like CCC, TIBA, PCB each at two concentrates revealed an increase in growth parameters *viz.,* CGR, RGR, NAR and LAI. The growth parameters showed significant difference among the treatments and the rates fluctuated with growth and developmental stages of plant.

Jadhav (2000) stated that the application of increasing concentrations of GA_3 and NAA increase the morphological and physiological parameters like CGR, RGR, NAR and LAR in soybean which inturn led to the increased yield and yield attributes. Similarly, Sarkar *et al*. (2002) showed that double spraying of GA_3 and IAA (100 ppm) at 20 and 42 days after sowing increased LAI, CGR and NAR in soybean (cv.BS-3). The foliar spray of GA_3 (100 ppm) at 30 DAS had the most regulatory effect to enhance root, stem, leaf and total dry matter, LAI, CGR, RGR and NAR in soybean (cv. PB-1) (Rahman *et al*., 2004).

2.2 Biochemical and quality parameters

Apart from morphological and physiological alterations, plant growth regulators also influence various biochemical parameters and thereby alter quality parameters in various crops.

2.2.1 Chlorophyll content

Koti (1997) observed significant variations in chlorophyll content in determinate and indeterminate cultivars of soybean. While, Dhopte and Suradkar (1998) conducted a field experiment to study the effect of hormones (GA and NAA 20 ppm each) in soybean and found that the dry matter production, chlorophyll and root nodule numbers remained unaffected. Among hormones, NAA was more effective than GA.

Tagade *et al*. (1998) studied the influence of PGRs by soaking seeds of soybean in 25-150 ppm IAA and kinetin before sowing and noticed that leaf chlorophyll and nitrogen contents, seed yield and seed protein and oil contents increased with IAA concentration upto 100 ppm then decreased with increasing concentrations. While, Bora and Sarma (2006) showed that chlorophyll content decreased at higher GA_3 concentration while it was increased by CCC.

Ibrahim *et al*. (2007) observed that the foliar application of growth retardant ancymidol on faba bean caused a significant increase in the content of photosynthetic pigments. The application of growth retardants and nipping at 35 DAS in cowpea increased the chlorophyll content. The maximum chlorophyll 'a', chlorophyll 'b' and total chlorophyll contents were recorded in maleic hydrazide and lihocin at higher concentrations (Reddy *et al*., 2009).

2.2.2 Nitrate reductase activity

The nitrate reductase activity, which is the key enzyme in nitrogen metabolism, is known to be regulated by various environmental factors apart from its own substrate. The reduction of nitrate by nitrate reductase is the rate limiting step in the utilization of nitrogen in the nitrate form and hence called as key enzyme. The enzyme nitrate reductase is cytoplasmic, containing molybdenum and flavin co-enzyme, FAD.

Wasnik and Bagga (1992) showed that there was no effect of CCC (500 ppm) foliar spray on NRAse activity in greengram. Pramod Kumar *et al*. (1999) reported that salicylic acid (SA *viz*; 0, 25, 50, 75, 100, 125 and 150 ppm) when sprayed on soybean at 12, 24 and 36 days after sowing accelerated the nitrate reductase activity and enhanced the content of total soluble proteins.

Senthil *et al*. (2005) conducted experiment to study the effect of growth regulators on IAA oxidase, peroxidase and NRAse activities in groundnut under different salinity levels and indicated that seed treatment with GA_3 and IAA solutions reduced the activity of IAA oxidase and increased the activity of NRAse enzyme. Similarly, Reddy *et al*. (2009) showed that nitrate reductase activity increased upto 60 DAS and then decreased.

2.2.3 Seed protein

Baz *et al*. (1984) observed that with foliar spray of 50, 100 or 150 ppm GA_3, CCC and IAA at 45, 70 and 110 days after sowing to soybean, increased the percentage of oil and N content of dried seeds. GA_3 was most effective than CCC and IAA. Nonglok and Rattanaphon (1985) reported that TIBA (15 ppm) application during six tri-foliate stage increased the seed yield and pod set, as well as the protein and oil contents of seeds.

Ravikumar and Kulkarni (1988) reported that foliar application of NAA (20 ppm), CCC (100 ppm) or TIBA (40 ppm) to 3 soybean cultivars at 50 per cent flowering had no effect on seed protein and oil contents compared with control. Similarly, Uppar and Kulkarni (1989) reported that application of TIBA (250 ppm), kinetin (15 ppm) and cycocel (2500 ppm) increased protein and oil contents in sunflower. While, Mishrinky *et al*. (1990) studied the effects of GA_3 and CCC on peas and observed that GA_3 tended to increase protein content of green pods.

Ela Patel and Saxena (1995) studied the influence of PGRs like GA, kinetin, NAA, ethrel, IAA and ABA and found that kinetin and ethrel were most effective in increasing the protein, starch and amino acid contents of the developing seeds in mungbean. While, pre-soaking treatment of 500 µg/ml of CCC recorded highest protein content in pea seeds (Bora and Sarma, 2006).

2.2.4 Seed oil content

Mahrous *et al*. (1990) reported that the application of cycocel and kinetin increased the oil per cent in soybean seeds. On the contrary, Ravikumar and Kulkarni (1988) reported that foliar application of 20 ppm NAA, 100 ppm CCC or 40 ppm TIBA to 3 soybean cv. at 50 per cent flowering stage had no effect on protein and oil content in seed compared with water spray. While, Al-Gharbi and Yousif (1989) recorded increased oil content with CCC treatment. Increased oil content in oilseeds due to application of growth regulators were also noticed by Pando and Srivastava (1987), Uppar and Kulkarni (1989) and Sawan *et al*. (2001).

2.3 Yield and yield attributes

Grain yield is determined by several components and it is therefore essential to know which of the growth characters are responsible for yield to achieve higher productivity. It is therefore essential to access the relative importance of yield components and growth characters as affected by growth regulators.

Lam-Sancehz *et al*. (1975) sprayed soybean with 1.0, 1.5 or 2 g CCC/ha at 20-35 days after germination and found increased number of seeds per pod and 100 seed weight. Similarly, Barthakur (1980) studied the effect of spraying soybean cv. Bragg with 25, 50 or 100 g TIBA/ ha at 25 or 40 days after sowing and found increase in yield by 18, 18 and 23.7 per cent, respectively.

Castro and Moraes (1981) sprayed soybean cultivar Davis with CCC (2000 ppm), 4000 ppm (Daminozide), GA (100 ppm) and NAA (100 ppm) or water and found that maximum pod weight, seed number and yield with GA. Basuchoudhari *et al*. (1986) gave different treatments 15 days before flowering of crop *viz*., defoliation (removal of 50 per cent alternate leaves) decapitation by spray of 500 and 1000 ppm GA and 200 and 400 ppm CCC. He reported that decapitation and CCC (400 ppm) significantly increased seed yield in soybean.

Sheelavantkar and Patil (1988) showed that in field trials, foliar application of TIBA (56 g/ha) or CCC (1000 ppm) at initiation stage, gave seed yield of 3.25, 2.80 t/ha respectively as compared to 2.73 t/ha for the untreated control in soybean. Urwiler and Stutte (1988) showed that in green house experiment, application of GA_3 to soybeans at pod filling stage and again 12 days later, inhibited the pod development and reduced the seed yield.

Chung and Kim (1989) sprayed soybean with TIBA, ABA or DGLP at different growth phases and noticed that TIBA and ABA increased podding rate and number of pods per plant, but, all treatments increased the number of seeds per pod and seed yield and only TIBA increased 100-seed weight.

Bruce (1990) observed that determinate soybean when treated with GA_3 and ethephon, GA_3 treatment mainly produced positive effects on number of pods per plant whereas ethephon decreased seed yield and 100 seed weight. Sharma *et al*. (1990) reported that in a soybean field trial cv. Bragg when sprayed with water (control), Paras, NAA, Biozyme and Atonik gave seed yield of 434, 477, 463, 492 and 477 grams, respectively. There were no differences in 100-seed weight.

Ravichandran *et al*. (1992) reported that in soybean, TIBA spray at 25, 50, 75 and 100 ppm before flowering produced seed yield of 1.72, 1.77, 1.70 and 1.61 t/ha, respectively as compared with 1.36 t/ha in water spray. Similarly, Umezaki *et al.* (1992) applied AMO-1618, paclobutrazol and CCC to soybean and observed increase in seed weight per plant.

Kim and Kim (1993) sprayed soybean cv. Bog-way-kong and Jangyeong with ABA (50 ppm), BA (100 ppm), Ethrel (1000 ppm), NAA (20 ppm) and TIBA (100 ppm) at growth stage R_1 and found that seed yield was significantly increased.

Mishra *et al.* (1994) studied the effect of fertility levels, cycocel, rhizobium culture and FYM on growth and yield of soybean and observed that combined application of these factors gave the highest seed yield as compared to control.

Mehetre and Lad (1995) studied the effect of foliar spray of maleic hydrazide, chloromequat, GA_3 and ABA (25-100 ppm) at floral initiation and again 7 days later to soybean cv. MAC-124 and reported that all the treatments increased yield over control.

Kamal *et al*. (1995) studied the effect of PGRs application at flowering and showed that soybean yield components differently responded to PGRs application which depended on growth regulator concentration and the cultivars. The application of GA_3 (1 ppm) in soybean (cv. Tachinagaha and Tidar) at flowering stage increased the grain yield by 5.8 per cent over the control. This increase was mainly due to higher grain and pod number through the increase of fertile nodes and number of pods per fertile node.

Kim *et al*. (2001) showed that TIBA (50 ppm) applied at V_6 (fifth leaf) stage recorded highest seed yield in soybean. Though TIBA decreased 100 seed weight it increased podding rate and seed yield by 8% compared to control.

Resmi and Gopalkrishnan (2004) reported that NAA (15, 30 or 45 ppm), 2, 4-D (2 ppm) and CCC (300, 400 or 500 ppm) increased seed yield, pod length, pod weight, pod number per plant and pod number per unit area of cowpea plants.

Tickoo *et al*. (2006) showed that pre-sowing seed treatment with TIBA (10-30 ppm) and 2,4-D produced maximum seed yield in mungbean varieties *viz*., Pusa Vishal, Pusa 9072,

Pusa 9531 and PS-16. This was due to more positive contributions by high HI, 100-seed weight, seeds per pod and pods per plant towards grain yield.

Salunkhe *et al*. (2008) studied the influence of plant growth regulators *viz*., TIBA (100 ppm), NAA (50 ppm), GA_3 (50 ppm), CCC (500 ppm), CCC (1000 ppm) on soybean cultivars (JS-335 and Phule Kalyani). Among the PGR treatments NAA (50 ppm) was found to be the best. The variety JS 335 recorded higher grain yield (q ha-1) than Phule Kalyani and was found to be promising in major yield contributing characters and morphological traits.

Vasudevan *et al.* (2008) revealed that interaction effect between apical bud pinching and GA_3 sprays showed a significant influence on growth, seed yield and yield attributes like number of pods per plant, number of seeds per pod *etc.* Kalyankar *et al*. (2008) observed that CCC (500 ppm) was effective to increase number of grains/pod, 100-seed weight and grain yield in soybean variety MAUS 61-2.

3. MATERIAL AND METHODS

A field experiment was conducted during *kharif*, 2009 at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad to study the influence of plant growth regulators on growth, development, physiology, yield and quality in soybean (*Glycine max* (L.) Merrill). The details of materials used and techniques adopted during the course of investigation are described in this chapter.

3.1 Experimental site

The experiment was carried out in E-block; plot no. 125 belonging to Department of Crop Physiology, College of Agriculture, University of Agricultural Sciences, Dharwad. which is situated at 15°12'N latitude with an altitude of 678 m above mean sea level.

3.2 Weather data during the crop growth period

The data on weather parameters such as rainfall (mm), mean maximum and minimum temperature (°C) and relative humidity (%) recorded at Meteorological Observatory, Main Agricultural Research Station, University of Agricultural Sciences, Dharwad during the experimental year and the mean of the last 59 years (1950-2009) are presented in Table 1.

The mean annual rainfall for the past 59 years was 806.2 mm and the maximum rainfall was received in the month of August (155.8 mm) followed by July (136.7 mm). The total rainfall during 2009-10 was 1272.6 mm and a maximum of 256.8 mm was received in July followed by September (229.0 mm). The mean maximum temperature ranged from 36.5 °C (April) to 26 °C (August) during year 2009. The months of April, May and June were hottest. While the mean maximum temperature during past 59 years indicated that, it was maximum in April (36°C) followed by May (34.4°C). The minimum temperature ranged from 15.4 (December) to 21.5°C (May) during the 2009-10. The average of last 59 years indicated that the mean minimum temperature was maximum during June (21.7°C) and minimum during December (13.2°C). The relative humidity ranged from 49 (March) to 88 per cent (July) during 2009-10, while it ranged from 54.5 per cent (February) to 88.7 per cent (August) during the last 59 year. The climatic conditions are very much favourable for the crop growth and development during *kharif,* 2009-10. The incidence of pest and diseases was not severe; the crop stand was good and healthy.

3.3 Soil and its characteristics

The soil of experimental site was medium black clay loam soil. Composite soil samples were collected from the experimental site and analyzed for various physical and chemical properties. The details along with methods employed are presented in Table 2.

3.4 Experimental details

The experiment was carried out in *kharif,* 2009 and the details of experiment are listed below.

3.4.1 Treatment details

The treatments involving plant growth regulators *viz*., Progibb (20, 40 and 60 ppm), cycocel (500 and 1000 ppm) and TIBA (100 and 200 ppm) were imposed at 30 days after sowing (DAS) in two varieties of soybean. The salient features of plant growth regulators used in the experiment are given in the Table 3. The details of the treatments are given below.

Genotypes:

V_1 - KHSb-2

V_2 - JS-335

The salient features of these genotypes are furnished in Table 4 (Basavaraja *et al*., 2004).

Table 1. Monthly meteorological data during crop growth period (2009-10) and the average of 59 years (1950-2009) at Main Agricultural Research Station, UAS, Dharwad

Months	Rainfall (mm)		Temperature (°C)				Relative humidity (%)	
	2009-10	1950-2009	Mean maximum		Mean minimum		2009-10	1950-2009
			2009-10	1950-2009	2009-10	1950-2009		
April	52.8	39.0	36.5	36.0	21.1	20.1	81.0	78.0
May	91.6	68.0	35.5	34.4	21.5	20.9	84.0	75.6
June	144.8	107.9	30.3	28.8	20.9	21.7	77.0	86.4
July	256.8	136.7	26.0	28.7	20.9	20.9	88.0	89.2
August	72.2	155.8	28.1	26.9	20.6	20.1	80.0	88.7
September	229.0	133.6	28.5	28.2	20.7	19.9	83.0	86.8
October	141.0	93.6	29.3	30.2	18.8	18.7	65.0	79.7
November	46.0	52.6	28.6	29.7	18.0	15.9	69.0	73.7
December	76.4	2.6	28.8	28.9	15.4	13.2	66.0	69.3
January	0.8	0.05	28.2	29.7	15.5	13.9	63.0	64.9
February	0.4	0.5	32.4	32.2	17.3	16.5	50.0	54.5
March	Trace	15.6	35.6	33.7	20.3	19.7	49.0	64.5
Total	**1272.6**	**806.2**						

Table 2. Physical and chemical properties of the soil in the experimental site

Sl. No.	Properties	Value obtained	Method employed
I	**Physical properties**		
1	Coarse sand (%)	6.28	International pipette method (Piper, 1966)
2	Fine sand (%)	14.27	International pipette method (Piper, 1966)
3	Silt (%)	27.52	International pipette method (Piper, 1966)
4	Clay (%)	51.99	International pipette method (Piper, 1966)
5	Bulk density (g/cc)	1.33	Core sample method
II	**Chemical properties**		
1	Soil pH (1:2.5 Soil: Water)	7.60	pH meter (Piper, 1966)
2	Electrical Conductivity (dS/m)	0.28	Conductivity bridge (Jackson, 1967)
3	Organic carbon (%)	0.52	Walkely and Black Wet oxidation method (Jackson, 1967)
4	Available Nitrogen (kg/ha)	221.0	Modified Kjeldahl method (Jackson, 1967)
5	Available Phosphorous (kg/ha)	32.4	Olsen’s method (Jackson, 1967)
6	Available Potassium (kg/ha)	318.7	Flame photometer (Jackson, 1967)

Treatments

T_1 - Foliar application of Progibb (20 ppm)

T_2 - Foliar application of Progibb (40 ppm)

T_3 - Foliar application of Progibb (60 ppm)

T_4 - Foliar application of CCC (500 ppm)

T_5 - Foliar application of CCC (1000 ppm)

T_6 - Foliar application of TIBA (100 ppm)

T_7 - Foliar application of TIBA (200 ppm)

T_8 - Control (water spray)

3.4.2 Design and layout

The experiment was laid out in factorial randomized block design with three replications. The plan of layout of the experiment is shown in Fig. 1.

Plot size :

Gross : 3.2 m × 2.3 m

Net : 3.0 m × 1.2 m

Spacing : Inter row spacing - 30 cm

Intra row spacing - 10 cm

3.5 Cultural practices

3.5.1 Land preparation

The land was ploughed and harrowed twice after the harvest of previous crop followed by planking to bring the soil to a fine tilth. Plots were laid out as per the plan of layout.

3.5.2 Fertilizer application

The crop was fertilized with nitrogen, phosphorus and potash @ 40:80:20 kg/ha in form of urea, single super phosphate and muriate of potash, respectively as basal dose.

3.5.3 Seed source and sowing

Seeds were obtained from the All India Co-ordinated Research Project on soybean, Main Research Station, Dharwad. Healthy and bold seeds were dibbled with spacing of 30 × 10 cm to a depth of 4 cm on 26th June, 2009.

3.5.4 Thinning operation

After 15 days of sowing, seedlings were thinned out by maintaining only one plant per hill.

3.5.5 Plant protection and intercultural operations

Intercultural operation was carried out twice at 20 and 35 days after sowing (DAS) immediately after hand weeding. The crop was sprayed with Endosulfon @ 2 ml l^{-1} and Chlorpyriphos @ 1.5ml l^{-1} at 35 and 60 DAS, respectively against leaf eating carterpillar and pod borer.

3.5.6 Harvesting and threshing

The genotypes differed in their maturity period and harvesting was done at physiological maturity stage of each genotype. Five plants from each plot were uprooted and collected for dry matter production and pod yield. Pods of rest of the plants from each net plot were collected and were processed for seeds. The seed yield was calculated both on plant basis and on per hectare basis based on seed yield of five plants and net plot, respectively.

Table 3. Salient features of plant growth regulators used in the experiment

Sl. No.	Common name/ Trade name	Chemical group	Chemical name	Physiological effects and uses
1	Progibb	Gibberelins	Gibberelic acid	Growth promoter, stimulates cell division, elongation, cell wall plasticity and permeability of cell membranes, RNA synthesis, induction of hydrolytic enzymes and increases plant height, increased mobilization and translocation of reserve food material.
2	Cycocel/Lihocin	Chlormequat	2-chloroethyl-trimethyl-ammonium chloride	Anti-gibberelin, inhibits cell elongation, increase chlorophyll synthesis and root development, improves sturdiness, prevents lodging, increase yield, control vegetative growth giving more compact plants.
3	TIBA/ Regim-8	Anti-auxin	2,3,5-Triiodobenzoic acid	Growth retardant, controls vegetative growth, increase pod set, acceleration of maturity.

Table 4. Salient features of the soybean genotypes selected for the experiment

Sl. No.	Characters	JS-335	KHSb-2
1	Pedigree	JS-78-77 x JS-71-05	Mamloxi x EC 39821
2	Year of release	1994	1979
3	Duration (days)	95-100	115-120
4	Pubescence colour	Almost absent	Tawny
5	Seed coat colour	White	Yellow

LEGEND

Genotypes:

V_1 – JS-335

V_2 – KHSb-2

Treatments:

T_1 - Progibb (20 ppm)

T_2 - Progibb (40 ppm)

T_3 - Progibb (60 ppm)

T_4 - CCC (500 ppm)

T_5 - CCC (1000 ppm)

T_6 - TIBA (100 ppm)

T_7 - TIBA (200 ppm)

T_8 - Control

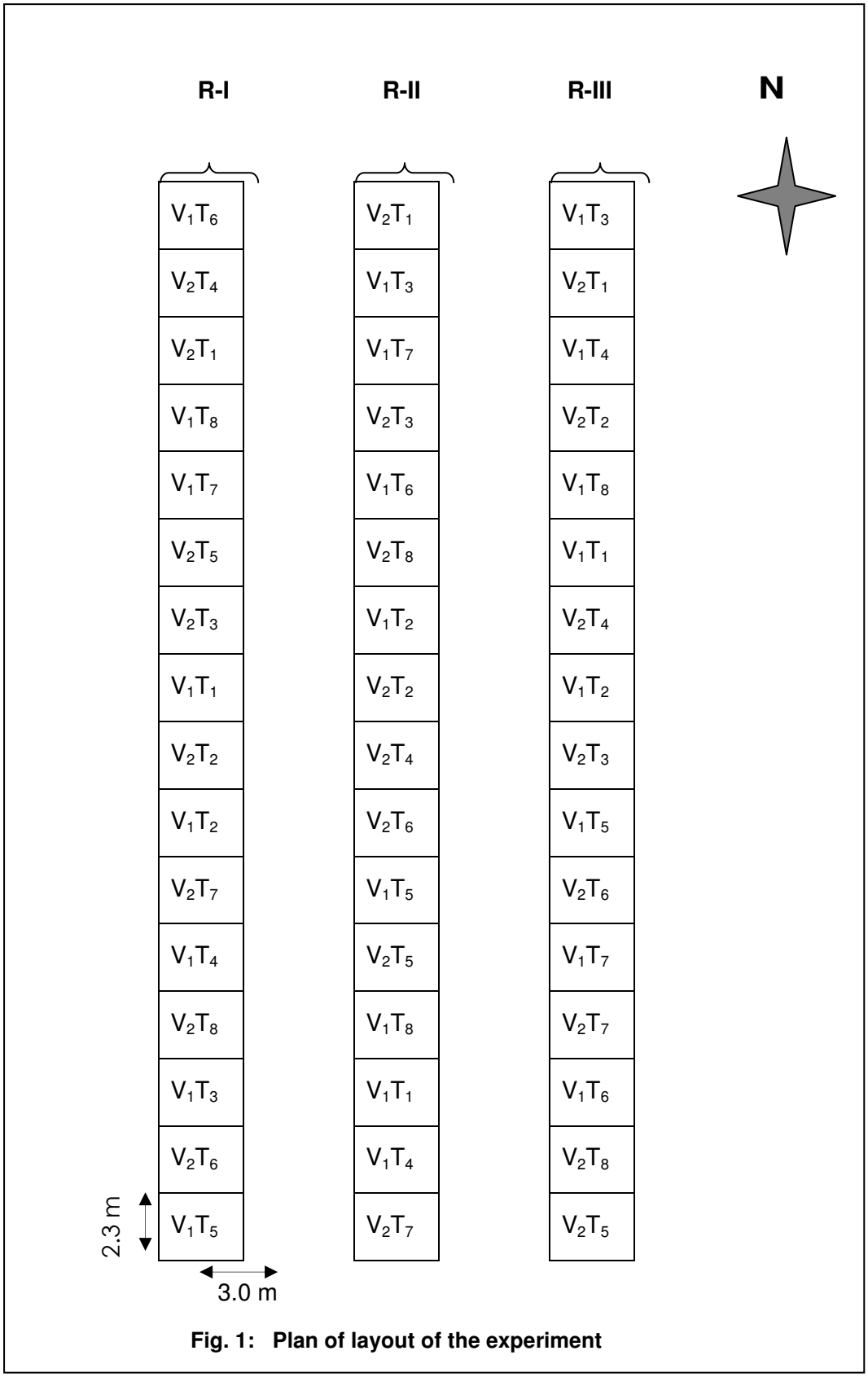


Fig. 1: Plan of layout of the experiment

3.6 Collection of experimental data

Five plants of uniform size were selected randomly and tagged from each treatment for recording various observations on growth and development at different stages.

3.6.1 Morpho-physiological characters

3.6.1.1 Plant height (cm)

The plant height was measured from base of the plant to the tip of fully opened leaf on the main shoot. Measurements were taken from five plants each tagged earlier and the average height was calculated and expressed in cm.

3.6.1.2 Total number of branches

The total number of branches were counted and recorded at different intervals at 40, 55, 70 DAS and at harvest.

3.6.1.3 Days to initiation of flowering

The date of first flower initiation in each treatment was recorded and expressed as days taken for initiation of flowering.

3.6.1.4 Days to 50 per cent flowering

Number of days required for 50 per cent of plants to flower after sowing was recorded.

3.6.1.5 Growth and growth parameters

Five plants in each treatment were uprooted randomly at 40, 55, 70 DAS and at harvest and used for recording dry matter distribution, leaf area and other growth characteristics as described below.

3.6.1.5.1 Dry matter production and its partitioning

Five plants uprooted at random in each treatment and partitioned into their component parts *viz*., stem, leaf and reproductive parts and were air dried and then transferred to hot air oven at 80^{o}C for 72 hrs until constant weights were obtained and their dry weights were recorded. The dry weight of different plant parts and total dry weight was recorded at 40, 55 and 70 days after sowing and at harvest and expressed on per plant basis.

3.6.1.5.2 Leaf area (cm^2)

Leaf area per plant was worked out by leaf disc method (Vivekanandan *et al*., 1972) on dry weight basis. Thirty leaf discs having a known diameter ($1cm^2$) were collected randomly from fully expanded leaves throughout the plant canopy by avoiding midrib of the leaf. The discs thus collected and rest of the leaves was oven dried separately at 80^{0}C for 72 hours. The dry weight of leaf discs and rest of the leaves was recorded and leaf area was computed and expressed in cm^2 per plant

3.6.1.5.3 Leaf area index

The leaf area index (LAI) is the ratio of leaf area per plant to the land area occupied by the plant and was calculated by using the formula as suggested by Sestak *et al*. (1971).

$$LAI = \frac{\text{Leaf area per plant } (cm^2)}{\text{Land area occupied by a plant } (cm^2)}$$

3.6.1.5.4 Absolute growth rate (g $plant^{-1}$ day^{-1})

Absolute growth rate (AGR) is the dry matter production per unit time (g day^{-1}), which was calculated by using formula given by Radford (1967).

KHSb-2 JS-335

At 40 days after sowing

KHSb-2 JS-335

At 55 days after sowing

KHSb-2 JS-335

At 70 days after sowing

Plate 1. General view of the experimental plots

$$\text{AGR (g plant}^{-1}\text{ day}^{-1}) = \frac{W_2 - W_1}{t_2 - t_1}$$

Where

W_1 = Dry matter of the plant (g) at time t_1

W_2 = Dry matter of the plant (g) at time t_2

3.6.1.5.5 Relative growth rate (g g^{-1} $plant^{-1}$)

Relative growth rate (RGR) is the rate of increase in the dry weight per unit dry weight already accumulated and was calculated by using the formula of Blackman (1919).

$$\text{RGR (g g}^{-1}\text{ plant}^{-1}) = \frac{\text{Log}_e W_2 - \text{Log}_e W_1}{t_2 - t_1}$$

Where,

W_1 = Dry matter of the plant (g) at time t_1

W_2 = Dry matter of the plant (g) at time t_2

3.6.1.5.6 Crop growth rate (g m^{-2} day^{-1})

Crop growth rate (CGR) is the ratio of dry matter production per unit ground area per unit time, which was calculated by adopting the formula given by Watson (1952) and expressed as g m^{-2} day^{-1}.

$$\text{CGR (g m}^{-2}\text{ day}^{-1}) = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{A}$$

Where,

W_1 = Dry matter of the plant (g) at time t_1

W_2 = Dry matter of the plant (g) at time t_2

A = Unit land area occupied by the plant (m^2)

3.6.1.5.7 Net assimilation rate (g m^{-2} day)

Net assimilation rate (NAR) is the rate of dry weight increase per unit leaf area per unit time, which was calculated by the formula as adopted by Gregory (1926) and expressed as g m^{-2} day^{-1}.

$$\text{NAR (g m}^{-2}\text{ day}^{-1}) = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\log_e A_2 - \log_e A_1}{A_2 - A_1}$$

Where,

A_1 and W_1 = leaf area (m^2) and dry weight of the plant (g) at time t_1

A_2 and W_2 = leaf area (m^2) and dry weight of the plant (g) at time t_2

3.6.1.5.8 Specific leaf weight (g m^{-2})

The Specific leaf weight (SLW) indicates the average leaf thickness and was determined by the method suggested by Radford (1967) and expressed as g m^{-2}.

$$\text{SLW (g m}^{-2}) = \frac{\text{Leaf dry weight per plant (g)}}{\text{Leaf area per plant (m}^2)}$$

3.6.1.5.9 Leaf area duration (days)

Leaf area duration (LAD) is nothing but relation of potential green leaf area for a particular period and was worked out by the formula as suggested by Power *et al*. (1967).

$$LAD\ (days) = \frac{L_1 + L_2}{2} \times (t_2 - t_1)$$

Where,

L_1 = LAI at time t_1

L_2 = LAI at time t_2

3.6.1.5.10 Biomass duration (g days)

The biomass duration (BMD) was calculated by using the following formula of Sestak *et al*. (1971).

$$BMD\ (g\ days) = \frac{TDM_1 + TDM_2}{2} \times (t_2 - t_1)$$

Where,

TDM_1 = total dry matter (g) at t_1

TDM_2 = total dry matter (g) at t_2

3.6.2 Biochemical parameters

3.6.2.1 Chlorophyll content (mg/g fresh wt)

Shoaf and Lium (1976) devised an improved method of extraction of chlorophyll by dimethyl sulphoxide (DMSO). The fresh leaves were gently washed in water to remove dirt and were blotted gently with tissue paper to remove water. The fresh leaf tissue was cut into small pieces avoiding midrib and thick veins, 100 mg was weighed and incubated in 7.0 ml of DMSO at 65ºC for 30 minutes. At the end of the incubation period, supernatant was decanted and leaf tissue was discarded. The volume was made upto 10.0 ml with DMSO. The absorbance of the extract was measured at 645 nm, 652 nm and 663 nm in spectrophotometer (Spectro UV-VIS dual beam UVS-2700, Labomed Inc., USA) using DMSO as a blank. The chlorophyll 'a', chlorophyll 'b' and total chlorophyll contents were calculated by using formulae as given below and expressed as mg/g fresh weight.

$$\text{Chlorophyll 'a'} = 12.7\ (A_{663}) - 2.69\ (A_{645}) \times \frac{V}{1000 \times W \times a}$$

$$\text{Chlorophyll 'b'} = 22.9\ (A_{645}) - 4.68\ (A_{663}) \times \frac{V}{1000 \times W \times a}$$

Total chlorophyll = Chlorophyll 'a'+ Chlorophyll 'b'

Where,

A = Absorbance at specific wave length (645 and 663 nm)

V = Final volume of the chlorophyll extract (ml)

W= Fresh weight of the sample (g)

a = Path length of light (1 cm)

3.6.2.2 Nitrate reductase activity(n moles NO_2 g fr. $wt.^{-1}$ h^{-1})

The nitrate reductase activity (NRA) *in vivo* was estimated by following the method of Saradhambal *et al*. (1978). Leaves were cut into small round discs, and their fresh weight was determined. These discs were floated in petridish having 0.1 M KNO_3 under bright light for one hr for complete stomatal opening. The discs were transferred to 25 ml flasks containing 5.0 ml of solution having 0.1M phosphate buffer (pH 7.5), 0.02 M KNO_3, propanol (5%) and two drops of chloromphenicol (0.5 mg/ml) and incubated at 30ºC for 30 minutes in dark. The reaction was stopped by adding 0.1 ml of zinc acetate (1.0 M) and 1.0 ml of ethanol (70%). The contents were centrifuged at 3000 g for 10 minutes and the supernatant was collected. To which, 1.0 ml of sulphanilamide (1%) and 1.0 ml of NNEDA (0.02%) were added and incubated at room temperature for 20 minutes. The total volume in the test tubes was 9.0 ml. The absorbance of pink colour developed at the end of incubation was measured at 540 nm in spectrophotometer (Spectro UV-VIS dual beam UVS-2700, Labomed Inc., USA). The activity of nitrate reductase was determined from a standard curve of KNO_2 and expressed as nmol NO_2 formed per g fresh weight per hour.

3.6.2.3 Quality parameters

3.6.2.3.1 Seed protein and oil content

The protein and oil content in the seed was determined with the help of NMR (Nuclear Magnetic Resonance) spectrophotometer by directly feeding the sample in the cuvette. The oil and protein content was expressed in per cent.

3.6.3 Yield and yield components

Tagged plants used for recording morphological characters were harvested at physiological maturity and were used for recording following yield and yield components.

3.6.3.1 Number of pods per plant

Total filled pods present in tagged plants were counted and the mean was calculated and expressed as number of pods per plant.

3.6.3.2 Number of seeds per plant

Total number of seeds present in tagged plants was counted and the mean was calculated and expressed as number of seeds per plant.

3.6.3.3 Pod weight per plant (g)

The pods from tagged plants were separated, weighed and the average was calculated and expressed as pod weight per plant in grams.

3.6.3.4 100-seed weight (g)

The weight of 100-seeds drawn at random from the seed yield of three plants was recorded and expressed in grams.

3.6.3.5 Seed yield (g/plant)

Five tagged plants were uprooted at maturity and processed for seed yield, from which, the average was calculated and expressed as seed yield per plant in grams.

3.6.3.6 Seed yield (q/ha)

The pods from each net plot were threshed; cleaned and seed yield was calculated and expressed as q ha^{-1}.

3.7 Statistical analysis

Fisher's method of analysis of variance was applied for the analysis and interpretation of the experimental data as suggested by Panse and Sukhatme (1967). The level of significance used in 'F' and 't' test was P=0.5. Critical difference (CD) values were calculated at 5 per cent level, wherever 'F' test was significant.

4. EXPERIMENTAL RESULTS

Field experiment was conducted during *kharif*, 2009 to study the effect of different plant growth regulators *viz*., Progibb (20, 40 and 60 ppm), CCC (500 and 1000 ppm) and TIBA (100 and 200 ppm) as foliar spray with two varieties (KHSb-2 and JS-335) on growth, development, physiology, yield and quality of soybean (*Glycine max* (L.) Merrill) at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad. The results obtained from the investigation are presented in this chapter.

4.1 Morphological characters

Morphological characters *viz*., plant height, number of branches, days to initiation of flowering and 50% flowering were determined at different stages of crop growth (Plate 2 and 3) an influenced by different plant growth regulator treatments.

4.1.1 Plant height (cm)

The data on plant height presented in Table 5 indicated significant differences between the treatments and the varieties at all the growth stages. However, the interaction between the treatments and the varieties was non-significant at all the stages. In general, the plant height increased progressively upto harvest. Among the varieties, it was maximum in KHSb-2 compared to JS-335 at all the stages.

At 40 DAS, the maximum height (47.2 cm) was recorded in Progibb (60 ppm) and was significantly superior over all the treatments; while, it was on par with T_2 and T_1. Among the treatments, minimum height (31.7 cm) was recorded in TIBA (200 ppm) followed by T_7 and T_4 which did not differ significantly among themselves. The treatments T_1, T_5 and control also were found to be at par with each other. At 55 DAS, the plant height was significantly superior (57.5 cm) in Progibb (60 ppm) over all other treatments, except T_2 with which it was on par. Significantly lower plant height (37.8 cm) was observed in TIBA (200 ppm) which was at par with T_6; while, it differed significantly from rest of the treatments. The treatments T_4, T_5, T_1 and control performed to be at par with each other.

The plant height was found to be significantly superior (61.0 cm) in Progibb (60 ppm) compared to rest of the treatments, but was on par with T_2 and T_1 at 70 DAS and at harvest. TIBA (200 ppm) continued to have significantly lower plant height (43.7 cm) followed by T_6, T_5, T_4 and control which did not differ significantly among themselves. Similarly, the treatments T_1 and control did not differ significantly with each other.

4.1.2 Number of branches per plant

In general, the number of branches increased from 40 to 70 DAS, irrespective of the treatments and it differed significantly between the treatments and the varieties at all the stages (Table 6). However, the interaction between the treatments and the varieties was not significant at all the stages. The number of branches was maximum in JS-335 which differed significantly with KHSb-2.

At 40 DAS, the number of branches per plant in growth regulator treatments was non-significant. The number of branches per plant was maximum (11.1) in TIBA (100 ppm) at 55 DAS followed by T_4, T_5 and T_7 with which it was at par. Among the treatments, lower number of branches (9.1) was recorded in Progibb (20 ppm) followed by T_2 and T_3. However, the treatment Progibb (20 ppm) and control performed to be at par with each other. Similarly, the treatments T_3 and T_2, T_7 and T_5 did not differ significantly from each other.

At 70 DAS, significantly higher number of branches (13.0) was noticed in TIBA (100 ppm) which was significantly superior over all the treatments; while it was on par with T_4, T_5 and T_7. Lower number of branches (10.8) was seen in control followed by T_1, T_2 and T_3. However, the treatments T_1 and T_2 and T_8 were on par with each other.

Table 5. Influence of plant growth regulators on plant height (cm) at different growth stages in soybean

Treatments	40 DAS			55 DAS			70 DAS			At Harvest		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	50.6	34.8	42.7	60.5	39.1	49.8	66.2	43.2	54.7	67.7	45.6	56.7
T_2 - Progibb (40 ppm)	51.4	37.7	44.5	62.2	41.6	52.4	69.0	45.3	57.1	71.0	46.5	58.8
T_3 - Progibb (60 ppm)	54.1	40.2	47.2	67.2	47.9	57.5	71.8	50.3	61.0	72.5	51.7	62.1
T_4 - CCC (500 ppm)	44.7	32.5	38.6	55.4	36.1	45.8	62.5	43.3	52.9	63.2	43.3	53.3
T_5 - CCC (1000 ppm)	42.3	31.1	36.7	52.6	35.4	44.0	60.0	41.8	50.9	60.7	42.9	51.8
T_6 - TIBA (100 ppm)	39.8	30.2	35.0	49.8	33.8	41.8	59.8	40.0	49.9	60.2	40.2	50.2
T_7 - TIBA (200 ppm)	36.5	26.8	31.7	44.4	31.1	37.8	52.2	45.2	43.7	52.9	36.9	44.9
T_8 - Control	48.7	33.7	41.2	59.0	38.2	38.6	65.2	42.8	54.0	66.1	44.0	55.1
Mean	46.0	33.4	**39.7**	56.5	37.9	**47.2**	63.3	42.7	**53.0**	64.3	43.9	**54.1**
For Comparing means of	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**
Varieties (V)	0.41		1.19	0.49		1.42	0.61		1.77	0.57		1.65
Treatments (T)	0.83		2.38	0.99		2.85	1.23		2.54	1.15		3.31
Interaction (V×T)	1.17		**NS**	1.39		**NS**	1.74		**NS**	1.62		**NS**

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

T1: Progibb (20 ppm)

T2: Progibb (40 ppm)

T3 : Progibb (60 ppm)

T4: CCC (500 ppm)

T5: CCC (1000 ppm)

T6: TIBA (100 ppm)

T7: TIBA (200 ppm)

T8: Control

Plate 2. Growth and development of KHSb-2 plants at 70 DAS

T1: Progibb (20 ppm)

T2: Progibb (40 ppm)

T3: Progibb (60 ppm)

T4: CCC (500 ppm)

T5 : CCC (1000 ppm)

T6: TIBA (100 ppm)

T7: TIBA (200 ppm)

T8: Control

Plate 3. Growth and development of JS-335 plants at 70 DAS

Table 6. Influence of plant growth regulators on number of branches per plant at different growth stages in soybean

Treatments	40 DAS			55 DAS			70 DAS		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	5.7	6.2	6.0	8.5	9.7	9.1	10.2	11.5	10.9
T_2 - Progibb (40 ppm)	5.8	6.4	6.1	8.8	10.2	9.5	10.2	11.7	11.0
T_3 - Progibb (60 ppm)	5.8	6.6	6.2	9.0	10.6	9.8	10.6	12.3	11.4
T_4 - CCC (500 ppm)	6.2	7.0	6.6	10.2	11.7	11.0	12.1	13.6	12.9
T_5 - CCC (1000 ppm)	6.1	6.7	6.4	10.0	11.2	10.6	11.7	13.1	12.4
T_6 - TIBA (100 ppm)	6.7	7.0	6.8	10.3	12.0	11.1	12.2	13.8	13.0
T_7 - TIBA (200 ppm)	6.2	6.8	6.5	10.1	11.7	10.9	11.7	13.4	12.6
T_8 - Control	5.7	6.1	5.9	8.4	9.6	9.0	10.4	11.1	10.8
Mean	6.0	6.6	**6.3**	9.4	10.9	**10.1**	11.1	12.6	**11.8**
For Comparing means of	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**
Varieties (V)	0.15		0.45	0.11		0.32	0.08		0.22
Treatments (T)	0.31		NS	0.22		0.64	0.15		0.44
Interaction (V×T)	0.44		NS	0.31		NS	0.22		NS

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

Table 7. Influence of plant growth regulators on days to flower initiation and 50% flowering in soybean

Treatments	Days to initiation of flowering			Days to 50% flowering		
	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	44.8	35.5	40.1	47.9	38.8	43.3
T_2 - Progibb (40 ppm)	45.2	35.6	40.4	48.8	38.0	43.4
T_3 - Progibb (60 ppm)	44.3	34.9	39.6	49.0	38.1	43.6
T_4 - CCC (500 ppm)	46.0	36.0	41.0	47.0	37.0	42.0
T_5 - CCC (1000 ppm)	46.5	36.5	41.5	47.5	37.6	42.5
T_6 - TIBA (100 ppm)	47.6	37.7	42.7	50.0	39.0	44.5
T_7 - TIBA (200 ppm)	47.0	37.0	42.0	49.0	39.5	44.3
T_8 - Control	48.4	38.3	43.3	49.3	39.5	44.3
Mean	46.2	36.4	**41.3**	47.7	37.6	**42.6**
For Comparing means of	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**
Varieties (V)	0.07		0.21	0.12		0.34
Treatments (T)	0.15		0.43	0.84		NS
Interaction (V×T)	0.21		NS	0.33		NS

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

4.1.3 Days to flower initiation and 50% flowering

The data with respect to days to flower initiation indicated significant differences between the treatments and the genotypes (Table 7). The variety KHSb-2 showed delayed number of days for flower initiation (46.2) irrespective of the treatments as compared to JS-335. Among the treatments, Progibb (60 ppm) recorded significantly lower number of days for flower initiation (39.6) which was significantly lower compared to rest of the treatments; it was followed by T_2, T_1, T_4, T_5 and T_7. Significantly higher number of days for flower initiation was noticed in control (43.3) which was significantly higher compared to rest of the treatments. However, the interaction effect was non-significant.

However, non-significant differences were noticed among the growth regulator treatments with respect to days to 50% flowering.

4.2 Physiological parameters

4.2.1 Leaf dry weight (g)

The data on leaf dry weight revealed that it increased upto 70 DAS and the extent of increase was more between 40-55 DAS (Table 8). The genotypes differed significantly at all the growth stages with JS-335 having significantly higher leaf dry weight at 40 and 55 DAS as compared to KHSb-2; whereas, it recorded significantly lower leaf dry weight at 70 DAS than KHSb-2. However, the interaction between the genotypes and growth regulators was non-significant at all the growth stages.

Among the treatments, non significant differences were recorded in the production of leaf dry weight at 40 DAS. At 55 DAS, significantly higher leaf dry weight (6.42 g) was observed in CCC (500 ppm) which was significantly superior over control; while on par with rest of the treatments. Control recorded lower leaf dry weight (5.35 g) followed by T_7, T_1 and T_2 which did not differ significantly among themselves. Similarly, the treatments T_5 and T_3 did not differ significantly from each other. The treatment CCC (500 ppm) continued to record higher leaf dry weight (7.18 g) at 70 DAS also which was significantly superior over T_1 and control; while it was on par with rest of the treatments. Similarly, the treatments T_1 and control did not differ significantly with each other.

4.2.2 Stem dry weight (g)

It is evident from Table 9 that there were significant differences between the treatments at all the growth stages with respect to stem dry weight, except at 40 DAS and harvest. The stem dry weight almost doubled between 40 and 70 DAS and increased marginally thereafter in all the treatments. The genotypes differed significantly at all the growth stages with KHSb-2 having significantly higher stem dry weight as compared to JS-335 at all the growth stages.

At 40 DAS, no significant differences were recorded among the treatments for the production of stem dry matter. However, at 55 DAS, CCC (500 ppm) recorded significantly higher stem dry weight (6.42 g). It was on par with T_3, T_5, T_6 and T_2. Lower stem dry weight (5.1 g) was observed in control followed by T_1 which performed to be at par with each other. CCC (500 ppm) continued to record significantly higher stem dry weight (8.60 g) at 70 DAS followed by T_5, T_3, T_6 and T_2 with which it was at par. Lowest stem dry weight (7.46 g) was recorded in control followed by T_1 and T_7. Similarly, the treatments T_3, T_5 and T_2, T_1 and T_7 did not differ significantly from each other. No significant differences were found with stem dry weight at harvest. Interaction between the genotypes and growth regulators was also not significant at all the growth stages.

4.2.3 Dry weight of reproductive parts

The data on dry weight of reproductive parts recorded an increase from 70 DAS till harvest (Table 10). Among the genotypes, JS-335 recorded significantly higher dry weight of reproductive parts at both the stages as compared to KHSb-2.

At 70 DAS, significantly higher dry weight of reproductive parts was noticed with all the treatments except with Progibb (20 ppm) and TIBA (200 ppm) as compared to control. The higher dry weight of reproductive parts (7.22 g) was observed in CCC (500 ppm) which was significantly superior over rest of the treatments; while, it was on par with T_3. It was

followed by T_3, T_6, T_5 and T_2 which did not differ significantly. Significantly lower dry weight of reproductive parts was recorded in control (5.78 g) which was significantly lower compared to rest of the treatments. However, the treatments T_1, T_7 and control were at par with each other. At harvest, CCC (500 ppm) produced significantly higher dry weight of reproductive parts (20.27 g). However, it was on par with T_3 and T_6. Among the treatments, Progibb (20 ppm) produced significantly lower dry weight of reproductive parts (17.89 g) which was significantly lower over rest of the treatments and was followed by T_1, T_7 and T_5 which were at par with each other. However, control recorded significantly lower dry weight of the reproductive parts (16.97 g) as compared to Progibb (20 ppm).

4.2.4 Total dry weight

The total dry weight increased from 40 DAS to harvest in all the treatments (Table 11). The maximum total dry weight was noticed at harvest in all the growth regulator treatments and the increase was very high from 55 to 70 DAS. Among the genotypes, KHSb-2 recorded significantly higher total dry matter production as compared to JS-335 at all the stages.

At 40 DAS, CCC (1000 ppm) recorded significantly higher total dry weight (8.44 g) as compared to control; while, it was on par with other treatments. Control recorded significantly lower total dry weight (7.59 g). The treatment CCC (500 ppm) produced significantly higher total dry weight (12.84 g) which was significantly superior over T_1 and control at 55 DAS. However, it was on par with rest of the treatments. Among the treatments, control recorded significantly lower total dry weight (10.54 g) followed by T_1 and T_7, T_2 and T_6 which did not differ significantly with each other. A similar trend was noticed at 70 DAS with the treatments T_3 and T_5; T_2 and T_6 being on par with each other.

CCC (500 ppm) continued to produce significantly higher total dry weight (29.12 g) at harvest which was significantly superior over rest of the treatments. Among the treatments, Progibb (20 ppm) produced minimum total dry weight (26.18 g) which was significantly lower compared to rest of the treatments. However, control produced significantly lower total dry weight than Progibb (20 ppm). The treatments T_3, T_6, T_5, T_7 and T_2 were at par with each other.

4.2.5 Leaf area (dm^2/plant)

The data on leaf area presented in Table 12 indicated that leaf area increased upto 55 DAS and decreased thereafter towards maturity in JS-335. However, it continued to increase in KHSb-2 upto 70 DAS. The interaction between genotypes and plant growth regulators was non significant at all the growth stages. The genotype KHSb-2 produced significantly higher leaf area per plant than JS-335 at all the growth stages.

The treatment Progibb (60 ppm) produced significantly higher leaf area (10.05 dm^2) at 40 DAS, which was significantly superior over rest of the treatments. However, Progibb (60 ppm) was on par with T_2 and T_1. TIBA (200 ppm) recorded significantly lower leaf area (8.6 dm^2) which was significantly lower compared to T_3, T_2, T_1 and control. It was followed by T_6, T_5 and T_4 which did not differ significantly with each other. At 55 DAS, Progibb (60 ppm) continued to produce significantly higher leaf area (14.17 dm^2) compared to rest of the treatments, while, it was on par with T_2. TIBA (200 ppm) produced significantly lower leaf area (11.14 dm^2) followed by T_6, T_5 and T_4. Similarly, the treatments T_2 and T_1; T_4, T_5 and T_6 performed to be at par with each other. A similar trend was noticed at harvest.

4.2.6 Lear area index (LAI)

The data on LAI revealed that LAI increased upto 55 DAS and decreased thereafter towards maturity in JS-335 (Table 13). However, KHSb-2 recorded significantly higher LAI over JS-335 at all the growth stages.

Among the treatments, Progibb (60 ppm) showed significantly higher LAI (3.54) over rest of the treatments except T_2 and T_1. Increased LAI was recorded with the growth regulator treatments except TIBA and CCC (at both concentrations) where it decreased with TIBA (200 ppm) having lowest LAI (2.87) compared to rest of the treatments. However, it was on par with T_6, T_5 and T_4. The interaction effect was non-significant.

Table 8. Influence of plant growth regulators on leaf dry weight (g plant^{-1}) at different growth stages in soybean

Treatments	40 DAS			55 DAS			70 DAS		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	3.48	4.37	3.93	5.53	6.54	6.03	7.04	5.93	6.49
T_2 - Progibb (40 ppm)	3.52	4.39	3.96	5.57	6.59	6.08	7.28	6.32	6.80
T_3 - Progibb (60 ppm)	3.54	4.41	3.98	5.80	6.81	6.31	7.51	6.51	7.01
T_4 - CCC (500 ppm)	3.58	4.47	4.03	5.89	6.95	6.42	7.73	6.63	7.18
T_5 - CCC (1000 ppm)	3.56	4.46	4.01	5.87	6.93	6.40	7.66	6.62	7.14
T_6 - TIBA (100 ppm)	3.50	4.37	3.94	5.68	6.70	6.19	7.41	6.42	6.92
T_7 - TIBA (200 ppm)	3.49	4.33	3.91	5.55	6.51	6.03	7.23	6.27	6.75
T_8 - Control	3.10	3.87	3.49	4.91	5.79	5.35	6.19	5.65	5.92
Mean	3.47	4.33	**3.90**	5.60	6.60	**6.10**	7.26	6.29	**6.78**
For Comparing means of	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**
Varieties (V)	0.11		0.33	0.08		0.23	0.11		0.33
Treatments (T)	0.23		NS	0.16		0.46	0.23		0.66
Interaction (V×T)	0.32		NS	0.23		NS	0.32		NS

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

Table 9. Influence of plant growth regulators on stem dry weight (g plant^{-1}) at different growth stages in soybean

Treatments	40 DAS			55 DAS			70 DAS			At Harvest		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	5.16	3.28	4.22	6.80	4.78	5.79	8.91	6.96	7.93	10.40	6.18	8.29
T_2 - Progibb (40 ppm)	5.34	3.38	4.36	7.29	5.21	6.25	9.37	7.34	8.35	10.51	6.34	8.43
T_3 - Progibb (60 ppm)	5.47	3.47	4.47	7.31	5.27	6.29	9.42	7.45	8.44	10.54	6.42	8.48
T_4 - CCC (500 ppm)	5.25	3.33	4.29	7.49	5.36	6.42	9.63	7.56	8.60	10.72	6.98	8.85
T_5 - CCC (1000 ppm)	5.42	3.43	4.43	7.43	5.32	6.38	9.51	7.49	8.50	10.66	6.45	8.56
T_6 - TIBA (100 ppm)	5.40	3.42	4.41	7.27	5.31	6.29	9.36	7.43	8.40	10.60	6.42	8.51
T_7 - TIBA (200 ppm)	5.14	3.27	4.21	7.17	5.15	6.16	9.34	7.32	8.33	10.53	6.31	8.42
T_8 - Control	5.02	3.18	4.10	6.11	4.27	5.19	8.43	6.49	7.46	9.98	6.13	8.05
Mean	5.28	3.35	**4.31**	7.11	5.08	**6.10**	9.25	7.26	**8.25**	10.49	6.41	**8.45**
For Comparing means of	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**
Varieties (V)	0.12		0.34	0.11		0.31	0.10		0.28	0.11		0.31
Treatments (T)	0.24		NS	0.21		0.62	0.19		0.56	0.21		NS
Interaction (V×T)	0.45		NS	0.30		NS	0.27		NS	0.30		NS

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

Table 10. Influence of plant growth regulators on dry weight of reproductive parts (g plant^{-1}) at different growth stages in soybean

Treatments	70 DAS			Harvest		
	V_1	**V_2**	**Mean**	**V_1**	**V_2**	**Mean**
T_1 - Progibb (20 ppm)	5.54	6.27	5.91	17.63	18.15	17.89
T_2 - Progibb (40 ppm)	5.73	6.95	6.34	18.63	19.45	19.04
T_3 - Progibb (60 ppm)	5.96	7.74	6.85	19.13	20.37	19.75
T_4 - CCC (500 ppm)	6.52	7.92	7.22	19.92	20.61	20.27
T_5 - CCC (1000 ppm)	5.85	7.10	6.48	19.25	19.60	19.43
T_6 - TIBA (100 ppm)	6.02	7.22	6.62	19.42	19.71	19.57
T_7 - TIBA (200 ppm)	5.65	6.54	6.10	19.05	19.05	19.05
T_8 - Control	5.41	6.14	5.78	16.81	17.12	16.97
Mean	5.84	6.98	**6.41**	18.73	19.26	**18.99**
For Comparing means of	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**
Varieties (V)	0.08		0.24	0.12		0.34
Treatments (T)	0.17		0.48	0.23		0.68
Interaction (V×T)	0.23		NS	0.33		NS

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

Table 11. Influence of plant growth regulators on total dry weight (g plant^{-1}) at different growth stages in soybean

Treatments	40 DAS			55 DAS			70 DAS			At Harvest		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	8.64	7.65	8.14	12.33	11.32	11.83	21.49	19.16	20.33	28.03	24.33	26.18
T_2 - Progibb (40 ppm)	8.86	7.77	8.31	12.86	11.81	12.34	22.38	20.61	21.50	29.14	25.79	27.47
T_3 - Progibb (60 ppm)	9.01	7.88	8.44	13.11	12.08	12.59	22.89	21.71	22.30	29.67	26.79	28.23
T_4 - CCC (500 ppm)	8.83	7.81	8.32	13.37	12.31	12.84	23.88	22.11	22.99	30.64	27.59	29.12
T_5 - CCC (1000 ppm)	8.98	7.89	8.44	13.31	12.25	12.78	23.02	21.21	22.11	29.91	26.05	27.98
T_6 - TIBA (100 ppm)	8.90	7.80	8.35	12.95	12.01	12.48	22.80	21.06	21.93	30.02	26.13	28.08
T_7 - TIBA (200 ppm)	8.63	7.61	8.12	12.72	11.66	12.19	22.22	20.13	21.18	29.58	25.36	27.47
T_8 - Control	8.12	7.05	7.59	11.02	10.06	10.54	20.03	18.28	19.16	26.79	23.25	25.02
Mean	8.75	7.68	**8.21**	12.71	11.69	**12.20**	22.34	20.53	**21.44**	29.22	25.66	**27.44**
For Comparing means of	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**
Varieties (V)	0.07		0.21	0.13		0.38	0.15		0.42	0.14		0.40
Treatments (T)	0.14		0.41	0.26		0.76	0.29		0.84	0.28		0.80
Interaction (V×T)	0.20		NS	0.37		NS	0.41		NS	0.39		NS

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

Table 12. Influence of plant growth regulators on leaf area (dm^2 $plant^{-1}$) at different growth stages in soybean

Treatments	40 DAS			55 DAS			70 DAS		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	10.77	9.32	10.05	14.25	12.14	13.19	16.21	10.55	13.38
T_2 - Progibb (40 ppm)	11.12	9.63	10.37	14.62	12.52	13.57	16.84	10.94	13.89
T_3 - Progibb (60 ppm)	11.31	9.94	10.62	15.28	13.07	14.17	17.16	11.31	14.24
T_4 - CCC (500 ppm)	9.51	8.66	9.08	12.47	11.12	11.80	14.72	10.14	12.43
T_5 - CCC (1000 ppm)	9.09	8.49	8.79	12.00	11.03	11.51	14.22	9.83	12.03
T_6 - TIBA (100 ppm)	9.00	8.43	8.71	11.76	10.97	11.37	13.89	9.77	11.83
T_7 - TIBA (200 ppm)	8.85	8.35	8.60	11.41	10.86	11.14	13.41	9.62	11.51
T_8 - Control	10.36	8.87	9.62	12.96	11.39	12.18	14.87	10.24	12.56
Mean	10.00	8.96	**9.48**	13.09	11.64	**12.37**	15.17	10.30	**12.73**
For Comparing means of	**S. Em±**	**CD (5%)**		**S. Em±**	**CD (5%)**		**S. Em±**	**CD (5%)**	
Varieties (V)	0.11	0.32		0.14	0.40		0.15	0.44	
Treatments (T)	0.22	0.65		0.28	0.80		0.30	0.87	
Interaction (V×T)	0.32	NS		0.39	NS		0.43	NS	

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

Table 13. Influence of plant growth regulators on leaf area index (LAI) at different growth stages in soybean

Treatments	40 DAS			55 DAS			70 DAS		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	3.58	2.91	3.25	5.51	3.48	4.49	5.83	3.29	4.56
T_2 - Progibb (40 ppm)	4.21	3.00	3.60	6.20	3.50	4.85	6.49	3.33	4.91
T_3 - Progibb (60 ppm)	4.57	3.14	3.86	6.38	4.23	5.30	6.58	3.41	4.99
T_4 - CCC (500 ppm)	2.80	3.33	3.06	6.30	4.26	5.28	6.81	3.68	5.25
T_5 - CCC (1000 ppm)	4.19	3.43	3.81	5.34	3.90	4.62	5.74	3.49	4.61
T_6 - TIBA (100 ppm)	3.16	2.38	2.77	4.78	3.59	4.19	5.42	2.74	4.08
T_7 - TIBA (200 ppm)	2.63	2.45	2.54	4.56	3.27	3.91	4.73	2.88	3.81
T_8 - Control	3.33	2.63	2.98	4.79	3.37	4.08	5.15	2.67	3.91
Mean	3.56	2.91	**3.23**	5.48	3.70	**4.59**	5.84	3.19	**4.51**
For Comparing means of	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**
Varieties (V)	0.05		0.14	0.07		0.21	0.07		0.19
Treatments (T)	0.10		0.28	0.14		0.41	0.13		0.38
Interaction (V×T)	0.14		NS	0.20		NS	0.19		NS

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

At 55 DAS, Progibb (60 ppm) recorded significantly higher LAI (4.72) which was on par with T_2 and T_1. However, it was significantly superior over rest of the treatments. A lower LAI (3.71) was observed in TIBA (200 ppm) followed by T_6, T_5, T_4 and control which did not differ significantly among themselves. A similar trend was noticed at 70 DAS with Progibb (60 ppm) recording higher LAI (4.74) and TIBA (200 ppm) having lower LAI (3.84) over other treatments. Similarly, no significant differences were observed between the treatments T_1 and T_2, T_4 and control; T_5, T_6 and T_7. The interaction effect was also non-significant at all the stages.

4.2.7 Specific leaf weight (SLW, mg cm^{-2})

Table 14 revealed that SLW increased with the age of the crop and per cent increase was higher between 40 and 55 DAS (19.9%). The SLW was significantly higher in JS-335 as compared to KHSb-2 at all the growth stages. The SLW differed significantly at all the stages due to growth regulators as compared to control. The interaction between the genotypes and growth regulators was found to be non-significant at all the stages.

At 40 DAS, all the growth regulator treatments recorded significantly higher SLW as compared to control. Among the treatments, CCC (1000 ppm) recorded significantly higher SLW (4.58 mg cm^{-2}) which was superior over rest of the treatments followed by T_7, T_6 and T_4. However, the treatments T_4, T_6 and T_7 were at par with CCC (1000 ppm). Progibb (60 ppm) exhibited a lower SLW (3.78 mg cm^{-2}) and was significantly lower over rest of the treatments but was on par with T_2, T_1 and control. CCC (1000 ppm) continued to record a higher SLW (5.59 mg cm^{-2}) at 55 DAS followed by T_4, T_6 and T_7 which did not differ significantly with each other. Lower SLW was seen in control followed by Progibb (all three concentrations). However, no significant differences were observed between the treatments T_1, T_2, T_3 and control. A similar trend was noticed at 70 DAS with CCC (1000 ppm) showing higher SLW (6.60 mg cm^{-2}) over T_1, T_2, T_3 and control.

4.2.8 Leaf area duration (LAD, days)

The data on LAD indicated that it increased from 40-55 to 55-70 DAS (Table 15). LAD differed significantly between genotypes at all the growth stages. However, KHSb-2 recorded significantly higher LAD over JS-335 at all the growth stages.

Significant differences were recorded among the growth regulator treatments and the treatment Progibb (60 ppm) recorded significantly higher LAD (62 days) over rest of the treatments. However, it was on par with T_2 and T_1. TIBA (200 ppm) recorded significantly lower LAD (49.4 days) followed by T_6, T_5 and T_8 which did not differ significantly with each other. Similarly, no significant differences were observed between T_1 and control.

At 55-70 DAS, Progibb (60 ppm) continued to record higher LAD (71.0 days) over rest of the treatments, except T_2. A significantly lower LAD (56.6 days) was observed in TIBA (200 ppm) which was significantly lower compared to other treatments and was followed by T_6 and T_5. However, the treatments T_6 and T_7; T_4, T_5 and control were found to be at par with each other.

4.2.9 Biomass duration (BMD, g days)

The data on BMD presented in Table 16 indicated that it increased with the age of the crop. The BMD differed significantly due to growth regulator treatments and genotypes at all the growth stages. However, the interaction effect was not significant at all the stages.

At 40-55 DAS, KHSb-2 recorded higher BMD (162 g days) compared to JS-335 (147 g days). The BMD was significantly higher in the treatment CCC (100 ppm) followed by T_4 and T3 with which it was on par. However, CCC (500 ppm) was significantly superior over other treatments. Lower BMD (145 g days) was observed in control which was significantly lower compared to rest of the treatments. Similarly, T_1 and T_7; T_6 and T_2 did not differ significantly from each other.

Among the treatments, CCC (500 ppm) recorded higher BMD (268 g days) which was significantly higher over all other treatments at 55-70 DAS. Significantly lower BMD (238 g days) was recorded in control followed by T_7, T_2 and T_1. The treatments T_3 and T_6, T_1 and T_7 were at par with each other.

Table 14. Influence of plant growth regulators on specific leaf weight (SLW, mg cm^{-2}) at different growth stages in soybean

Treatments	40 DAS			55 DAS			70 DAS		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	3.23	4.68	3.96	3.88	5.39	4.64	4.35	5.80	5.08
T_2 - Progibb (40 ppm)	3.16	4.55	3.86	3.81	5.26	4.54	4.32	5.78	5.05
T_3 - Progibb (60 ppm)	3.13	4.43	3.78	3.80	5.21	4.51	4.32	5.76	5.04
T_4 - CCC (500 ppm)	3.76	5.16	4.46	4.72	6.25	5.49	5.25	6.54	5.90
T_5 - CCC (1000 ppm)	3.91	5.25	4.58	4.89	6.28	5.59	5.39	6.73	6.06
T_6 - TIBA (100 ppm)	3.88	5.18	4.53	4.83	6.11	5.47	5.33	6.57	5.95
T_7 - TIBA (200 ppm)	3.94	5.19	4.57	4.86	5.99	5.42	5.39	6.52	5.96
T_8 - Control	3.09	4.36	3.73	3.79	5.10	4.45	4.16	5.52	4.84
Mean	3.51	4.85	**4.18**	4.32	5.70	**5.01**	4.81	6.15	**5.48**
For Comparing means of	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**
Varieties (V)	0.06		0.17	0.06		0.17	0.07		0.20
Treatments (T)	0.12		0.35	0.12		0.33	0.14		0.40
Interaction (V×T)	0.17		NS	0.16		NS	0.20		NS

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

Table 15. Influence of plant growth regulators on leaf area duration (LAD, days) at different growth stages in soybean

Treatments	40-55 DAS			55-70 DAS		
	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	62.6	53.7	58.1	76.2	56.7	66.4
T_2 - Progibb (40 ppm)	64.4	55.4	59.9	78.6	58.6	68.6
T_3 - Progibb (60 ppm)	66.5	57.5	62.0	81.0	60.9	71.0
T_4 - CCC (500 ppm)	54.9	49.4	52.2	68.0	53.1	60.6
T_5 - CCC (1000 ppm)	52.7	48.8	50.8	65.6	52.1	58.8
T_6 - TIBA (100 ppm)	51.9	48.5	50.2	64.1	51.8	57.9
T_7 - TIBA (200 ppm)	50.7	48.0	49.4	62.0	51.2	56.6
T_8 - Control	58.0	50.6	54.3	69.6	54.1	61.8
Mean	57.7	51.5	**54.6**	70.6	54.8	**62.7**
For Comparing means of	**S. Em±**	**CD (5%)**		**S. Em±**	**CD (5%)**	
Varieties (V)	0.70	2.02		0.60	1.75	
Treatments (T)	1.40	4.03		1.21	3.49	
Interaction (V×T)	1.98	NS		1.71	NS	

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

Table 16. Influence of plant growth regulators on biomass duration (BMD, g days) at different growth stages in soybean

Treatments	40 -55 DAS			55-70 DAS		
	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	160	145	153	262	237	250
T_2 - Progibb (40 ppm)	163	146	155	265	243	254
T_3 - Progibb (60 ppm)	166	150	158	270	249	259
T_4 - CCC (500 ppm)	167	151	159	278	258	268
T_5 - CCC (1000 ppm)	167	151	159	272	251	262
T_6 - TIBA (100 ppm)	164	149	156	268	248	258
T_7 - TIBA (200 ppm)	160	144	152	262	238	250
T_8 - Control	153	137	145	248	228	238
Mean	162	147	**154**	266	244	**255**
For Comparing means of	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**
Varieties (V)	0.18		0.51	0.31		0.89
Treatments (T)	0.35		1.02	0.62		1.78
Interaction (V×T)	0.50		NS	0.87		NS

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

4.2.10 Crop growth rate (CGR, g m^{-2} day^{-1})

The data on crop growth rate (CGR) revealed that there was a decline in CGR with advancement in crop growth (Table 17). The CGR almost doubled at 55-70 DAS and decreased thereafter. Among the genotypes KHSb-2 was significantly superior over JS-335 at 55-70 DAS. However, no significant differences were recorded among the genotypes at other stages.

Among the growth regulator treatments, CCC (500 ppm) recorded significantly higher CGR (10.05 g m^{-2} day^{-1}) which was significantly higher compared to rest of the treatments except T_5 with which it was at par at 40-55 DAS. Lower CGR (8.18 g m^{-2} day^{-1}) was observed in Progibb (20 ppm) which was significantly lower compared to other treatments, but was on par with T_8. However, the treatments T_3, T_6, T_7 and T_2 did not differ significantly with each other. At 55-70 DAS, CCC (500 ppm) continued to record higher CGR (22.57 g m^{-1} day^{-1}) followed by T_3 and T_6. CCC (500 ppm) was significantly superior over T_5, T_2, T_7, T_1 and control; while it was on par with T_3 and T_6. Progibb (20 ppm) exhibited a lower CGR (19.32 g m^{-2} day^{-1}) followed by T_7 and T_2. However, Progibb (20 ppm) and control did not differ significantly. The interaction effect was also non-significant.

4.2.11 Absolute growth rate (AGR, g $plant^{-1}$ day^{-1})

The AGR decreased with an advancement in the crop growth. The AGR was maximum at 55-70 DAS and thereafter it decreased substantially (Table 18).

At 40-55 DAS, maximum AGR (0.301 g $plant^{-1}$ day^{-1}) was observed in CCC (500 ppm) which was significantly superior over T_1 and control. Significantly lower AGR (0.293 g $plant^{-1}$ day^{-1}) was seen in control followed by T_1, T_2, T_7, T_6 and T_3. However, the treatments T_3, T_6, T_7 and T_2 were found to be at par with each other. Again at 55-70 DAS, CCC (500 ppm) recorded significantly higher AGR (0.677 g $plant^{-1}$ day^{-1}) which was significantly superior over all the treatments, while it was at par with T_3. Among the treatments Progibb (20 ppm) recorded lower AGR (0.567 g $plant^{-1}$ day^{-1}) which was significantly lower than rest of the treatments except control. Similarly, T_6, T_5 and T_2; T_7 and T_1 did not differ significantly with each other.

No significant differences were observed among the treatments at 70 DAS.

4.2.12 Relative growth rate (RGR, g g^{-1} day^{-1} x 10^{-3})

The data on relative growth rate indicated that it decreased as growth advanced (Table 19) and maximum RGR was noticed at 40-55 DAS. The genotype JS-335 recorded significantly higher RGR as compared to KHSb-2 at all the growth stages except at 40-55 DAS. The interaction effect was however non-significant at all the stages.

The treatment CCC (500 ppm) showed significantly higher RGR (16.88 g g^{-1} day^{-1}) over T_2, T_7, T_5, T_1 and control at 40-55 DAS. However, it was on par with rest of the treatments. Significantly lower RGR (15.56 g g^{-1} day^{-1}) was seen in control followed by T_1, T_5, T_7 and T_2. However, the treatments T_2 and T_7, T_5, T_1 and T_8 were found to be at par with each other. At 55-70 DAS, CCC (500 ppm) continued to record significantly higher RGR (12.59 g g^{-1} day^{-1}) which was significantly superior over rest of the treatments except T_5 with which it was on par. Significantly lower RGR was observed in control (10.65 g g^{-1} day^{-1}) and was at par with T_1. It was followed by T_2, T_3, T_6 and T_7 which did not differ significantly from each other. At 70 DAS to harvest, no significant differences were recorded between the genotypes and treatments.

4.2.13 Net assimilation rate (NAR, g dm^{-2} day^{-1}×10^{-3})

It was observed from Table 20 that the NAR increased with an advancement in crop growth and maximum NAR was obtained at 55-70 DAS. Significant differences were noticed among the growth regulator treatments at all the growth stages. The interaction effect was non-significant. Among the genotypes, JS-335 recorded significantly higher NAR at all growth stages over KHSb-2.

Table 17. Influence of plant growth regulators on crop growth rate (CGR, g m^{-2} day^{-1}) at different growth stages in soybean

Treatments	40-55 DAS			55 -70 DAS			70-Harvest		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	8.20	8.16	8.18	20.36	18.27	19.32	5.45	5.74	5.59
T_2 - Progibb (40 ppm)	8.89	8.98	8.94	21.16	19.56	20.36	5.63	5.76	5.69
T_3 - Progibb (60 ppm)	9.11	9.33	9.22	21.73	21.40	21.57	5.65	5.84	5.75
T_4 - CCC (500 ppm)	10.10	10.00	10.05	23.36	21.78	22.57	5.63	6.09	5.86
T_5 - CCC (1000 ppm)	9.62	9.69	9.66	21.58	19.19	20.74	5.74	5.38	5.56
T_6 - TIBA (100 ppm)	9.00	9.38	9.19	21.89	20.11	21.00	6.02	5.63	5.82
T_7 - TIBA (200 ppm)	9.09	9.02	9.06	21.21	18.82	19.97	6.13	5.81	5.97
T_8 - Control	8.11	8.11	8.11	19.07	18.22	18.64	5.63	5.52	5.58
Mean	9.02	9.08	**9.05**	21.28	19.76	**20.52**	5.73	5.72	**5.73**
For Comparing means of	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**
Varieties (V)	0.12		NS	0.27		0.79	0.08		NS
Treatments (T)	0.25		0.71	0.55		1.58	0.15		NS
Interaction (V×T)	0.35		NS	0.77		NS	0.21		NS

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

Table 18. Influence of plant growth regulators on absolute growth rate (AGR, g plant^{-1} day^{-1}) at different growth stages in soybean

Treatments	40-55 DAS			55 -70 DAS			70-Harvest		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	0.246	0.245	0.245	0.611	0.547	0.567	0.167	0.172	0.170
T_2 - Progibb (40 ppm)	0.267	0.269	0.268	0.635	0.587	0.611	0.169	0.173	0.171
T_3 - Progibb (60 ppm)	0.273	0.280	0.277	0.652	0.642	0.647	0.170	0.169	0.170
T_4 - CCC (500 ppm)	0.303	0.300	0.301	0.701	0.653	0.677	0.169	0.183	0.176
T_5 - CCC (1000 ppm)	0.289	0.291	0.290	0.647	0.597	0.622	0.172	0.168	0.169
T_6 - TIBA (100 ppm)	0.271	0.281	0.276	0.656	0.603	0.630	0.181	0.169	0.175
T_7 - TIBA (200 ppm)	0.273	0.271	0.272	0.633	0.566	0.599	0.184	0.174	0.179
T_8 - Control	0.243	0.242	0.242	0.566	0.545	0.556	0.169	0.166	0.168
Mean	0.271	0.273	**0.272**	0.638	0.589	**0.613**	0.172	0.171	**0.172**
For Comparing means of	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**
Varieties (V)	0.006		NS	0.007		0.019	0.005		NS
Treatments (T)	0.012		0.036	0.013		0.039	0.010		NS
Interaction (V×T)	0.017		NS	0.055		NS	0.014		NS

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

Table 19. Influence of plant growth regulators on relative growth rate (RGR, g g^{-1} day^{-1}x10^{-3}) at different growth stages in soybean

Treatments	40-55 DAS			55 -70 DAS			70-Harvest		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	16.08	15.24	15.66	10.30	11.35	10.82	2.88	3.48	3.18
T_2 - Progibb (40 ppm)	16.04	16.12	16.08	10.79	12.12	11.45	2.87	3.25	3.06
T_3 - Progibb (60 ppm)	16.14	16.96	16.55	10.86	12.37	11.62	2.82	3.04	2.93
T_4 - CCC (500 ppm)	16.79	16.97	16.88	12.01	13.17	12.59	2.71	3.21	2.96
T_5 - CCC (1000 ppm)	15.86	15.89	15.88	11.39	12.74	12.07	2.84	2.99	2.92
T_6 - TIBA (100 ppm)	16.38	16.26	16.32	10.86	12.53	11.70	2.99	3.12	3.06
T_7 - TIBA (200 ppm)	16.15	15.81	15.98	11.23	12.39	11.81	3.11	3.34	3.23
T_8 - Control	15.97	15.15	15.56	10.01	11.28	10.65	2.77	3.01	2.89
Mean	16.18	16.05	**16.11**	10.93	12.24	**11.59**	2.87	3.18	**3.03**
For Comparing means of	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**
Varieties (V)	0.09		NS	0.09		0.27	0.05		0.15
Treatments (T)	0.19		0.55	0.18		0.53	0.10		NS
Interaction (V×T)	0.27		NS	0.26		NS	0.21		NS

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

Table 20. Influence of plant growth regulators on net assimilation rate (NAR, g dm^{-2} day^{-1} $\times 10^{-3}$) at different growth stages in soybean

Treatments	40-55 DAS			55-70 DAS		
	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	9.15	10.50	9.82	17.44	21.74	19.59
T_2 - Progibb (40 ppm)	9.30	10.62	9.96	17.55	21.75	19.65
T_3 - Progibb (60 ppm)	9.41	10.64	10.02	17.66	22.91	20.29
T_4 - CCC (500 ppm)	12.03	13.24	12.63	22.43	26.71	24.57
T_5 - CCC (1000 ppm)	11.94	13.01	12.48	21.50	24.90	23.20
T_6 - TIBA (100 ppm)	11.66	12.68	12.17	22.29	25.30	23.80
T_7 - TIBA (200 ppm)	11.55	12.31	11.93	22.14	23.98	23.06
T_8 - Control	9.10	10.26	9.68	17.35	21.62	19.49
Mean	10.52	11.66	**11.09**	19.80	23.61	**21.70**
For Comparing means of	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**
Varieties (V)	0.09		0.26	0.17		0.50
Treatments (T)	0.18		0.51	0.35		1.00
Interaction (V×T)	0.25		NS	0.35		NS

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

At 40-55 DAS, CCC (500 ppm) recorded significantly higher NAR (12.63 g dm^{-2} day^{-1} $\times 10^{-3}$) over all the other treatments. However, it was on par with T_5 and T_6 which did not differ significantly with each other. The minimum NAR (9.68 g dm^{-2} day^{-1} 10^{-3}) was noticed in control which was significantly lower compared to T_4, T_5, T_6 and T_7 but on par with rest of the treatments. Similarly, the treatments T_1, T_2 and T_3 did not differ significantly with control. Among the treatments, CCC (500 ppm) recorded significantly higher NAR (24.57 g dm^{-2} $day^{-1}10^{-3}$) followed by T_6, T_5 and T_7 which did not differ significantly among themselves. Significantly lower NAR (19.49 g dm^{-2} day^{-1} 10^{-3}) was recorded in Progibb (20 ppm) which was significantly lower compared to rest of the treatments; while it was on par with T_3, T_2 and control.

4.3 Biochemical parameters

4.3.1 Chlorophyll 'a' content (mg/g fr. wt)

The data on influence of growth regulators on chlorophyll 'a' content in leaf at different growth stages presented in Table 21 indicated that it decreased at later stage of crop (70 DAS). The significant difference in chlorophyll 'a' content was found at different growth stages due to genotypes. The genotype KHSb-2 recorded significantly lower chlorophyll 'a' content as compared to JS- 335 at all the stages except at 70 DAS. However, no significant differences were observed among the growth regulator treatments at 40 DAS.

Among the treatments, CCC (500 ppm) recorded significantly higher chlorophyll 'a' content (2.822 mg g fr. wt^{-1}) at 55 DAS which was significantly higher over T_2, T_7 ,T_1 and control; while on par with T_5 and T_3. Similarly, lower chlorophyll 'a' content (2.441 mg g fr. wt^{-1}) was observed in control which was significantly lower compared to rest of the treatments. It was followed by T_1 and T_2 which did not differ significantly with each other.

At 70 DAS, all the growth regulator treatments recorded higher chlorophyll 'a' content over control. The treatment CCC (500 ppm) exhibited significantly higher chlorophyll 'a' content (2.083 mg g fr. wt^{-1}) over T_2, T_1, T_7 and control; while it was on par with other treatments. Among the treatments lower chlorophyll 'a' content was recorded in Progibb (20 ppm) which was on par with T_7 and T_2. However, control recorded significantly lower chlorophyll 'a' content (1.745 mg g fr. wt^{-1}) than Progibb (20 ppm). The interaction effect between genotypes and growth regulators was non-significant at all the growth stages.

4.3.2 Chlorophyll b' content (mg/g fr. wt)

The chlorophyll 'b' content decreased with the age of the crop and differed significantly with genotypes and growth regulators at all the growth stages, except for the growth regulator treatments at 40 DAS (Table 22).

At 40 DAS, no significant differences were observed among the growth regulator treatments for chlorophyll 'b' content. However, at 55 DAS, CCC (500 ppm) recorded significantly higher chlorophyll 'b' content (0.725 mg g fr. wt^{-1}) which was significantly superior over control; while it did not differ significantly from rest of the treatments. It was followed by T_5, T_3, T_6, T_7 and T_2 which performed to be at par with each other. Control exhibited significantly lower chlorophyll 'b' content (0.600 mg g fr. wt^{-1}) compared to rest of the treatments. A similar trend was observed at 70 DAS with the treatment CCC (500 ppm) recording significantly higher chlorophyll 'b' content (0.597 mg g fr. wt^{-1}) over control (0.520 mg g fr. wt^{-1}).

4.3.3 Total chlorophyll content (mg/g fr. wt)

The total chlorophyll content decreased with advancement in crop growth and differed significantly between the treatments and varieties (Table 23). However, the interaction was found to be non-significant at all the stages. Among the genotypes, total chlorophyll content was maximum in JS-335 than KHSb-2 at all the stages except at 70 DAS.

At 40 DAS, no significant differences were observed among the growth regulator treatments for total chlorophyll content. Among the treatments, CCC (500 ppm) recorded significantly higher total chlorophyll content (3.547 mg g fr. wt^{-1}) at 55 DAS which was significantly superior over rest of the treatments. It was followed by T_5, T_3 and T_6 which performed to be at par with each other. Among the growth regulator treatments Progibb (20

ppm) exhibited significantly lower total chlorophyll content which was significantly lower compared to rest of the treatments. However, the control recorded significantly lower total chlorophyll content (3.040 mg g fr. wt^{-1}) than Progibb (20 ppm). The treatments T_3 and T_6; T_7 and T_2 did not differ significantly from each other.

At 70 DAS, CCC (500 ppm) continued to have significantly higher total chlorophyll content (2.677 mg g fr. wt^{-1}) which was significantly higher over rest of the treatments. Control recorded significantly lower total chlorophyll content (2.265 mg g fr. wt^{-1}) compared to other treatments. It was followed by T_1, T_2 and T_7 which did not differ significantly from each other. Similarly the treatments T_5, T_3 and T_6 were found to be at par with each other.

4.3.4 Nitrate reductase activity (NRA, µmol NO_2 g fr. $wt.^{-1}$ h^{-1})

The data on NRA presented in Table 24 indicated significant differences between the treatments and varieties at all the growth stages. It was observed in general that NRA was maximum at 55 DAS and reduced further at 70 DAS in all the treatments and in both the varieties. Among the varieties, the NRA was maximum in JS-335 at all the growth stages.

At 40 DAS, CCC (500 ppm) recorded significantly higher NRA (230 µmol NO_2 g fr. wt^{-1} h^{-1}) over the treatments T_1 and control; while on par with rest of the treatments. Significantly lower NRA (208.1 µmol NO_2 g fr. $wt.^{-1}$ h^{-1}) was seen in control followed by T_1, T_7 and T_2 which were at par with each other. Similarly, the treatments T_1 and T_8 did not differ significantly from each other.

Among the treatments, CCC (500 ppm) continued to record significantly higher NRA (294.8 µmol NO_2 g fr. wt^{-1} h^{-1}) at 55 DAS over all other treatments. The treatment Progibb (20 ppm) showed significantly lower NRA which was significantly lower compared to rest of the treatments. However, control recorded significantly lower NRA (244.7 µmol NO_2 g fr. $wt.^{-1}$ h^{-1}) than Progibb (20 ppm). The treatments T_3 and T_6; T_5, T_2 and T_7 performed to be at par with each other. A similar trend was noticed at 70 DAS with treatment CCC (500 ppm) recording significantly higher NRA (255.1 µmol NO_2 g fr. wt^{-1} h^{-1}) and control recording significantly lower NRA (211.6 µmol NO_2 g fr. $wt^{-1}h^{-1}$) compared to rest of the treatments.

4.3.5 Seed oil content (%)

The data pertaining to oil content in seed presented in Table 25 showed significant differences due to growth regulators. However, the genotypes did not differ significantly from each other. The interaction effect was also non-significant.

Among the treatments, TIBA (200 ppm) recorded significantly higher oil content (18.77%) over control and T_1; while, it was on par with rest of the treatments. The treatments T_5, T_6, T_4 and T_3; T_8 and T_1 performed to be at par with each other. The interaction effect was non-significant.

4.3.6 Seed protein content (%)

The data pertaining to seed protein content presented in Table 25 showed significant differences only due to genotypes with genotype KHSb-2 having significantly higher protein content (38.17 %) as compared to JS-335 (37.48%).

4.4 Yield and yield components

4.4.1 Number of pods per plant

The data on number of pods per plant presented in Table 26 indicated significant differences between genotypes and growth regulators. The genotype KHSb-2 was found to be significantly superior over JS-335 whereas, all the treatments registered significantly higher number of pods per plant over control. Among the treatments, CCC (500 ppm) recorded significantly higher number of pods per plant (77.2) which was significantly superior over rest of the treatments. However, the treatments T_3 and T_6; T_5 and T_2 were at par with each other. Significantly lower number of pods per plant was observed in control (64.0) which was significantly lower compared to rest of the treatments. The interaction of growth regulators and genotypes was non-significant.

Table 21. Influence of plant growth regulators on chlorophyll 'a' content (mg g fr. wt.$^{-1}$) in leaf at different growth stages in soybean

Treatments	40 DAS			55 DAS			70 DAS		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	1.325	1.770	1.547	2.357	3.022	2.689	2.051	1.873	1.962
T_2 - Progibb (40 ppm)	1.340	1.785	1.563	2.400	3.057	2.729	2.070	1.900	1.985
T_3 - Progibb (60 ppm)	1.348	1.806	1.577	2.441	3.098	2.769	2.106	1.927	2.017
T_4 - CCC (500 ppm)	1.366	1.830	1.598	2.486	3.158	2.822	2.145	2.020	2.083
T_5 - CCC (1000 ppm)	1.362	1.824	1.593	2.443	3.133	2.788	2.107	1.950	2.029
T_6 - TIBA (100 ppm)	1.352	1.799	1.576	2.445	3.090	2.767	2.091	1.937	2.014
T_7 - TIBA (200 ppm)	1.346	1.796	1.571	2.428	3.063	2.746	2.057	1.910	1.984
T_8 - Control	1.300	1.740	1.520	2.160	2.722	2.441	1.880	1.610	1.745
Mean	1.342	1.794	**1.568**	2.395	3.043	**2.719**	2.063	1.891	**1.977**
For Comparing means of	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**
Varieties (V)	0.021		0.060	0.010		0.028	0.012		0.034
Treatments (T)	0.041		NS	0.02		0.057	0.023		0.068
Interaction (V×T)	0.058		NS	0.028		NS	0.033		NS

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

Table 22. Influence of plant growth regulators on chlorophyll 'b' content (mg g fr. wt.$^{-1}$) in leaf at different growth stages in soybean

Treatments	40 DAS			55 DAS			70 DAS		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	0.391	0.462	0.426	0.789	0.588	0.689	0.666	0.473	0.569
T_2 - Progibb (40 ppm)	0.395	0.466	0.431	0.806	0.594	0.700	0.672	0.478	0.575
T_3 - Progibb (60 ppm)	0.399	0.474	0.436	0.820	0.602	0.711	0.683	0.482	0.583
T_4 - CCC (500 ppm)	0.404	0.480	0.442	0.837	0.613	0.725	0.696	0.497	0.597
T_5 - CCC (1000 ppm)	0.402	0.478	0.440	0.817	0.608	0.713	0.684	0.486	0.585
T_6 - TIBA (100 ppm)	0.395	0.472	0.434	0.821	0.600	0.711	0.678	0.484	0.581
T_7 - TIBA (200 ppm)	0.395	0.469	0.432	0.815	0.595	0.705	0.667	0.479	0.573
T_8 – Control	0.380	0.403	0.392	0.700	0.500	0.600	0.610	0.430	0.520
Mean	0.395	0.463	**0.429**	0.801	0.588	**0.694**	0.670	0.476	**0.573**
For Comparing means of	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**
Varieties (V)	0.01		0.02	0.01		0.018	0.01		0.02
Treatments (T)	0.01		NS	0.01		0.036	0.01		0.03
Interaction (V×T)	0.17		NS	0.02		NS	0.02		NS

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

Table 23. Influence of plant growth regulators on total chlorophyll content (mg g fr. wt.$^{-1}$) in leaf at different growth stages in soybean

Treatments	40 DAS			55 DAS			70 DAS		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	1.715	2.232	1.973	3.146	3.610	3.378	2.717	2.347	2.532
T_2 - Progibb (40 ppm)	1.735	2.251	1.993	3.206	3.651	3.428	2.741	2.380	2.561
T_3 - Progibb (60 ppm)	1.747	2.280	2.014	3.260	3.700	3.480	2.789	2.407	2.598
T_4 - CCC (500 ppm)	1.771	2.310	2.041	3.324	3.771	3.547	2.841	2.513	2.677
T_5 - CCC (1000 ppm)	1.764	2.302	2.033	3.260	3.742	3.501	2.791	2.440	2.616
T_6 - TIBA (100 ppm)	1.747	2.271	2.009	3.266	3.690	3.478	2.769	2.420	2.595
T_7 - TIBA (200 ppm)	1.740	2.264	2.002	3.243	3.658	3.451	2.724	2.390	2.557
T_8 - Control	1.680	2.190	1.935	2.860	3.220	3.040	2.490	2.040	2.265
Mean	1.737	2.262	**2.00**	3.196	3.630	**3.413**	2.733	2.367	**2.550**
For Comparing means of	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**
Varieties (V)	0.015		0.044	0.01		0.02	0.010		0.029
Treatments (T)	0.031		NS	0.015		0.042	0.020		0.058
Interaction (V×T)	0.17		NS	0.02		NS	0.028		NS

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

Table 24. Influence of plant growth regulators on nitrate reductase activity (μ moles NO_2 g fr. wt.$^{-1}$ h^{-1}) in leaf at different growth stages in soybean

Treatments	40 DAS			55 DAS			70 DAS		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	202.0	218.5	210.3	246.2	282.8	264.5	211.8	246.1	228.9
T_2 - Progibb (40 ppm)	212.4	229.3	220.9	264.3	296.6	280.4	227.2	258.3	242.8
T_3 - Progibb (60 ppm)	217.3	239.1	228.2	269.6	308.5	289.1	231.8	268.6	250.2
T_4 - CCC (500 ppm)	219.1	240.9	230.0	276.1	313.5	294.8	237.3	272.8	255.1
T_5 - CCC (1000 ppm)	214.1	230.6	222.3	265.3	297.4	281.3	228.2	259.2	243.7
T_6 - TIBA (100 ppm)	218.7	233.8	226.2	271.1	302.0	286.5	233.2	263.2	248.2
T_7 - TIBA (200 ppm)	210.8	227.9	219.3	260.5	294.5	277.5	224.3	256.3	240.3
T_8 - Control	201.2	215.1	208.1	232.8	256.5	244.7	200.2	223.1	211.6
Mean	212.0	229.4	**220.7**	260.7	294.0	**277.3**	224.3	256.0	**240.1**
For Comparing means of	**S. Em±**	**CD (5%)**		**S. Em±**	**CD (5%)**		**S. Em±**	**CD (5%)**	
Varieties (V)	1.80	5.19		0.79	2.27		0.79	2.28	
Treatments (T)	3.59	10.38		1.57	4.54		1.58	4.55	
Interaction (V×T)	5.08	NS		2.23	NS		2.23	NS	

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

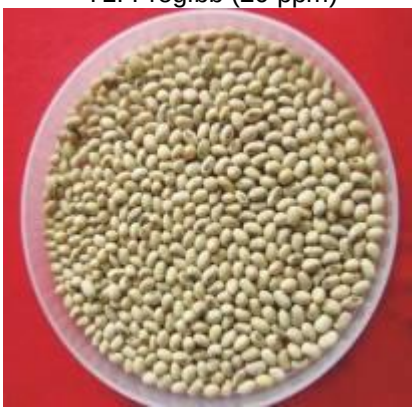
Table 25. Influence of plant growth regulators on seed quality parameters in soybean

Treatments	Seed oil content (%)			Seed protein content (%)		
	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	18.40	18.13	18.27	38.53	37.60	38.07
T_2 - Progibb (40 ppm)	18.87	18.67	18.77	37.97	37.50	37.73
T_3 - Progibb (60 ppm)	18.30	18.63	18.46	38.33	37.33	37.83
T_4 - CCC (500 ppm)	18.37	18.77	18.57	38.33	37.20	37.77
T_5 - CCC (1000 ppm)	18.67	18.50	18.58	38.11	37.47	37.79
T_6 - TIBA (100 ppm)	18.57	18.59	18.58	38.47	37.50	37.98
T_7 - TIBA (200 ppm)	18.83	18.70	18.77	37.93	37.50	37.72
T_8 - Control	18.60	18.20	18.40	37.67	37.73	37.70
Mean	18.58	18.52	**18.55**	38.17	37.48	**37.82**
For Comparing means of	**S. Em±**		**CD (5%)**	**S. Em±**		**CD (5%)**
Varieties (V)	0.05		NS	0.07		0.19
Treatments (T)	0.10		0.28	0.13		NS
Interaction (V×T)	0.14		NS	0.19		NS

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

T1: Progibb (20 ppm)

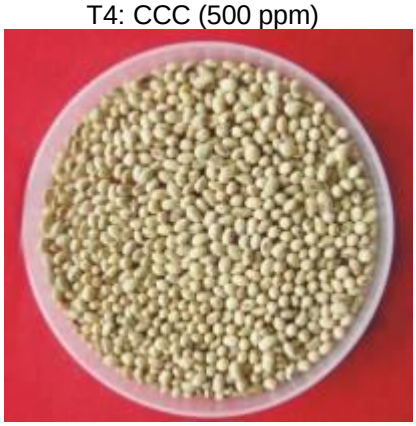
T2: Progibb (40 ppm)



T3: Progibb (60 ppm)

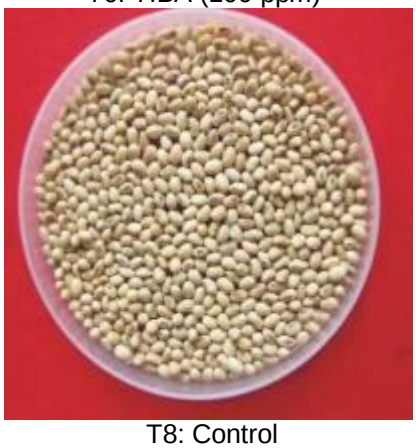
T4: CCC (500 ppm)

T5: CCC (1000 ppm)



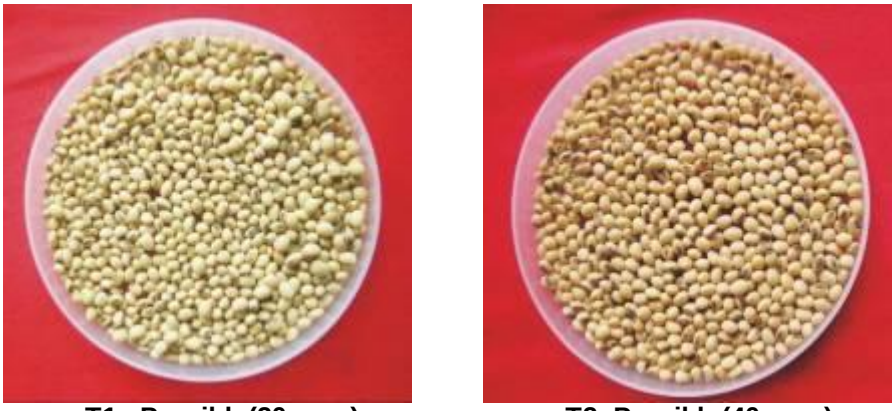
T6: TIBA (100 ppm)

T7: TIBA (200 ppm)



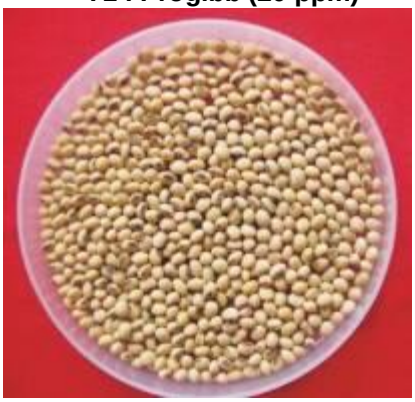
T8: Control

Plate 4. Influence of plant growth regulators on JS-335 seeds



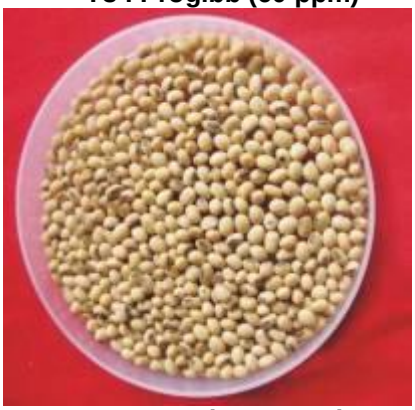
T1 : Progibb (20 ppm)

T2: Progibb (40 ppm)



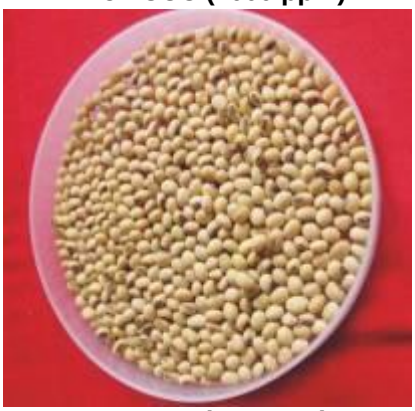
T3 : Progibb (60 ppm)

T4: CCC (500 ppm)

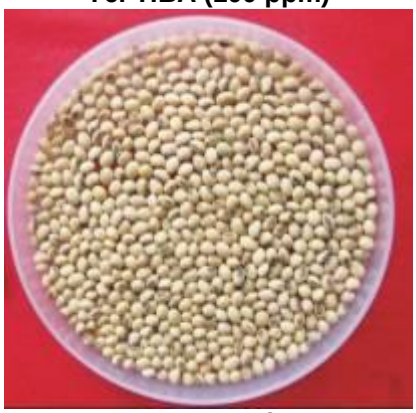


T5 : CCC (1000 ppm)

T6: TIBA (100 ppm)



T7: TIBA (200 ppm)



T8: Control

Plate 5. Influence of plant growth regulators on KHSb-2 Seeds

Table 26. Influence of plant growth regulators on yield components in soybean

Treatments	No. of seeds / plant			No. of pods/plant			Pods weight/plant (g.)			100 –seed wt. (g.)		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	110.1	121.6	115.8	71.7	66.8	69.2	15.0	18.1	16.6	9.10	12.00	10.55
T_2 - Progibb (40 ppm)	118.6	127.7	123.1	77.0	70.1	73.5	16.1	19.0	17.6	9.80	12.61	11.21
T_3 - Progibb (60 ppm)	121.1	132.7	126.9	78.5	72.7	75.6	16.4	19.7	18.1	10.00	13.10	11.55
T_4 - CCC (500 ppm)	124.2	134.4	129.3	80.4	74.0	77.2	16.8	20.1	18.5	10.20	13.37	11.78
T_5 - CCC (1000 ppm)	119.4	128.4	123.7	77.6	70.4	74.0	16.2	19.1	17.6	9.78	12.70	11.24
T_6 - TIBA (100 ppm)	121.9	130.0	125.9	79.1	71.2	75.2	16.5	19.4	18.0	10.00	12.87	11.43
T_7 - TIBA (200 ppm)	117.4	126.6	122.0	75.9	69.6	72.7	15.9	18.8	17.3	9.62	12.52	11.07
T_8 - Control	104.7	110.3	107.5	67.6	60.3	64.0	14.1	16.4	15.3	8.60	10.91	9.75
Mean	**117.2**	**126.4**	**121.8**	**76.0**	**69.4**	**72.7**	**15.9**	**18.8**	**17.4**	**9.64**	**12.51**	**11.07**
For Comparing means of	**S. Em±**	**CD (5%)**		**S. Em±**	**CD (5%)**		**S. Em±**	**CD (5%)**		**S. Em±**	**CD (5%)**	
Varieties (V)	0.36	1.03		0.17	0.50		0.16	0.37		0.12	0.34	
Treatments (T)	0.71	2.05		0.35	1.00		0.33	0.94		0.23	0.67	
Interaction (V×T)	1.01	NS		0.49	NS		0.46	NS		0.33	NS	

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

Table 27. Influence of plant growth regulators on yield in soybean

Treatments	Seed yield per plant (g)			Seed yield (q ha^{-1})		
	V_1	V_2	Mean	V_1	V_2	Mean
T_1 - Progibb (20 ppm)	8.85	10.05	9.45	29.5	33.6	31.6
T_2 - Progibb (40 ppm)	9.40	10.62	10.01	31.5	35.3	33.4
T_3 - Progibb (60 ppm)	9.65	11.11	10.38	32.5	37.1	34.8
T_4 - CCC (500 ppm)	10.05	11.21	10.63	33.5	37.5	35.5
T_5 - CCC (1000 ppm)	9.71	10.72	10.22	32.3	35.7	34.0
T_6 - TIBA (100 ppm)	9.80	10.73	10.27	32.9	36.2	34.5
T_7 - TIBA (200 ppm)	9.61	10.62	10.12	31.7	35.3	33.5
T_8 - Control	8.48	9.34	8.91	28.2	31.2	29.7
Mean	**9.44**	**10.55**	**10.00**	**31.5**	**35.2**	**33.3**
For Comparing means of	**S. Em±**	**CD (5%)**		**S. Em±**	**CD (5%)**	
Varieties	0.11	0.32		0.08	0.24	
Treatments	0.22	0.64		0.17	0.48	
Interaction (V×T)	0.31	NS		0.23	NS	

V_1 : KHSb-2 V_2 : JS-335 NS : Non-significant

4.4.2 Number of seeds per plant

It is evident from Table 26 that significant differences were noticed both in growth regulator treatments and genotypes with respect to number of seeds per plant (Plate 4 and 5). Among the genotypes, JS-335 recorded significantly higher number of seeds per plant (110.3) over KHSb-2 (104.7). Among the treatments, CCC (500 ppm) recorded significantly higher number of seeds per plant (129.3) which was significantly higher over rest of the treatments. All other treatments also recorded significantly higher number of seeds per plant as compared to control. However, T_3 and T_6; T_5, T_2 and T_7 did not differ significantly with each other. Significantly lower number of seeds per plant was observed in control (107.5). The interaction effect was non-significant.

4.4.3 Pod weight per plant (g/plant)

The pod weight per plant indicated significant differences due to genotypes and growth regulators (Table 26). Among the genotypes, JS-335 recorded significantly higher pod weight per plant (18.8 g) over KHSb-2 (15.9 g) whereas, among the treatments, CCC (500 ppm) exhibited significantly higher pod weight per plant (18.50 g) followed by T_3, T_6, T_5 and T_2 which did not differ significantly among themselves. Significantly lower pod weight (15.30 g) was observed in control which was significantly lower than rest of the treatments. However, the interaction of growth regulators and genotypes was non-significant.

4.4.4 100-seed weight (g)

The data on 100-seed weight revealed significant differences due to genotypes and growth regulator treatments (Table 26). The treatment CCC (500 ppm) recorded significantly higher 100-seed weight (11.78 g) which was significantly higher over T_1 and control; while, on par with rest of the treatments. Significantly lower 100-seed weight (9.75 g) was noticed in control which was significantly lower compared to other treatments while the treatments T_1, T_7, T_2 and T_5 which did not differ significantly among themselves. The interaction of growth regulators and genotypes was non-significant.

4.4.5 Seed yield (g/plant)

It is evident from Table 27 that growth regulators had significant influence on seed yield per plant. Similarly, the genotypes also differed significantly with JS-335 having significantly higher seed yield per plant (10.55 g) compared to KHSb-2 (9.44 g), irrespective of the treatments. CCC (500 ppm) exhibited significantly higher seed yield per plant (10.63 g) which was significantly superior over T_1 and T_8 while on par with rest of the treatments. Significantly lower seed yield per plant (8.91 g) was seen in control followed by T_1, T_2, T_7, T_5 and T_6. However, the treatments T_6, T_7 and T_5; T_2 and T_1 were at par with each other. The interaction was non-significant.

4.4.6 Seed yield (q/ ha)

The data related to seed yield (q. ha^{-1}) revealed significant differences due to genotypes and growth regulator treatments (Table 27). However, the treatment CCC (500 ppm) maintained significantly higher value (35.5 q ha^{-1}) over other treatments and control except T_3 with which it was at par. Significantly lower seed yield per ha was recorded in control (29.7 q ha^{-1}) which was significantly lower compared to rest of the treatments followed by T_1, T_2, T_7, T_5 and T_6. However, T_3 and T_6; T_2 and T_7 did not differ significantly with each other. Among the genotypes, JS-335 recorded significantly higher seed yield (35.2 q ha^{-1}) as compared to KHSb-2. However, the interaction effect was found to be non-significant.

5. DISCUSSION

Soybean, an important grain legume is making a headway in Indian agriculture to meet the protein and oil requirement. It is an excellent source of major nutrients including vitamin A, B and D, unsaturated fatty acids and minerals like Ca and P that can meet different nutritional needs. Soybean contributes more than 41 per cent of total oil seed production of the world. As a feed and food crop, soybean is gaining an important position in the agriculture of tropical and sub- tropical countries including India, Sri- Lanka, Thailand and Bangladesh. Hence, there is vast scope for improving the productivity potential of soybean by using different means particularly, the use of plant growth regulators.

In view of the ever increasing national population (1162.3 millions, Anon., 2010) and depleting natural resources (reduced cropping area and water supply in coming decades), a quantum jump in food production is the most desired goal. Our visionaries have enabled us to achieve the marvels of Green-Revolution by best organic practices, intensive land use and high yielding crop varieties. Any further demand of additional food production must be met by better and integrated management practices. This is particularly true in food-sector, wherein increasing resistance to GMOs (Genetically Modified Organisms) and GM-Foods are felt. Hence, there is an immediate need to enhance the yield potential of crops by managerial amendments. Although high yielding hybrid-crop varieties do extremely well under normal management practices, very seldom their full genetic potential is realised. Faced with such constraints, application of plant growth regulators (PGRs), for higher yields, is gaining momentum. PGR-induced higher yields are due to altered photosynthate distributive patterns within the plant and as such do not require any additional agricultural inputs.

As the plant growth and development is a complex process and there are two factors which influence the reaction and metabolism of plants and thus regulate the developmental pattern of plant. One of them is a system of endogenous chemical messengers, called hormones. The second one comprises more or less interdependent set of external environmental factors such as light, water, temperature and gravity, which play indispensable role in the development as do hereditary factors which have been transmitted from its biological parents.

Thus an attempt has been made to find out the influence of plant growth regulators on crop growth, physiology, yield and quality in two soybean varieties, KHSb-2 and JS-335. The results obtained from the investigation are discussed in this chapter.

5.1 Morphological characters

The effect of various growth regulators on morphological characters like plant height, number of branches, days to flower initiation and 50% flowering indicated that these parameters differed significantly due to growth regulators. It is further evident that the genotypes differed significantly with respect to all the morphological characters in all growth regulator treatments, but none of the morphological characters showed significant interaction between growth regulator and genotypes.

Basically, plant height is a genetically controlled character, but several studies indicated that the plant height is influenced by the application of PGRs. Remarkable increase in plant height was observed with Progibb application and it was maximum with the foliar application of Progibb (60 ppm) and minimum in TIBA (200 ppm). There are numerous reports in the literature showing that GA promotes the growth of intact plants. The promotion of growth either in terms of increase in plant height or the leaf area has been thought to be by increasing plasticity of the cell wall followed by hydrolysis of starch to sugars which lowers the water potential of cell, resulting in the entry of water into the cell causing elongation. These osmotic driven responses under the influence of GA might have attributed for an increase in photosynthetic activity, accelerated translocation and efficiency of utilizing photosynthetic products, thus resulting in increased cell elongation and rapid cell division in growing portion (Sargent, 1965). These results are in conformity with the findings of Emongor (2007) in cowpea and Vasudevan *et al*. (2008) in fenugreek.

Increasing concentration of growth retardants like CCC and TIBA significantly reduced the plant height to a greater extent and the application of TIBA (200 ppm) caused a greater reduction in plant height. The mechanism of reduction in plant height appears to be

due to the nature of onium compounds to which CCC belongs, which is known to interfere in GA biosynthetic pathway before the cyclization of geranyl-geranyl pyrophosphate. Thus, the reduced plant height is due to retardation of transverse cell division, particularly in stellar cambium, which is zone of meristematic activity (Grossman, 1990). Though, TIBA is also a growth retardant and its mode of action is different from CCC which inhibit the basipetal polar transport of auxin leading to decreased plant height (Hopkins, 1995). Among the genotypes, KHSb-2 had significantly higher plant height compared to JS-335 indicating differential response of growth regulators with genotypes.

The number of branches per plant differed significantly among the treatments and increased due to application of PGRs. Among these, TIBA followed by CCC and Progibb recorded maximum number of branches which was in accordance with the study of Deotale *et al*. (1995). An increase in number of branches by TIBA might be due to inhibition of apical bud dominance and breaking of lateral bud dormancy.

The knowledge of influence of PGRs application on flowering is of interest for understanding both internal mechanisms regulating flowering and practical usefulness of controlling the time and degree of flowering. The treatment Progibb (60 ppm) hastened the days for flower initiation followed by CCC and TIBA. PGRs application increased the synthesis of certain endogenous growth substances, which triggers metabolic processes and narrows down the carbon - nitrogen ratio in the plant inturn stimulating flowering and fruit set. Similar results were obtained by Castro and Vello (1981) in soybean; Resmi and Gopalkrishnan (2004) in yard long bean.

5.2 Physiological parameters

The amount of total dry matter produced is an indication of the overall efficiency of utilization of resources and better interception of light. The partitioning of total dry matter in leaf, stem and reproductive parts varied significantly due to the genotypes and growth regulator treatments.

In both the genotypes, leaf dry weight increased only upto 70 DAS, whereas, stem dry weight increased upto maturity only in genotype KHSb-2. The decline in stem and leaf dry weight in JS-335 after 70DAS might be due to translocation of stored photosynthates towards the developing reproductive organs. Similarly, Morandy *et al*. (1984) also reported decreased stem dry weight due to CCC treatment. The dry weight of reproductive parts increased continuously throughout the growing period due to growth regulator treatments. The enhanced dry weight of reproductive parts by growth regulators is due to increased pods per plant and also efficient translocation of assimilates from leaf and stem to reproductive parts which was similar with findings of Kulkarni (1993) in sunflower. Among the genotypes, KHSb-2 recorded significantly higher total dry weight than JS-335 due to different growth habits and duration of variety (Figure 2).

5.3 Growth parameters

Crop yield is mainly dependent on the interplay of various physiological and biochemical functions of the plant in addition to the impact of growing environment. The cause and effect relationship is difficult to understand mainly because of complexity in understanding the interplay of several processes and functions which ultimately lead to changes not only in growth, development and physiology, but also on the yield, which is the most complex character. It is well established that the infrastructure of the plant is decided by the growth parameters like leaf area, LAI, AGR, CGR, RGR, TDM, NAR and BMD. The growth analysis technique has been adopted as one of the standard approaches in the absence of sophisticated instruments to analyze the structure of yield in several crops.

It has been observed in the present study that the application of plant growth regulators had profound influence on assimilatory surface area and its associated characters. Leaf area fairly gives a good idea of photosynthetic capacity of the plant. The leaf area increased upto 55 DAS in JS-335 and upto 70 DAS in KHSb-2 and decreased thereafter till physiological maturity due to senescence and ageing of leaves (Figure 3). Significant differences were also noticed with regard to leaf area among the genotypes and the leaf area was significantly higher in KHSb-2 as compared to JS-335 at all the stages.

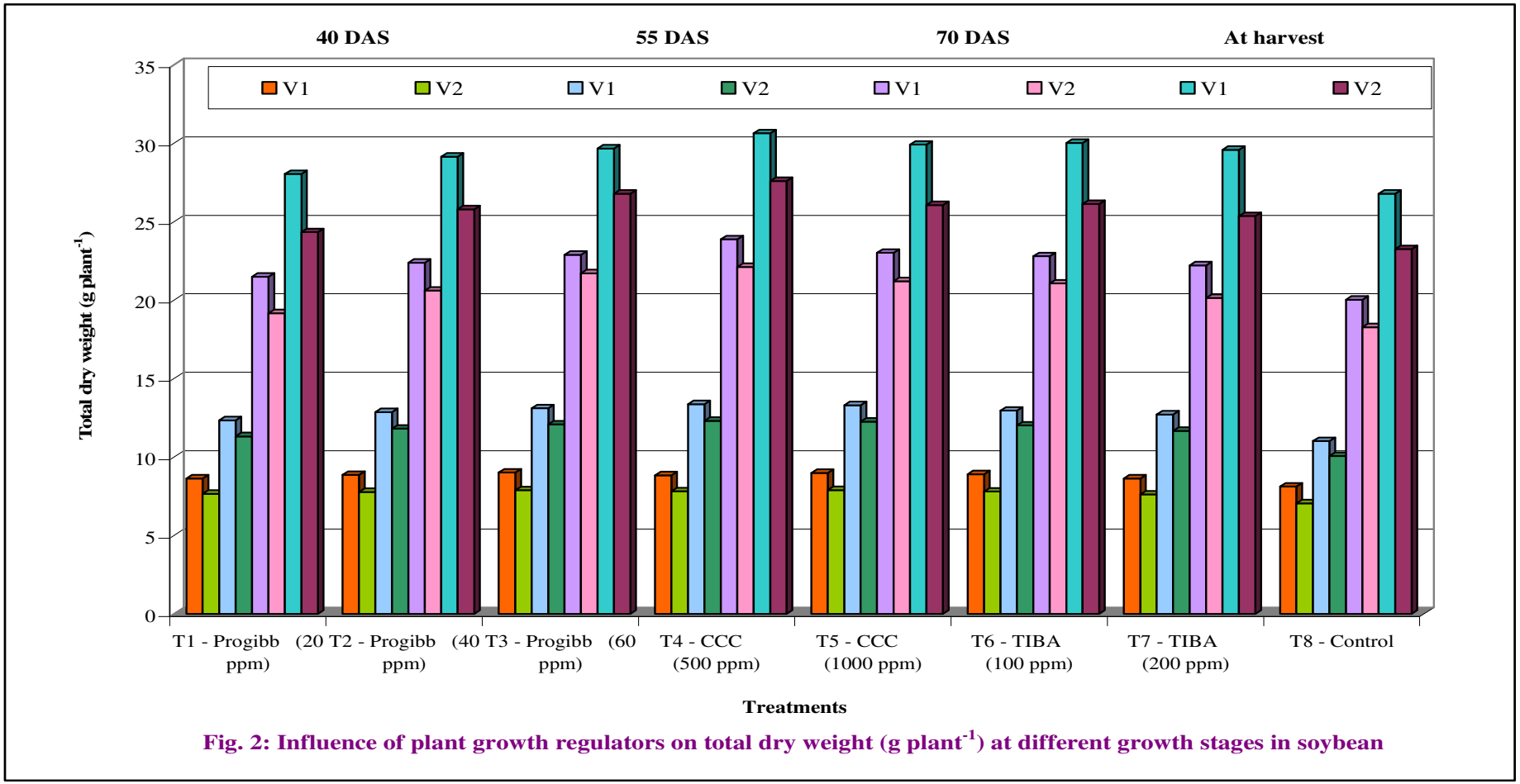


Fig. 2: Influence of plant growth regulators on total dry weight (g plant^{-1}) at different growth stages in soybean

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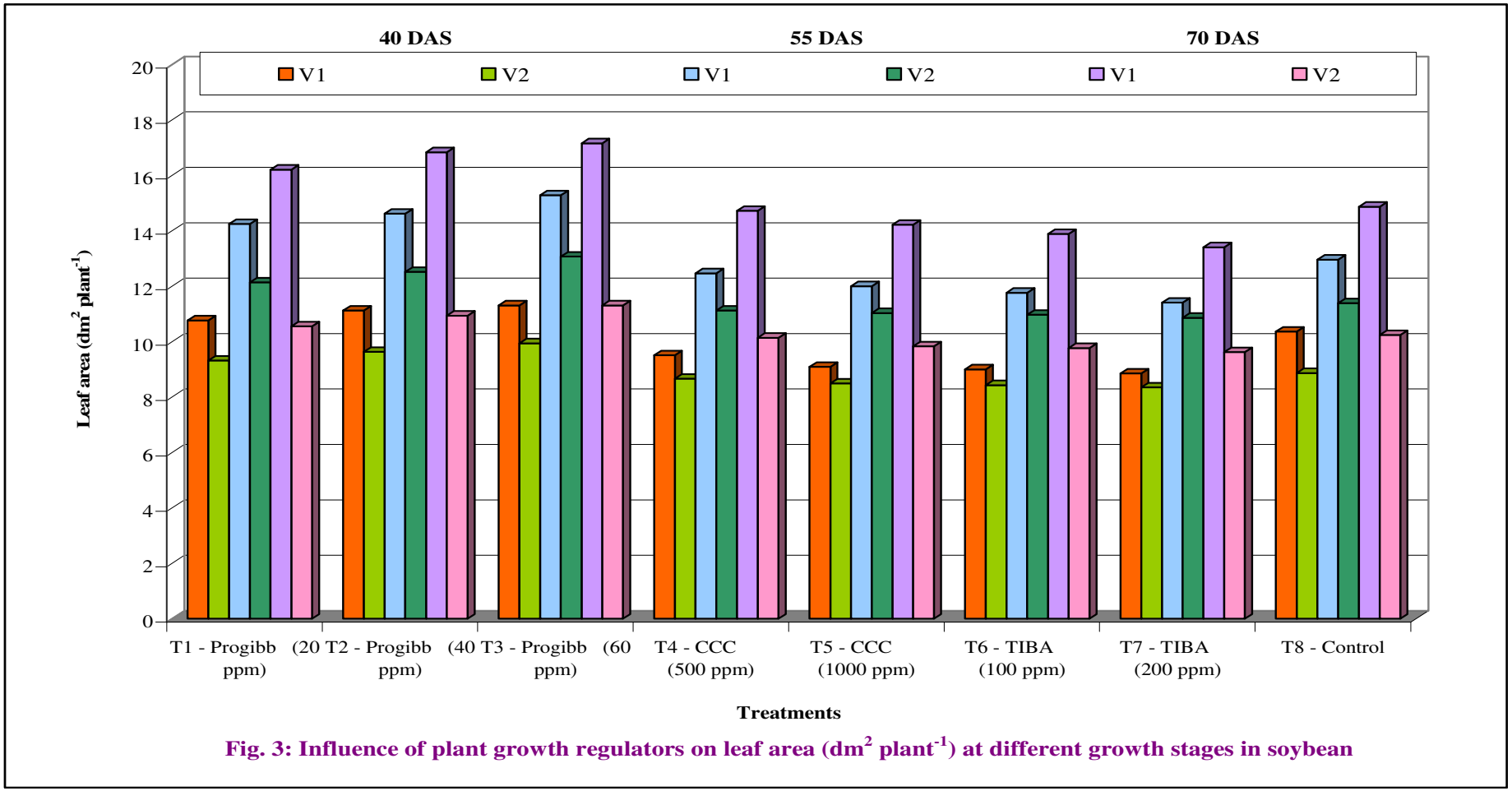

Fig. 3: Influence of plant growth regulators on leaf area (dm^2 $plant^{-1}$) at different growth stages in soybean

Fig. 3: Influence of plant growth regulators on leaf area (dm2 plant-1) at different growth stages in soybean

The leaf area was decreased by application of growth retardants (CCC and TIBA) as compared to Progibb @ 60 ppm, whereas, PGRs maintained a higher leaf area at later stage (70 DAS) of the crop growth. Since, leaf senescence is one of the most obvious constraints during peak grain filling period and application of growth regulators arrested the chlorophyll degradation and protease activity inturn promoting soluble protein and photosynthetic enzyme synthesis resulting in more assimilatory surface area for longer period. Similarly, Basuchaudhari *et al*., (1986) and Deotale *et al*. (1994) also reported that application of cycocel and TIBA reduced leaf area in soybean. On the contrary, Chougale (1997) showed increased leaf area due to application of growth retardants in sesamum.

The application of growth promoter Progibb (60 ppm) increased leaf area due to positive effects on cell division and cell elongation leading to enhanced leaf growth. This is in accordance with Kalyankar *et al*. (2008) and Ibrahim *et al*. (2007) who obtained significantly higher leaf area due to GA_3 treatment in soybean and faba bean. Leaf area index followed the same trend as that of leaf area in all the growth regulator treatments and in both the genotypes.

Leaf area duration (LAD) is the total amount of leaf area present over a particular period of growth which was significantly higher in growth regulator treatments. The use of growth regulators was found to be more effective in increasing LAD particularly at later stages, which could be attributed to retention of leaves for longer duration. Similarly, Morandi *et al*. (1984) and Kulkarni (1993) also reported increased LAD by application of growth regulators in soybean. The specific leaf weight (SLW) is an index of leaf thickness and it increased upto 70 DAS and declined thereafter towards maturity due to senescence of leaves. Significantly higher values for SLW were observed in CCC followed by TIBA and Progibb. Kulkarni (1993) also reported increased SLW due to growth retardants like cycocel and mepiquat chloride.

Crop growth rate (CGR) is influenced by LAI, photosynthetic rate and leaf angle and is an index of amount of light interception. The CGR increased and reached its peak at 55-70 DAS and declined gradually thereafter towards maturity. Such a decline could be attributed to decrease in rate of dry matter production due to senescence and shading. The rapid increase in CGR observed under the effect of growth regulators over that of control might be due to higher production of dry matter due to increased photosynthetic activities coupled with increased cell multiplication. Similar results were obtained by Deotale and Sorte (1996), Sarkar *et al.* (2002) in soybean.

Net assimilation rate (NAR) denotes increase in plant dry weight unit $^{-1}$ leaf area unit^{-1} time. The NAR was maximum at 55-70 DAS and then decreased. NAR tended to increase with growth regulator treatments at pod filling stage which might be related to the increased sink demand and pod photosynthesis. Also, more photosynthetic products were available to growing parts like flowers and pods showing higher assimilation. These results are in conformity with Deotale and Sorte (1996) and Rahman *et al*. (2004) who found increased NAR due to growth regulator treatments in soybean.

The relative growth rate (RGR) decreased as the growth advanced. During the early growth stages, JS-335 maintained higher RGR values. Similarly, Patil (1994) also reported that the foliar application of cycocel, TIBA and mepiquat chloride significantly increased the RGR in soybean. GA_3 has been reported to increase RGR in soybean due to an increase in leaf weight ration (Dijkstra *et al*., 1990).

Biomass duration (BMD) indicates the maintenance of dry matter over a period of time and is essential for prolonged supply of photosynthates to the developing sinks. Significantly higher BMD values were recorded in growth regulator treatments at all the stages of soybean crop. This suggests that growth regulators resulted in increased TDM, LAI, LAD, AGR, CGR, NAR and SLW and finally resulted in increased BMD.

5.4 Biochemical parameters

The plant performance is attributed to the genetic factors which are controlled by the differences in the biochemical parameters. It is well known that the thousands of biochemical reactions are undergoing in plants simultaneously which ultimately decide the plant growth and development and the final yield. Plant growth regulators (PGRs) have been shown to influence these parameters in one way or the other.

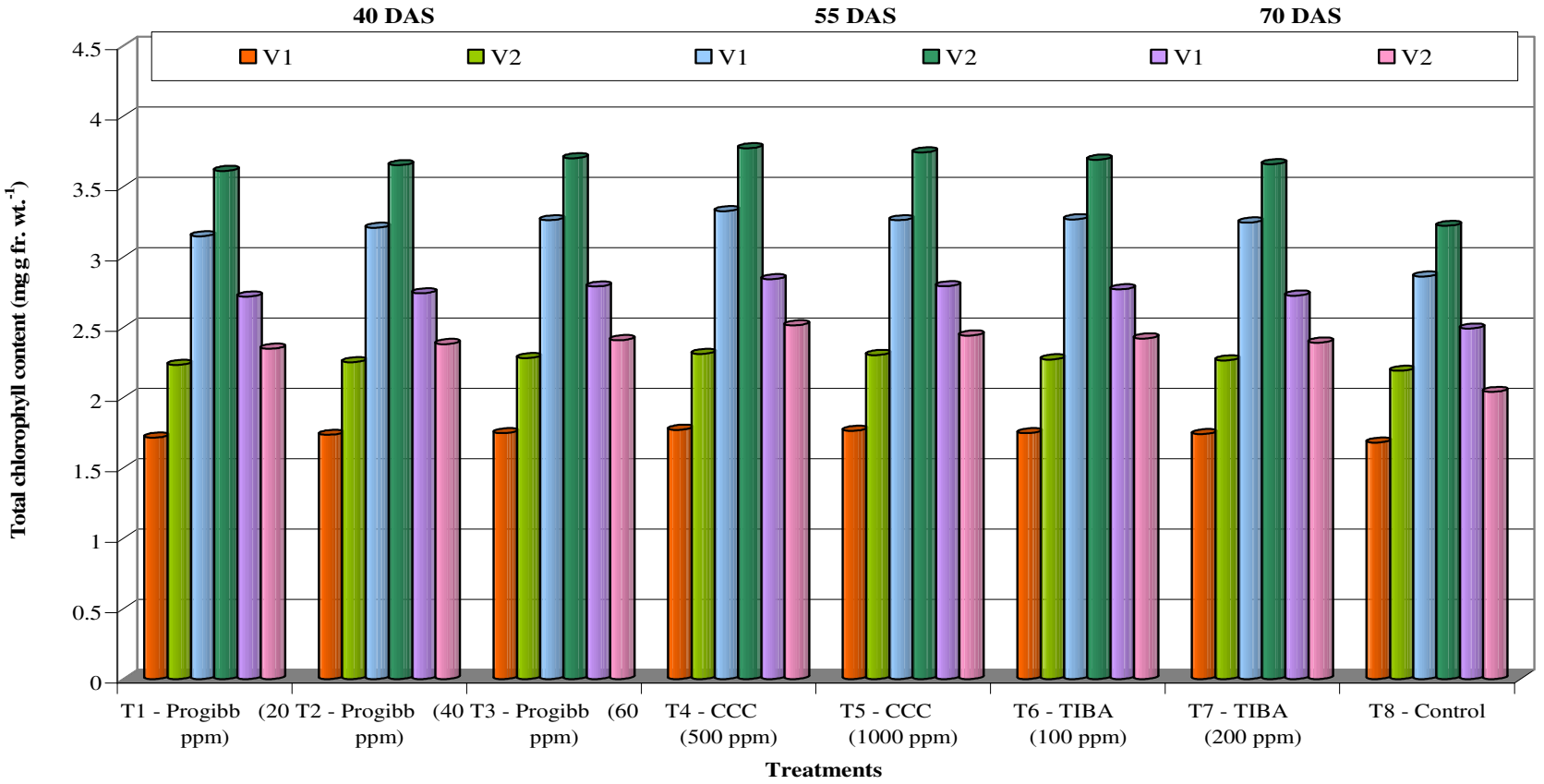

Fig. 4: Influence of plant growth regulators on total chlorophyll content (mg g fr. wt.$^{-1}$) in leaf at different growth stages in soybean

Fig. 4: Influence of plant growth regulators on total chlorophyll content (mg g fr. wt.-1) in leaf at different growth stages in soybean

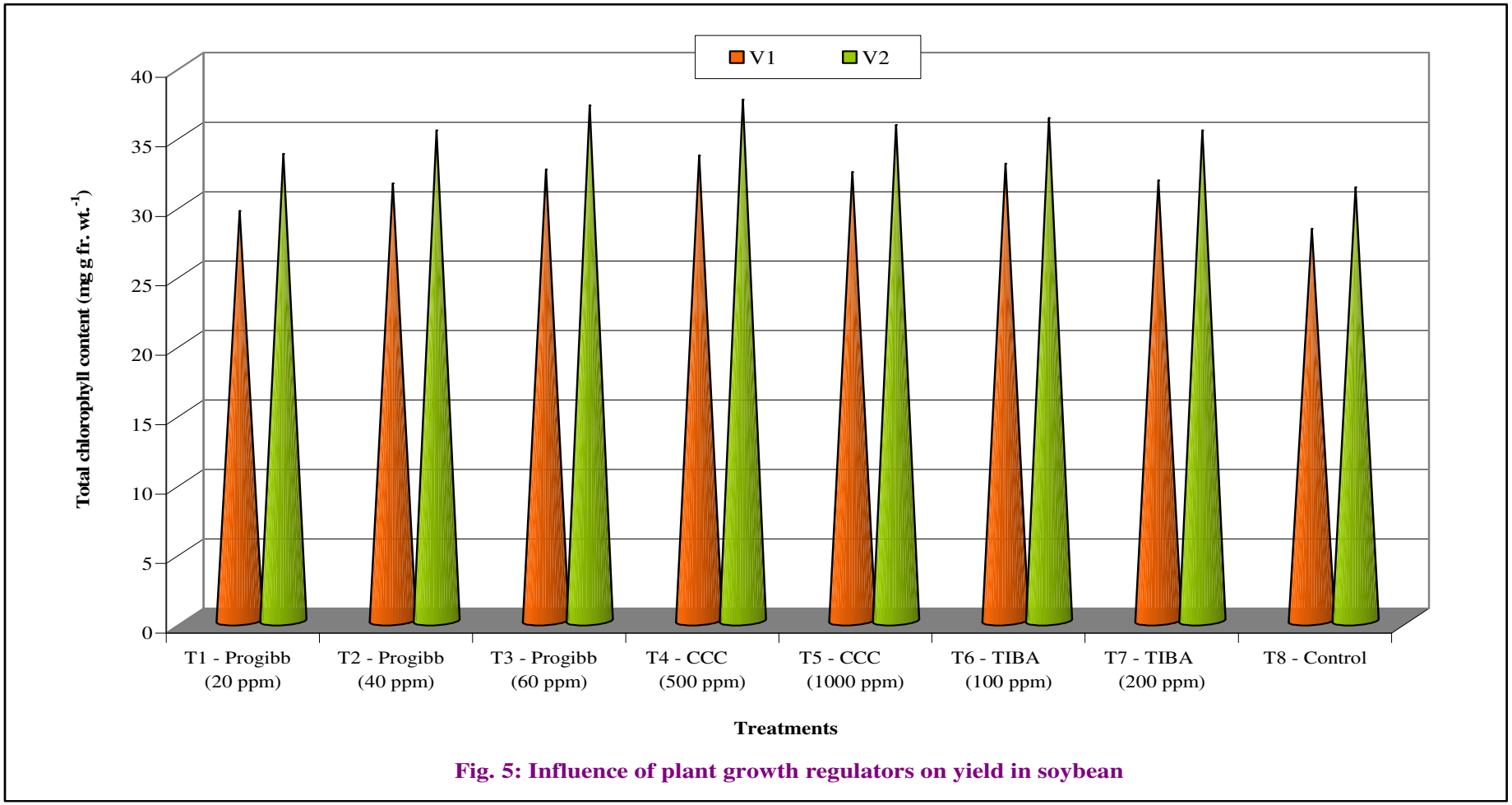

Fig. 5: Influence of plant growth regulators on yield in soybean

Fig. 5: Influence of plant growth regulators on yield in soybean

Chlorophylls have been rightly designated as “Pigments of life” because of their central role in living systems responsible for harvesting sunlight and transforming its energy into biochemical energy essential for life on earth. In the present investigation, it was observed that PGRs had profound effect on chlorophyll content. Significant differences were noticed among the treatments and varieties with respect to chlorophyll a, chlorophyll b and total chlorophyll at all growth stages except at 40 DAS in soybean. The variation in chlorophyll content due to PGRs may be attributed to decreased chlorophyll degradation and increased chlorophyll synthesis. From the data, it is clear that chlorophyll content was maximum at 55 DAS and decreased at later stages which may be attributed to senescence of leaves (Arteca and Dong, 1981).

The genotype JS-335 recorded significantly higher total chlorophyll content as compared to KHSb-2 at all growth stages except at 70 DAS (Figure 4) which may be attributed to the early and late growth habit of JS-335 and KHSb-2, respectively. The foliar application of CCC (500 and 1000 ppm), TIBA (100 ppm) and Progibb (60 ppm) resulted in higher chlorophyll content. It has been suggested that the application of PGRs increased the availability of assimilates, which in turn may caused prolonged chlorophyll synthesis. The results of present investigation are in conformity with the findings of Stein *et al.* (1983), Kumari and Bharti (1992), Mansour *et al*. (1995), Pankaj kumar (1998) and Reddy (2009).

PGRs exhibited significant differences in nitrate reductase activity (NRA) in leaf. The enzyme nitrate reductase (NR) catalyses the reduction of nitrate to nitrite (Beevers and Hageman, 1969) and is a rate limiting step in nitrogen metabolism. It has been observed that NRA increased significantly with the foliar application of CCC (500 ppm), TIBA (100 ppm) and Progibb (40 ppm) as compared to control. NRA was maximum at 55 DAS and decreased later on. NR is a key enzyme in nitrogen metabolism and its activity should always be higher to have higher nitrogenous compounds in plants. It is generally believed that NRA depends on the activity of substrates and proteinaceous compounds and therefore it is suggested that the application of PGRs results in enhanced nitrate uptake by plants (Kuchenberg and Jung, 1988). Similarly, Goswami and Srivastava (1989), Pankaj kumar (1998) in soybean and Reddy (2009) in cowpea also reported an increase in NRA due to PGRs.

The oil content in seed differed significantly due to the application of PGRs, which could be due to increased accumulation of hexose sugars at the time of synthesis of triacylglycerol (Purohit, 1993). Similarly, Al-Gharbi and Yousif (1989), Kene *et al*. (1992) and Kulkarni (1993) also reported increased oil content. The seed protein was significantly higher in KHSb-2 as compared to JS-335. However, the application of PGRs did not show any significant effect on protein content though its content was increased in seed which indicated that the applied growth regulators had no influence on biosynthetic pathways related to protein and amino acid synthesis which was in accordance with the findings of Reddy (2009) in cowpea.

5.5 Yield and yield parameters

Seed yield and its related parameters in soybean were influenced by the application of different growth regulators in both genotypes which indicated that these chemicals have differential influence on the allocation of assimilates between vegetative and reproductive organs. In general, crop yield depends on the accumulation of photo-assimilates during the growing period and the way they are partitioned between desired storage organs of plant. In the present study, it was revealed that the application of PGRs significantly increased the number of seeds, number of pods, pod weight per plant, 100-seed weight and finally seed yield per plant which are the most important yield determining components in soybean. Among the genotypes, JS-335 recorded significantly higher yield parameters except number of pods per plant which was higher in KHSb-2.

Among growth regulator treatments, the seed yield per plant was significantly higher in CCC (500 ppm) followed by Progibb (60 ppm) and TIBA (100 ppm) which may be due to an increase in number of seeds per plant, number of pods per plant, pod weight per plant, 100-seed weight and higher partitioning towards reproductive organs (Figure 5).

Ravichandran and Ramaswami (1991) observed that the application of PGRs increased number of seeds per pod and per plant and seed yield (26%) whereas, the 100-seed weight decreased in soybean. Similarly, foliar application of CCC (500 ppm) increased

the seed yield, number of seeds per pod and 100-seed weight as compared to control in soybean (Lam sanche *et al*., 1975, Kamal *et al*., 1995, Pankaj kumar, 1998 and Kalyankar *et al*., 2008). Similarly, Ravichandran *et al*. (1992) in soybean and Reddy (2009) in cowpea also reported increased seed yield with 50 ppm TIBA and decreased at higher concentration which may be due to toxic effects of TIBA. Seed yield (q/ha) was also maximum in CCC (500 ppm) followed by Progibb (60 ppm) and TIBA (100 ppm).

5.6 Economics

The present study also indicated that, among the various growth regulators the cost: benefit ratio was higher with CCC 500 ppm (1:2.5) followed by Progibb 60 ppm (1:1.58) and TIBA 100 ppm (1:1.5) (Table 28).

5.7 Future line of work

Based on the results obtained in the present investigation, the following suggestions have been made for further studies.

1. The response of genotypes to various growth regulators needs to be studied based on sound physiological approach.
2. Several studies indicated that photo-assimilates distribution within the plant is under hormonal control and there is scope for detailed anatomical and histo-chemical studies regarding effect of plant hormones on vascular connections between vegetative and reproductive structures.
3. It is necessary to identify suitable bio-regulator for improving flower production and fruit set per cent in soybean.
4. Little is known about the influence of different growth regulators on nitrate reductase activity, oil synthesizing enzymes and protein biosynthetic pathways and there is ample scope for such studies.
5. It is also important to study the interaction between externally applied growth regulators and endogenous hormones.

6. SUMMARY AND CONCLUSIONS

A field experiment was conducted during *kharif*, 2009 at College of Agriculture, University of Agricultural Sciences, Dharwad to study the growth, development, physiology, yield and quality of soybean (*Glycine max* (L.) Merrill) as influenced by plant growth regulators (PGRs). The experiment was laid out in factorial randomized block design replicated thrice with different plant growth regulators *viz*., Progibb (20, 40 and 60 ppm), CCC (500 and 1000 ppm) and TIBA (100 and 200 ppm) as foliar spray, with two varieties (KHSb-2 and JS-335). The results obtained from the investigation are summarized in this chapter.

- Among the treatments, Progibb (60 ppm) showed significantly higher plant height at all the stages. The lowest plant height was noticed in TIBA (200 ppm) compared to control.
- The number of branches per plant differed significantly due to genotypes and growth regulators. TIBA (100 and 200 ppm), CCC (1000 ppm) and Progibb (60 ppm) recorded significantly higher number of branches per plant.
- PGRs showed significant effect on days to flower initiation and Progibb (60 ppm) hastened the days for flower initiation followed by CCC (500 ppm), TIBA (200 ppm) as compared to control.
- The leaf dry weight increased upto 70 DAS in both the genotypes and was significantly higher with CCC (500 ppm), Progibb (60 ppm) and TIBA (100 ppm). The stem dry weight was significantly higher with CCC followed by Progibb and TIBA at 55 and 70 DAS.
- The dry weight of reproductive parts and total dry matter increased upto harvest in both genotypes and all the PGRs treatments showed higher values as compared to control. CCC (500 ppm) showed significantly higher total dry matter followed by Progibb (60 ppm) and TIBA (100 ppm) as compared to control.
- The leaf area and leaf area index increased upto 55 DAS in JS-335 and upto 70 DAS in KHSb2 and declined thereafter in JS-335. The leaf area and leaf area index was found to be maximum in Progibb (60 ppm) followed by CCC (500 ppm) and TIBA (100 ppm). The lowest leaf area was recorded in TIBA (200 ppm).
- Specific leaf weight increased significantly due to PGRs treatment and was more at 70 DAS. The SLW was more in retardants *viz*., CCC (500 ppm) and TIBA (200 ppm) followed by Progibb.
- Important growth parameters *viz*., AGR, CGR, RGR, NAR, LAD and BMD were significantly influenced by the application of PGRs and were found to be lower in control. CCC (500 ppm) was found to be superior over other treatments in most of the parameters followed by Progibb (60 ppm) and TIBA (100 ppm).
- The foliar spray of PGRs enhanced the chlorophyll content (a, b and total) in leaf and the effect was more with CCC (500 ppm). Chlorophyll content (a, b and total) increased upto 55 DAS and declined thereafter in all the treatments. Among the varieties, chlorophyll content was maximum in JS-335 compared to KHSb-2.
- There was a decline in nitrate reductase activity (NRA) in leaf with an advancement in crop age. The NRA was found to be higher in CCC (500 ppm) followed by Progibb (60 ppm) and TIBA (100 ppm).
- PGRs had significant influence on oil content but the genotypes did not differ significantly. However, significant difference was not found with respect to seed protein content due to growth regulators. The genotype KHSb-2 showed significantly higher seed protein content than JS-335.
- The results on various yield and yield attributes indicated that all the yield contributing characters *viz*., seed yield per plant, number of seeds per plant, number of pods per plant, pod weight per plant and 100-seed weight increased significantly due to PGRs. Among the treatments, CCC (500 ppm) was found to be very effective in increasing

the seed yield followed by Progibb (60 ppm) and TIBA in both the genotypes. JS-335 recorded significantly higher yield than KHSb-2.

- From the point of economics, CCC (500 ppm) was found to be more profitable in terms of net returns followed by Progibb (20, 40 and 60 ppm)) and TIBA (100 ppm) compared to other treatments.

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INFLUENCE OF PLANT GROWTH REGULATORS ON GROWTH PHYSIOLOGY, YIELD AND QUALITY OF SOYBEAN [*Glycine max* (L.) Merrill]

RAKSHA V. SHINDE **2010** **DR. C. M. NAWALGATTI**
MAJOR ADVISOR

ABSTRACT

A field experiment was conducted during *kharif*, 2009 at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad to study the growth, physiology, yield and quality of soybean (*Glycine max* (L.) Merrill) as influenced by plant growth regulators (PGRs). The experiment was laid out in factorial randomized block design replicated thrice with different plant growth regulators *viz*., Progibb (20, 40 and 60 ppm), CCC (500 and 1000 ppm) and TIBA (100 and 200 ppm) as foliar spray, with two varieties (KHSb-2 and JS-335).

The PGRs *viz*., cycocel and TIBA decreased the plant height whereas, Progibb increased it significantly. The number of branches increased significantly with PGRs. The application of PGRs hastened the days for flower initiation. The growth regulator treatments significantly increased leaf dry weight, dry weight of stem, reproductive parts and total dry weight. The growth parameters *viz*., leaf area, LAI, LAD, SLW, BMD, CGR, AGR, RGR and NAR increased significantly due to PGRs. The cycocel was effective in increasing CGR, SLW and BMD whereas, Progibb was very effective in increasing in leaf area, LAI and LAD.

Biochemical parameters *viz*., chlorophyll 'a', chlorophyll 'b', total chlorophyll content and NRA were significantly higher with the application of CCC (500 ppm). Seed oil content was found to be superior with the application of PGRs. The seed yield plant^{-1}, number of seeds plant^{-1}, number of pods plant^{-1} and 100 seed weight increased significantly due to growth regulators. The application of CCC (500 ppm) recorded significantly highest seed yield in both the genotypes followed by Progibb (60 ppm) and TIBA (100 ppm). From the economic point of view, CCC (500 ppm) was more profitable in terms of net returns.