Original Research Article

Impact of plant growth retardants and detopping on growth parameters in soybean (*Glycine max* L. Merrill)

ABSTRACT

The present study was executed with the prime objective to study the effect of different concentrations of chlormequat chloride, paclobutrazol and detopping on morpho-physiological parameters of soybean variety NRC-37. The field trial was carried out in*kharif*2023 at Department of Plant Physiology, Anand Agricultural University, Anand in randomized block design with ten treatments replicated thrice. The growth retardants were sprayed at 30 and 45 days after sowing. Detopping was done on 45 days after sowing. Morphological parameters like plant height and number of leaves per plant were recorded lowest with increasing concentrations of growth retardants. Paclobutrazol @ 100 mg/l recorded the lowest plant height and number of leaves per plant. Chlormequat chloride @ 750 mg/l promoted early flowering and recorded highest stem and total dry weight. Minimum values for leaf area index and leaf area ratio were observed with chlormequat chloride @ 750 mg/l and paclobutrazol @ 75 mg/l at different growth stages. Net assimilation rate and crop growth rate also observed similar trends recording higher values in chlormequat chloride @ 750 mg/l and paclobutrazol @ 75 mg/l at various crop growth stages. Foliar application of chlormequat chloride @ 750 mg/l or paclobutrazol @ 75 mg/l exerted a profound effect on the growth characters in soybean crop.

Keywords: Chlormequat chloride, Paclobutrazol, Detopping, Leaf area index

1. INTRODUCTION

Soybean, an ancient and significant oilseed and protein crop native to China, belongs to the Papilionaceae subfamily and the Leguminosae family. Known as the “Golden Bean” and “Miracle bean”, soybean is valued for its high nutritional content and versatility (Khatun*et al*., 2016), earning names like “Cow of the field” and “Gold from soil” (Horvath, 1926). It contains about 20% oil, 38-42% protein, 26% carbohydrates, 4% minerals, and 2% phospholipids. Rich in calcium, phosphorus, magnesium, potassium, and iron, it also provides vitamins A, B (especially thiamine and riboflavin), and D (Bramhankar*et al*., 2018). With a protein yield up to three times higher than other pulses, soybean can help bridge the gap between the nation's supply and demand for edible oils and pulses. Growth parameters like plant height, number of branches, number of leaves, days to initiation of flowering, dry matter accumulation in plant parts, Leaf area index, Leaf area ratio, Net assimilation rate, Crop growth rate are used to describe and quantify plant growth, biomass accumulation, and partitioning of assimilates. Modification of these parameters influences crop growth patterns which are reflected in final yield and thus crop productivity, which can be achieved by certain chemicals like growth retardants and agronomic practices like detopping (Ramesh and Ramprasad, 2013). Plant growth regulators (promoters, inhibitors or retardants) have been reported to be an effective tool for increasing crop yields due to their important role in various physiological and biochemical processes in plant, leading to rapid change in phenotype of the plant within the season to achieve desirable results. Growth retardants are known to improve the source-sink relationship, translocation of photoassimilates, and plant photosynthetic ability by reducing inter-nodal distance. As a result, they are important in achieving high productivity levels and higher crop yields(Lui*bet al*., 1987).Chlormequat Chloride (CCC) and Paclobutrazol are efficient plant growth retardants.They result in a range of morphological, physiological, and biochemical reactions in plants, such as decreased stem elongation and increased flowering and rooting. As a result of a reduction in vegetative growth, yield increases, increasing chlorophyll and carotenoids content, altering carbohydrate status, increasing stress tolerance, delaying senescence, reducing gibberellin biosynthesis, increasing cytokinin synthesis and causing alterations in secondary metabolite contents. The primary mechanism of action of CCC and paclobutrazol is the disruption of the hormonal equilibrium. Due to its ability to prevent the production of gibberellin, decrease cell division and elongation, and slow down plant growth, it can lead to higher yields (El-Aal and Eid, 2017). Detopping, an effective agricultural practice is based on the theory of apical dominance (Jahan, 2017), which thereby increases the number of lateral branches, pod setting and better source-sink relationship along with synchronous plant growth (Jaidka*et al.,* 2020).Looking to this importance of growth retardants and detopping practices, theexperiment was carried out with the objective to study the effect of foliar application of plant growth retardants anddetopping on growth parameters of soybean.

2. METHODOLOGY

2.1 Experimental Site

The experiment is conducted at Regional Research Station farm, Anand Agricultural University, Anand, India during *kharif,* 2023.

2.2 Experimental Details

The investigation was conducted on NRC-37 soybean variety with ten treatments replicated thrice involving foliar application of plant growth retardants chlormequat chloride,paclobutrazol and detopping in a randomized block design. The crop was raised with spacing of 45 x 10 cm by following all the recommended package of practices for better crop growth and production. The data collected from field and laboratory was subjected to the statistical analysis as per the procedures of randomized block design (Panse and Sukhatme, 1995).

LIST 1Treatment details

T_1	Chlormequat Chloride @ 250 mg/l
T_2	Chlormequat Chloride @ 500 mg/l
T_3	Chlormequat Chloride @ 750 mg/l
T_4	Chlormequat Chloride @ 1000 mg/l
T_5	Paclobutrazol @ 25 mg/l
T_6	Paclobutrazol @ 50 mg/l

T_7	Paclobutrazol @ 75 mg/l
T_8	Paclobutrazol @ 100 mg/l
T_9	Detopping
T_{10}	Control

2.3Chemical Preparation and Conduct of Experiment

The plant growth retardants chlormequat chloride and paclobutrazol were used from the Department of Plant Physiology, Anand Agricultural University, Anand, Gujarat, India. The chemical used for chlormequat chloride spray solution preparation was chlorocholine chloride aqueous solution 50% which was procured from Lobachemie private limited. The chemical used for paclobutrazol spray solution preparation was paclobutrazol powder obtained from HiMedia laboratories private limited. Plant growth retardant chlormequat chloride spray solution of 250, 500, 750 and 1000 mg/l concentration was prepared by dissolving 0.25, 0.5, 0.75 and 1 ml of chlormequat chloride solution in one litre of water, respectively. Paclobutrazol spray solution of 25, 50, 75 and 100 mg/l concentration were prepared by dissolving 25, 50, 75 and 100 mg of paclobutrazol in small amount of NaOH and later making up the volume with one litre of water, respectively. Detopping was done by removing the apical portion of the main stem, which was around 4-5 cm in length with the help of a pair of scissors. First foliar spray of plant growth retardants was given prior to initiation of flowering (at 30 DAS). Second foliar spray was given after 15 days of the first foliar spray *i.e.* 45 DAS.Detopping (removal of the apical portion of the main stem) was done during 2^{nd} foliar spray of plant growth retardants.

2.4 Observations Recorded

2.4.1 Morphological parameters

The observations on various plant morphological characters, *viz.,* plant height, number of branches per plant, number of leaves per plant and days to initiation of flowering were recorded from a group of five randomly tagged plants in net plot area at 30, 50, 70, 90 DAS and at harvest and average was worked out. For calculating stem and total dry weight of the plant at 30, 50, 70, 90 DAS and at harvest, five plants from each gross plot were uprooted randomly and separated into leaves, stem, root and reproductive part which were dried separately in hot air oven at 105 ºC until constant weight was achieved and mean stem and total dry weight was recorded as respective observation per plant.

2.4.1.1 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 were recorded at different intervals at 30, 50, 70, 90 DAS and at harvest and the average height was recorded for analysis.

2.4.1.2 Number of branches per plant

Total number of branches were counted from the tagged plants and recorded at different intervals at 30, 50, 70, 90 DAS and at harvest and average number of branches were calculated.

2.4.1.3 Number of leaves per plant

Total number of leaves in the tagged plants were counted and recorded at different intervals at 30, 50, 70, 90 DAS and at harvest and average number of leaves were calculated.

2.4.1.4 Days to initiation of flowering

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

2.4.1.5 Stem and total dry weight(g)

Five plants from each gross plot were uprooted randomly at 30, 50, 70, 90 DAS and at harvest and separated into leaves, stems, and reproductive parts which were dried separately in hot air oven at 105 ºC until constant weight was achieved and mean stem and total dry weight was recorded as respective observation per plant.

2.4.2 Physiological Parameters

2.4.2.1 Leaf area index (LAI)

The observations were recorded in different intervals like 30, 50, 70, 90 days after sowing and at the time of harvest. The LAI is the ratio of leaf area per plant to the land area occupied by the plant and was calculated using the formula (Watson, 1952).

$$\text{LAI} = \frac{\text{Leaf area}}{\text{Land area occupied by plant}}$$

2.4.2.2 Leaf area ratio (LAR) (cm^2/g)

LAR expresses the ratio between the area of leaf lamina to the total plant biomass or the LAR reflects the leafiness of a plant or amount of leaf area formed per unit of biomass which was measured at 30, 50, 70, 90 DAS and at harvest for each treatment and expressed in cm^2/g and was calculated using the formula given by Radford (1967),

$$\text{LAR} = \frac{\text{Total leaf area}}{\text{Total dry weight of plant}}$$

2.4.2.3 Net assimilation rate (NAR) (g/m^2/day)

NAR is the increase in dry weight per unit leaf area or it is a measure of the index of productive efficiency, which was calculated by the formula as given below and expressed as g/m^2/day. It was measured at 30-50, 50-70, 70-90 DAS and 90 DAS-at harvest for each treatment and calculated by using the formula suggested by Srivastava and Prasad (2010).

$$\text{NAR} = \frac{W_2 - W_1}{A_2 - A_1} \times \frac{\ln A_2 - \ln A_1}{t_2 - t_1}$$

Where,

$\ln A_2 - \ln A_1$ = Natural log difference of leaf area at time t_2 and t_1

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

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

$t_2 - t_1$ = Time interval in days

2.4.2.4 Crop growth rate (CGR) (g/m^2/day)

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 $g/m^2/day$. The observations were recorded in different intervals of 30-50, 50-70, 70-90 DAS and 90 DAS-at harvest.

$$\text{CGR} = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{P}$$

Where,

W_1 = Dry matter production $plant^{-1}$(g) at time t_1

W_2 = Dry matter production $plant^{-1}$(g) at time t_2

$t_2 - t_1$= Time interval in days

P = Ground area covered by the plant (m^2)

3. RESULTS AND DISCUSSION

3.1 Morphological Parameters

3.1.1 Plant height

Table 1 provides the evaluation of mean data on soybean's periodical plant height recorded at 30, 50, 70, 90 DAS as well as at harvest, which showed that plant height increased with increase in the age of crop. Plant height at 50 DAS showed that significantly lowest plant height of 34.63 cm was recorded with application of paclobutrazol @ 100 mg/l (T_8). It was found statistically at par with treatments T_2 (40.10 cm), T_3 (38.73 cm), T_4 (36.47 cm), T_6 (37.87 cm), T_7 (36.20 cm) and T_9 (37.07 cm). The highest plant height of 44.80 cm was recorded with control (T_{10}). The significantly minimum plant height at 70 DAS (56.14 cm) was recorded with the application of paclobutrazol @ 100 mg/l (T_8) which was statistically at par with T_4 (60.50 cm), T_6 (64.66 cm)and T_7 (62.51 cm). Conversely, maximum plant height at 70 DAS (77.92 cm) was noted with control (T_{10}). A perusal of data indicated that significantly lowest plant height at 90 DAS (58.15 cm) was recorded with the application of paclobutrazol @ 100 mg/l (T_8) which was statistically at par with T_4 (63.99 cm), T_6 (66.91 cm) and T_7 (65.45 cm). Conversely, highest plant height at 90 DAS (79.29 cm) was recorded with control (T_{10}). Significantly lowest plant height at harvest (59.33 cm) was recorded with application of paclobutrazol @ 100 mg/l (T_8) which was found statistically at par with T_4 (64.97 cm), T_6 (68.20 cm) and T_7 (66.29 cm). While, highest plant height at harvest (79.85 cm) was noted in control (T_{10}). Growth retardants like paclobutrazol and cycocel cause reduction in plant height by inhibiting gibberellin biosynthesis, a plant growth hormone responsible for stem elongation. Gibberellin, whose primary role is in promoting cell elongation and division, when inhibited results in stunted growth and reduced plant height. The inhibition of gibberellin biosynthesis by paclobutrazol is done by inhibiting the oxidation of ent-kaurene to ent-kauronoic acid through inactivating cytochrome P450-dependent oxygenase (Desta and Amare, 2021). Cycocel reduce the growth by blocking and conversion of geranyl pyrophosphate to copalyl pyrophosphate which is the first step of gibberellins synthesis (Moore, 1980). The findings are in conformity with the results of Techapinyawat*et al.* (1999) and Tarun*et al.* (2016) in soybean, Win *et al.* (2017) and Zhao *et al.* (2023) in peanut and Banoo*et al.* (2022) in mustard.

Table 1. Effect of plant growth retardants and detopping on plant height at 30, 50, 70, 90 DAS and at harvest

Treat. number	Treatment details	Plant height (cm)				
		30 DAS	50 DAS	70 DAS	90 DAS	Harvest
T_1	CCC @ 250 mg/l	17.60	43.07	73.12	75.26	75.89
T_2	CCC @ 500 mg/l	17.00	40.10	69.93	72.01	72.41
T_3	CCC @ 750 mg/l	17.43	38.73	66.51	69.19	70.57
T_4	CCC @ 1000 mg/l	17.51	36.47	60.50	63.99	64.97
T_5	Paclobutrazol @ 25 mg/l	17.10	42.90	73.03	74.66	75.29
T_6	Paclobutrazol @ 50 mg/l	17.40	37.87	64.66	66.91	68.20
T_7	Paclobutrazol @ 75 mg/l	17.40	36.20	62.51	65.45	66.29
T_8	Paclobutrazol @ 100 mg/l	17.23	34.63	56.14	58.15	59.33
T_9	Detopping	18.03	37.07	65.80	67.90	69.14
T_{10}	Control	17.16	44.80	77.92	79.29	79.85
S.Em. ±		0.84	1.92	3.46	3.67	3.50
C.D at 5%		NS	5.69	10.28	10.90	10.39
C.V%		8.37	8.47	8.94	9.17	8.63

3.1.2 Number of branches per plant

The data on number of branches per plant at 50, 70, 90 DAS as well as at harvest, of soybean as influenced by different plant growth retardants and detopping is presented in Table 2 and it was found non-significant in all the respective observations. There were no branches observed during 30 DAS. Numerically maximum number of branches was recorded in detopping at 70 DAS, 90 DAS and at harvest followed by the treatment CCC @ 750 mg/l. This shows the principle of removal of apical dominance by detopping.

Table 2. Effect of plant growth retardants and detopping on number of branches per plant at 50, 70, 90 DAS and at harvest

Treat. No.	Treatment details	Number of branches per plant			
		50 DAS	70 DAS	90 DAS	Harvest
T_1	CCC @ 250 mg/l	3.47	5.07	5.80	6.00
T_2	CCC @ 500 mg/l	3.73	5.27	5.87	6.00
T_3	CCC @ 750 mg/l	4.00	5.80	6.60	6.65

T_4	CCC @ 1000 mg/l	3.60	5.07	6.27	6.33
T_5	Paclobutrazol @ 25 mg/l	3.53	5.33	5.87	6.13
T_6	Paclobutrazol @ 50 mg/l	3.73	5.67	6.00	6.13
T_7	Paclobutrazol @ 75 mg/l	3.80	5.73	6.47	6.67
T_8	Paclobutrazol @ 100 mg/l	3.33	5.27	6.13	6.13
T_9	Detopping	3.80	5.80	6.87	6.87
T_{10}	Control	3.33	5.00	5.40	5.53
S.Em. ±		0.22	0.29	0.32	0.33
C.D at 5%		NS	NS	NS	NS
C.V%		10.66	9.26	9.01	9.25

3.1.3 Number of leaves per plant

The number of leaves per plant increase as the days of crop stage increase which at the end due to senescence number of leaves were reduced which is represented in Table 3. At 30 DAS and at harvest number of leaves per plant due to growth retardant spray and detopping were found to be non-significant. At 50 DAS number of leaves per plant was recorded significantly lowest (66.20) with application of paclobutrazol @ 100 mg/l (T_8). It was found statistically at par with treatments T_2 (75.67), T_3 (70.40), T_4 (67.20), T_6 (73.33) and T_7 (72.00). The highest number of leaves per plant at 50 DAS (87.87) was recorded in control (T_{10}). Significantly lowest number of leaves per plant at 70 DAS (89.49) was recorded with the application of paclobutrazol @ 100 mg/l (T_8) which was at par with T_2 (102.50), T_3 (100.89), T_4 (92.09), T_6 (98.58) and T_7 (93.50). While, highest number of leaves per plant at 70 DAS (114.54) was noted in control (T_{10}). Similar trends werealso observed at 90 DAS and significantly lowest number of leaves per plant was recorded with the application of paclobutrazol @ 100 mg/l (T_8) (94.20) which was statistically at par T_2 (107.27), T_3 (102.33), T_4 (97.20) and T_7 (101.07). The highest number of leaves per plant at 90 DAS (119.53) was recorded in control (T_{10}). There was a decrease in leaf number as the concentration of paclobutrazol increases. Paclobutrazol is perceived as a stressor by plants, triggering various stress responses. These responses can include reduced leaf production as the plant minimizes stress and conserves energy for essential functions. The growth of plants is often regulated by complex feedback mechanisms involving hormones and signaling pathways. The introduction of paclobutrazol disrupts these regulatory mechanisms, leading to altered growth patterns, including a decrease in leaf number (Ghadiali, 2023). The findings are in conformity with the results of Kashid (2010) in sunflower and Tarun*et al.* (2016) in soybean.

Table 3. Effect of plant growth retardants and detopping on number of leaves per plant at 30, 50, 70, 90 DAS and at harvest

Treatment number	Treatment details	Number of leaves per plant				
		30 DAS	**50 DAS**	**70 DAS**	**90 DAS**	**Harvest**
T_1	CCC @ 250 mg/l	21.07	82.40	107.31	110.12	1.70

T_2	CCC @ 500 mg/l	22.07	75.67	102.50	107.27	1.78
T_3	CCC @ 750 mg/l	22.93	70.40	100.89	102.33	1.79
T_4	CCC @ 1000 mg/l	20.93	67.20	92.09	97.20	1.70
T_5	Paclobutrazol @ 25 mg/l	22.80	80.60	109.06	115.20	1.99
T_6	Paclobutrazol @ 50 mg/l	20.60	73.33	98.58	109.80	1.79
T_7	Paclobutrazol @ 75 mg/l	20.73	72.00	93.50	101.07	1.99
T_8	Paclobutrazol @ 100 mg/l	21.20	66.60	89.49	94.20	1.82
T_9	Detopping	22.13	80.80	106.42	111.93	1.79
T_{10}	Control	21.40	87.87	114.54	119.53	1.99
S.Em. ±		1.11	3.52	5.08	5.03	0.12
C.D at 5%		NS	10.45	15.09	14.94	NS
C.V%		8.91	8.05	8.67	8.15	11.43

3.1.4 Days to initiation of flowering

Data (Table 4) on days to initiation of flowering indicated that different levels of CCC, paclobutrazol and detopping exerted significant effect on the parameter. Foliar spray of CCC @750 mg/l (T_3) recorded significantly minimum number of days to flower initiation (39.00), which was found to be statistically at par with treatments T_2 (39.33), and T_7 (39.33). The maximum number of days for flower initiation was taken by control (T_{10}), *i.e.* 40.67 days. The early flowering induced in the cycocel and paclobutrazol treatments might be due to suppression of vegetative growth, which leads to less demand for food materials synthesized by treated plant and so the excessive carbohydrate reserves might have induced early flowering and accelerated reproductive phase of the plant (Pateliya*et al.* 2008). The findings are in conformity with the results of Pateliya*et al.* (2008), Rajput *et al.* (2011), Kumar *et al.* (2018) and Malshe *et al.* (2021) in okra, Tarun *et al.*(2016) in soybean and AbouElhassan*et al.* (2021) in chrysanthemum.

Table 4. Effect of plant growth retardants and detopping on days to initiation of flowering

Treatment number	Treatment details	Days to initiation of flowering
T_1	CCC @ 250 mg/l	40.00
T_2	CCC @ 500 mg/l	39.33
T_3	CCC @ 750 mg/l	39.00
T_4	CCC @ 1000 mg/l	40.00
T_5	Paclobutrazol @ 25 mg/l	40.33
T_6	Paclobutrazol @ 50 mg/l	40.00
T_7	Paclobutrazol @ 75 mg/l	39.33

T_8	Paclobutrazol @ 100 mg/l	40.33
T_9	Detopping	40.33
T_{10}	Control	40.67
S.Em. ±		0.33
C.D at 5%		0.98
C.V%		1.44

3.1.5 Stem dry weight (g)

Table 5 presents the stem dry weight at different crop growth stages, which depicts that stem dry weight at 50 DAS recorded significantly highest (10.98 g) with the application of CCC @ 750 mg/l (T_3), which was significantly at par with T_7 (10.70 g). Lowest stem dry weight at 50 DAS (6.32 g) was recorded with control (T_{10}). The significantly maximum stem dry weight at 70 DAS (14.10 g) was recorded with treatment T_3, which was statistically at par with T_7 (12.59 g). The treatment T_{10} (control) resulted in minimum stem dry weight at 70 DAS (9.73 g). Results indicated that the significantly highest stem dry weight at 90 DAS (14.39 g) was recorded with application of CCC @ 750 mg/l (T_3), which was statistically at par T_7 (13.18 g), whereas lowest stem dry weight (9.27 g) was noted with control (T_{10}).Results showed that significantly highest stem dry weight at harvest (10.92 g) was recorded with treatment T_3, which was statistically at par with T_2 (9.95 g), T_4 (10.16 g), T_6 (9.68 g), T_7 (10.70 g) and T_9 (10.23 g), while lowest stem dry weight at harvest (8.38 g) was observed with control (T_{10}).Stem dry weight increased only up to 90 DAS, after which the decline might be due to translocation of stored photosynthates towards the developing reproductive organs. Growth retardants reduce the elongation of stems and branches, redirecting the plant's energy away from excessive vegetative growth. Instead, the energy is diverted towards other metabolic processes, such as root development, flowering, and fruiting, which can result in increased dry weight (Ghadiali, 2023).These results are similar to the results reported Techapinyawat*et al.* (1999) and Shinde (2010) in soybean, Kashid (2010) in sunflower and Ghadiali (2023) in groundnut.

Table 5. Effect of plant growth retardants and detopping on stem dry weight at 30, 50, 70, 90 DAS and at harvest

Treatment number	Treatment details	Stem dry weight (g)				
		30 DAS	**50 DAS**	**70 DAS**	**90 DAS**	**Harvest**
T_1	CCC @ 250 mg/l	0.97	6.83	10.36	10.88	9.27
T_2	CCC @ 500 mg/l	1.10	7.74	11.77	10.21	9.95
T_3	CCC @ 750 mg/l	1.08	10.98	14.10	14.39	10.92
T_4	CCC @ 1000 mg/l	1.01	8.62	11.84	12.15	10.16
T_5	Paclobutrazol @ 25 mg/l	0.99	7.33	11.39	11.03	9.41
T_6	Paclobutrazol @ 50 mg/l	1.04	7.88	11.44	10.93	9.68
T_7	Paclobutrazol @ 75 mg/l	1.08	10.70	12.59	13.18	10.70

T_8	Paclobutrazol @ 100 mg/l	1.05	7.67	11.76	12.07	9.29
T_9	Detopping	0.96	8.94	11.93	12.30	10.23
T_{10}	Control	1.03	6.32	9.73	9.27	8.38
S.Em. ±		0.07	0.36	0.70	0.56	0.46
C.D at 5%		NS	1.08	2.09	1.66	1.37
C.V %		11.02	7.61	10.44	8.29	8.17

3.1.6 Total dry weight (g)

Total dry weight in Table 6 at 50 DAS showed that significantly maximum with treatment T_3 (22.30 g), which remained at par with treatment T_7 (21.25 g).The minimum total dry weight at 50 DAS (13.84 g) was recorded with control (T_{10}). The significantly highest total dry weight at 70 DAS (33.30 g) was recorded with treatment T_3, which was statistically at par with T_7 (32.60 g) and T_9 (30.35 g). The treatment T_{10} (control) recorded lowest total dry weight at 70 DAS (20.73 g). Results on total dry weight indicated that the significantly highest total dry weight at 90 DAS (44.37 g) was recorded treatment T_3,which was statistically at par with T_7 (43.16 g) and T_9 (40.39 g). Lowest total dry weight at 90 DAS (28.63 g) was noted with control (T_{10}). An examination of results indicated that the significantly maximum total dry weight at harvest (47.77 g) was recorded with treatment T_3, which was statistically at par with T_7 (46.84 g) and T_9 (43.59 g). Minimum total dry weight at harvest (30.73 g) was noted with control. Increase in dry matter accumulation by growth retardants could be attributed to increased RuBP activity, chlorophyll content, leaf thickness, and specific leaf weight (Kashid, 2010). Jeyakumar and Thangaraj (1998) also reported that, application of CCC found to increase RuBP carboxylase enzyme activity, photosynthesis and dry matter partitioning in groundnut. Ravinchandran and Ramaswami (1991) also indicated that the application of mepiquat chloride, cycocel and TIBA significantly increased the amount of dry matter production in soybean. The findings are also in confirmity with Sarkar and Pal (2005) in sesamum, Kashid (2010) in sunflower, Win *et al.* (2017) in peanut, and Jaidka*et al.* (2020) in soybean.

Table 6. Effect of plant growth retardants and detopping on total dry weight at 30, 50, 70, 90 DAS and at harvest

Treatment number	Treatment details	Total dry weight (g)				
		30 DAS	**50 DAS**	**70 DAS**	**90 DAS**	**Harvest**
T_1	CCC @ 250 mg/l	2.06	15.56	23.78	32.38	35.11
T_2	CCC @ 500 mg/l	2.13	16.80	26.10	35.12	38.29
T_3	CCC @ 750 mg/l	2.30	22.30	33.30	44.37	47.77
T_4	CCC @ 1000 mg/l	2.17	16.84	26.84	36.41	39.90
T_5	Paclobutrazol @ 25 mg/l	2.00	15.20	23.90	32.17	34.88
T_6	Paclobutrazol @ 50 mg/l	2.04	16.04	25.35	34.40	37.74
T_7	Paclobutrazol @ 75 mg/l	2.25	21.25	32.60	43.16	46.84

T_8	Paclobutrazol @ 100 mg/l	2.10	17.10	27.20	36.64	39.94
T_9	Detopping	2.19	19.69	30.35	40.39	43.59
T_{10}	Control	2.01	13.84	20.73	28.63	30.73
S.Em. ±		0.10	0.87	1.25	1.69	1.70
C.D at 5%		NS	2.58	3.72	5.03	5.05
C.V %		7.81	8.62	8.03	8.06	7.46

3.2 Physiological Parameters

3.2.1 Leaf area index (LAI)

The data regarding leaf area index at 30, 50, 70, 90 DAS as well as at harvest as influenced by plant growth retardants and detopping are presented in Table 7. LAI was found to be non-significant at 30 DAS. Leaf area index at 50 DAS was recorded significantly minimum (14.96) with application of paclobutrazol @ 75 mg/l (T_7) which was significantly at par with T_1 (16.86), T_2 (15.92), T_3 (15.08), T_4 (17.58), T_5 (16.00), T_6 (15.98) and T_8 (17.37). While, maximum leaf area index at 50 DAS (18.78) were recorded with control (T_{10}). Results indicated that the significantly lowest leaf area index at 70 DAS (24.75) was recorded with application of paclobutrazol @ 75 mg/l (T_7) which was significantly at par with T_3 (27.51), T_4 (28.46) and T_8 (28.02). While, highest leaf area index at 70 DAS (34.46) was noted with control (T_{10}). Significantly lowest leaf area index at 90 DAS (26.02) was recorded with application of paclobutrazol @ 75 mg/l (T_7), which was statistically at par with T_1 (30.65), T_2 (30.03), T_3 (28.19), T_4 (29.65), T_6 (30.15) and T_8 (28.38). Whereas, highest leaf area index at 90 DAS (34.72) was recorded with control (T_{10}). The decrease in leaf area index due to growth retardants is a direct result of the growth regulatory effects on leaf development and resource allocation within the plant. Maheswari and Krishnasamy (2019) also reported that reduction in LAI by growth retardants might also be due to increased juvenility. These results are in close conformity with the results of Shinde (2010) in soybean, Win *et al.* (2017) and Ghadiali (2023) in groundnut, Nurainiet *al.* (2018) in potato, Maheswari and Krishnasamy (2019) in cotton.

Table 7. Effect of plant growth retardants and detopping on leaf area index at 30, 50, 70, 90 DAS and at harvest

Treatment Number	Treatment details	Leaf area index (LAI * 100)				
		30 DAS	50 DAS	70 DAS	90 DAS	Harvest
T_1	CCC @ 250 mg/l	11.34	16.86	29.99	30.65	4.63
T_2	CCC @ 500 mg/l	11.41	15.92	29.57	30.03	4.64
T_3	CCC @ 750 mg/l	11.16	15.08	27.51	28.19	4.44
T_4	CCC @ 1000 mg/l	11.32	17.58	28.46	29.65	4.52
T_5	Paclobutrazol @ 25 mg/l	10.97	16.00	31.11	31.22	4.79
T_6	Paclobutrazol @ 50 mg/l	11.06	15.98	29.94	30.15	4.69
T_7	Paclobutrazol @ 75 mg/l	11.15	14.96	24.75	26.02	4.30

T_8	Paclobutrazol @ 100 mg/l	11.36	17.37	28.02	28.38	4.86
T_9	Detopping	11.45	18.78	33.39	34.11	5.04
T_{10}	Control	11.29	19.57	34.46	34.72	5.09
S.Em. ±		0.53	0.96	1.52	1.61	0.23
C.D at 5%		NS	2.86	4.52	4.77	NS
C.V%		8.22	9.92	8.87	9.18	8.51

3.2.2 Leaf area ratio (LAR) (cm^2/g)

Data pertaining to leaf area ratio at 30, 50, 70, 90 DAS as well as at harvest as influenced by plant growth retardants and detopping presented in table 8 revealed that LAR was non-significant during 30 DAS. Analysis of data indicated that the leaf area ratio at 50 DAS was highly significant with highest value being recorded at control (6.39 cm^2/g), while lowest value was recorded with treatment T_3 (3.09 cm^2/g), which was statistically at par with T_7 (3.16 cm^2/g).An examination of data indicated that the significantly highest leaf area ratio at 70 DAS (7.50 cm^2/g) was recorded with control (T_{10}). Lowest leaf area ratio at 70 DAS (3.43 cm^2/g) was observed with the application of paclobutrazol @ 75 mg/l (T_7). It was statistically at par with T_3 (3.72 cm^2/g). At 90 DASsignificantly maximum leaf area ratio (5.45 cm^2/g) was recorded with control (T_{10}). Minimum leaf area ratio at 90 DAS (2.74 cm^2/g) was observed with application of paclobutrazol @ 75 mg/l (T_7). It was statistically at par with T_3 (2.86 cm^2/g).Significantly highest leaf area ratio at harvest (0.75 cm^2/g) was recorded with control (T_{10}). While, lowest leaf area ratio at harvest (0.42 cm^2/g) was noted with application of paclobutrazol @ 75 mg/l (T_7) and CCC @ 750 mg/l (T_3). It was statistically at par with T_4 (0.51 cm^2/g). Leaf area ratio denotes the allocation of resources towards leaf growth. A high leaf area ratio indicates that the plant is allocating a significant portion of its resources towards leaf development. LAR had significantly higher values at 70 DAS after which there was decline in LAR when crop grew towards maturity. Excessive leaf area relative to biomass is indicated by high LAR values, and vice versa. Decreased LAR pattern in the growth retardants treatments shows that dry matter partitioning is more towards reproductive organs in case of growth retardants, which is vice versa in control. The similar results were reported by Ghadiali (2023) in groundnut.

Table 8. Effect of plant growth retardants and detopping on leaf area ratio at 30, 50, 70, 90 DAS and at harvest

Treatment number	Treatment details	Leaf area ratio (cm^2/g)				
		30 DAS	**50 DAS**	**70 DAS**	**90 DAS**	**Harvest**
T_1	CCC @ 250 mg/l	24.84	4.89	5.70	4.28	0.60
T_2	CCC @ 500 mg/l	24.20	4.28	5.14	3.86	0.55
T_3	CCC @ 750 mg/l	21.84	3.09	3.72	2.86	0.42
T_4	CCC @ 1000 mg/l	23.58	4.71	4.80	3.67	0.51
T_5	Paclobutrazol @ 25 mg/l	24.90	4.81	5.87	4.39	0.62
T_6	Paclobutrazol @ 50 mg/l	24.37	4.49	5.32	3.96	0.56

T_7	Paclobutrazol @ 75 mg/l	22.25	3.16	3.43	2.74	0.42
T_8	Paclobutrazol @ 100 mg/l	24.37	4.60	4.66	3.49	0.55
T_9	Detopping	23.77	4.34	4.97	3.82	0.52
T_{10}	Control	25.76	6.39	7.50	5.45	0.75
S.Em. ±		1.81	0.35	0.33	0.25	0.04
C.D at 5%		NS	1.05	0.99	0.73	0.11
C.V%		13.11	13.64	11.29	11.12	11.49

3.2.3 Net assimilation rate (NAR) (g/m^2/day)

Table 9 containing data regarding net assimilation rate of soybean subjected to growth retardants treatment and detopping recorded at 30-50 DAS, 50-70 DAS, 70-90 DAS and at 90 DAS-harvest revealed that significantly maximum net assimilation rate at 30-50 DAS (173.60 g/m^2/day) was recorded with treatment T_3.It was at par with T_7 (166.27 g/m^2/day), while minimum net assimilation rate at 30-50 DAS (87.50 g/m^2/day) was noted in control. The data regarding net assimilation rate at 50-70 DAS (66.14 g/m^2/day) showed that significantly higher with treatment $T_{7,}$ which was at par with T_3 (59.53 g/m^2/day). The minimum net assimilation rate at 50-70 DAS (29.03 g/m^2/day) was recorded with T_{10} (control). Results indicated that significantly highest net assimilation rate at 70-90 DAS (46.62 g/m^2/day) was recorded with application of paclobutrazol @ 75 mg/l (T_7), which was at par with T_3 (44.30 g/m^2/day), while lowest net assimilation rate at 70-90 DAS (25.40 g/m^2/day) was noted with control (T_{10}). Significantly highest net assimilation rate at 90 DAS-harvest (33.94 g/m^2/day) was recorded with treatment T_7, which was at par with T_2 (25.90 g/m^2/day), T_3 (29.74 g/m^2/day), T_4 (29.20 g/m^2/day), T_6 (27.30 g/m^2/day) and T_8 (27.57 g/m^2/day), while lowest net assimilation rate at 90 DAS-harvest (15.09 g/m^2/day) was noted with T_{10} (control). The plant's efficiency in using its resources such as light, water, and nutrients to create new biomass is measured by net assimilation rate. As a plant builds its root system and starts to photosynthesize, NAR typically tends to be high throughout the early growth stages. NAR begins to decline as the crop ages, mostly as a result of leaf competition for light and self-shading. A similar tendency is seen in the mean values shown in Table 9. The crop devotes more energy and resources to its reproductive organs like flowers, pods and seeds as it ages. NAR decreases as a result of this change in resource allocation, which takes energy away from photosynthesis and vegetative development. These results are in close conformity with the results of Nawalagatti*et al.* (1991) in groundnut, Kashid (2010) in sunflower and Jie*et al.* (2017) in rapeseed.

Table 9. Effect of plant growth retardants and detopping on net assimilation rate at 30-50 DAS, 50-70 DAS, 70-90 DAS and at 90 DAS-harvest

Treatment number	Treatment details	Net assimilation rate (g/m^2/day)			
		30-50 DAS	50-70 DAS	70-90 DAS	90 DAS-Harvest
T_1	CCC @ 250 mg/l	107.98	40.19	31.75	22.70
T_2	CCC @ 500 mg/l	120.50	47.66	34.09	25.90
T_3	CCC @ 750 mg/l	173.60	59.53	44.30	29.74

T_4	CCC @ 1000 mg/l	115.13	49.19	36.62	29.20
T_5	Paclobutrazol @ 25 mg/l	110.31	42.61	29.62	21.37
T_6	Paclobutrazol @ 50 mg/l	116.45	46.51	33.59	27.30
T_7	Paclobutrazol @ 75 mg/l	166.27	66.14	46.62	33.94
T_8	Paclobutrazol @ 100 mg/l	118.49	50.41	37.20	27.57
T_9	Detopping	132.46	46.63	33.00	23.38
T_{10}	Control	87.50	29.03	25.40	15.09
S.Em. ±		11.36	3.83	2.69	2.80
C.D at 5%		33.75	11.38	7.99	8.31
C.V%		15.76	13.88	13.23	18.92

3.2.4 Crop growth rate (CGR) (g/m^2/day)

Table 10 provides information on crop growth rate at 30-50 DAS, 50-70 DAS, 70-90 DAS and at 90 DAS-harvest on account of plant growth retardants and detopping. Significantly highest crop growth rate at 30-50 DAS (22.22 g/m^2/day) was recorded with CCC @ 750 mg/l (T_3) which was at par with T_7 (21.11 g/m^2/day) and T_9 (19.44 g/m^2/day), while lowest crop growth rate at 30-50 DAS (13.15 g/m^2/day) was noted in control (T_{10}). Crop growth rate at 50-70 DAS was recorded significantly maximum (12.60 g/m^2/day) with paclobutrazol @75 mg/l (T_7), which was at par with T_3 (12.22 g/m^2/day), T_4 (11.11 g/m^2/day), T_8 (11.22 g/m^2/day) and T_9 (11.85 g/m^2/day). Minimum crop growth rate at 50-70 DAS (7.66 g/m^2/day) were recorded with T_{10} (control). The data presented in Table 10 indicated that significantly maximum crop growth rate at 70-90 DAS (12.30 g/m^2/day) was recorded with T_3, which was at par with T_4 (10.63 g/m^2/day), T_7 (11.73 g/m^2/day), T_8 (10.49 g/m^2/day) and T_9 (11.15 g/m^2/day), while minimum crop growth rate at 70-90 DAS (8.78 g/m^2/day) was noted with T_{10} (control). Significantly maximum crop growth rate at 90 DAS-harvest (4.09 g/m^2/day) was recorded with application of paclobutrazol @ 75 mg/l (T_7), which was at par with T_2 (3.52 g/m^2/day), T_3 (3.78 g/m^2/day), T_4 (3.88 g/m^2/day), T_6 (3.70 g/m^2/day), T_8 (3.67 g/m^2/day) and T_9 (3.56 g/m^2/day), while minimum crop growth rate at 90 DAS-harvest (2.33 g/m^2/day) was noted with T_{10} (control). Crop growth rate (CGR) is influenced by LAI, photosynthetic rate and leaf angle and is an index of amount of light interception. The CGR was highest at early stages, which then decreased and gradually increased during 70-90 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 ageing. The rapid increase in CGR observed under the effect of growth retardants over that of control might be due to higher production of dry matter due to increased photosynthetic activities coupled with increased cell multiplication (Shinde, 2010). The findings were also in confirmity with Nawalagatti*et al.* (1991) in groundnut, Kashid (2010) in sunflower and Win *et al.* (2017) in peanut.

Table 10. Effect of plant growth retardants and detopping on crop growth rate at 30-50 DAS, 50-70 DAS, 70-90 DAS and at 90 DAS-harvest

Treatment number	Treatment details	Crop growth rate (g/m^2/day)			
		30-50 DAS	50-70 DAS	70-90 DAS	90 DAS-Harvest

T_1	CCC @ 250 mg/l	15.00	9.13	9.56	3.04
T_2	CCC @ 500 mg/l	16.30	10.33	10.03	3.52
T_3	CCC @ 750 mg/l	22.22	12.22	12.30	3.78
T_4	CCC @ 1000 mg/l	16.30	11.11	10.63	3.88
T_5	Paclobutrazol @ 25 mg/l	14.67	9.67	9.19	3.01
T_6	Paclobutrazol @ 50 mg/l	15.56	10.34	10.06	3.70
T_7	Paclobutrazol @ 75 mg/l	21.11	12.60	11.73	4.09
T_8	Paclobutrazol @ 100 mg/l	16.67	11.22	10.49	3.67
T_9	Detopping	19.44	11.85	11.15	3.56
T_{10}	Control	13.15	7.66	8.78	2.33
S.Em.±		0.99	0.71	0.65	0.30
C.D at 5%		2.96	2.14	1.93	0.91
C.V%		10.11	11.76	10.82	15.28

4. CONCLUSION

The results of the present experiment showed that foliar spray of growth retardant-paclobutrazol @ 100 mg/l (T_8) performed well in terms of morphological parameters like plant height and number of leaves per plant. Meanwhile, CCC @ 750 mg/l performed well in parameters like days to initiation of flowering; stem dry weight, total dry weight. CCC @ 750 mg/l and paclobutrazol @ 75 mg/l (T_7) recorded better results on physiological traits (LAI, LAR, CGR, and NAR). In summary, farmers aiming to higher yield were recommended to use of growth retardant CCC @ 750 mg/l or paclobutrazol @ 75 mg/l by foliar spray.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

REFERENCES

1. Khatun S, Roy TS, Haque MN, Alamgir B. Effect of plant growth regulators and their time of application on yield attributes and quality of soybean. Int J Plant Soil Sci.2016;11(1):1-9. https://doi.org/10.9734/ijpss/2016/25981
2. Horvath AA. Changes in the blood composition of rabbits fed on raw soy beans. JBiol Chem.1926;68(2):343-55.

3. Ramesh R, Ramprasad E. Effect of Plant growth regulators on morphological, physiological and biochemical parameters of soybean (*Glycine max* L. Merrill). Helix. 2013;6:441-47.
4. El-Aal MMM, Eid RS. Optimizing growth, seed yield and quality of soybean (*Glycine max* L.) plant using growth substances. Asian Research Journal of Agriculture.2017;6(3):1-19. https://doi.org/10.9734/arja/2017/36034
5. Jahan, N. (2017). Effect of detopping on the growth and yield of sesame. (M.Sc. (Agri.) Thesis, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh).
6. Jaidka M, Deol JS, Kaur R, Sikka R. Source-sink optimization and morpho-physiological response of soybean (*Glycine max*) to detopping and mepiquat chloride application. Legume Research-An International Journal. 2020;43(3):401-07. https://doi.org/10.18805/lr-3971
7. Panse VG, Sukhatme PV. Statistical methods for agricultural workers. New Delhi: ICAR.1995.
8. Watson DJ. The physiological basis of variation in yield. In Advances in Agronomy. 1952;4:101-45.
9. Radford PJ. Growth analysis formulae□their use and abuse. Crop Sci. 1967;7(3):171-75.
10. Srivastava GC, Prasad NK. Modern methods in plant physiology.2010;19-23.
11. Desta B, Amare G. Paclobutrazol as a plant growth regulator. ChemBiolTechnol Agric.2021;8:1-15. https://doi.org/10.1186/s40538-020-00199-z
12. Moore TC, Biochemistry and Physiology of Plant Hormone, Narosja publishing house, New Delhi. 1980;107-31.
13. Techapinyawat S, Nakorn MN, Sinbuathong N. Effects of ethephon and paclobutrazol on growth and yield of soybean (*Glycine max* L.) Merill cv. SJ5. WitthayasanKasetsart. 1999;29(2):193-204.
14. Tarun K, Samaiya RK, Singh Y, Dwivedi SK, Meena, KC. Effect of foliar application of plant growth retardants on growth, yield and yield attributing parameters of soybean (*Glycine max* L.) Merrill. International Journal of Agriculture Sciences. 2016;8(50):2158-62.
15. Win A, Htwe NM, Myint NO, Toe K, Hom NH. Effects of paclobutrazol on growth of groundnut (*Arachishypogaea* L.). J Agric Res. 2017;4(1):15-22.
16. Zhao J, Lai H, Bi C, Zhao M, Liu Y, Li X, Yang D. Effects of paclobutrazol application on plant architecture, lodging resistance, photosynthetic characteristics, and peanut yield at different single-seed precise sowing densities. Crop J. 2023;11(1):301-10.
17. Banoo M, Sinha BK, Chand G, Sinha R, Gupta M, Sharma M, Sharma D. Response of growth retardants paclobutrazol and cycocel on morphological characteristics in Indian mustard (*Brassica juncea* L.) genotypes under rainfed condition. Pharma Innov.2022;11(12):715-19.
18. Ghadiali, J. J. (2023). Amelioration of water stress and effect of paclobutrazole on morpho-physiology, growth and yield in groundnut (*Arachishypogaea*L.). (Doctoral thesis, Anand Agricultural University, Anand, India).
19. Kashid, D. A. (2010*).* Effect of growth retardants on morpho-physiological traits and yield in sunflower. (M.Sc. (Agri.) Thesis, University of Agricultural Sciences, Dharwad, India).
20. Pateliya CK, Parmar BR, Tandel YN. Effect of different growth retardants on flowering, yield and economics of okra (*Abelmoschusesculentus* L. Moench) cv. GO-2 under South Gujarat conditions. Asian Journal of Horticulture. 2008;3(2):317-18.
21. Rajput BS, Singh A, Patel P, Gautam US. Study of different plant growth retardants on flowering, fruiting, yield and economics of okra (*Abelmoschusesculentus*). Progressive Horticulture. 2011;43(1):166-67.
22. Kumar P, Haldankar P, Haldavanekar P. Study on effect of plant growth regulators on flowering, yield and quality aspects of summer okra (*Abelmoschusesculentus* L.

Moench) Var. VarshaUphar. Pharma Innov.2018;7(6):180-84.
23. Malshe KV, Haldavanekar PC, Khandekar RG. Effect of growth retardants on yield attributing characters of okra (*Abelmoschusesculentus* L. Moench) Var. ParbhaniKranti. Journal of Eco-Friendly Agriculture. 2021;16(2):83-85. https://doi.org/10.5958/2582-2683.2021.00033.2
24. AbouElhassan MH, Bosila HA, Hamza MA, Elateeq AA, Abdel-Gawad AI. Effect of cycocel and paclobutrazol on the dwarfing characteristics of *Chrysanthemum indicum* L. Al-Azhar Journal of Agricultural Research. 2021;46(2):41-50.
25. Shinde, R. V. (2010). Influence of plant growth regulators on growth, physiology, yield and quality in soybean (*Glycine max* (L.) Merrill). (M.Sc. (Agri.) Thesis, University of Agricultural Sciences, Dharwad, India).
26. Jeyakumar P, Thangaraj M. Effect of mepiquat chloride on certain physiological and yield characteristics of groundnut (*Arachishypogaea* L.). J Agron Crop Sci. 1996;176(3):159-64.
27. Ravichandran VK, Ramaswami C. Source and sink relationship in soybean as influenced by TIBA. Indian J Plant Physiol.1991;34(1):80-83.
28. Sarkar RK, Pal PK. Effect of crop geometry, fertility level and nipping on parameters in relation to productivity of sesame *(Sesamumindicum).* Indian Journal of Agricultural Science.2005;75(3):143-46.
29. Maheswari MU, KrishnasamySM.Effect of crop geometries and plant growth retardants on physiological growth parameters in machine sown cotton. J PharmacognPhytochem. 2019;8(2):541-545.
30. Nuraini A, Sumadi, Mubarok S, Hamdani JS. Effects of application time and concentration of paclobutrazol on the growth and yield of potato seed of G2 cultivar medians at medium altitude.J Agron.2018;17(3),169-73. http://docsdrive.com/pdfs/ansinet/ja/2018/169-173.pdf
31. Nawalagatti CM, Panchal YC, Manjunath S, Channappagoudar BB. Effects of different levels of plant growth regulators on growth and yield of groundnut.J Maharashtra Agric Univ.1991;16(1):122-23.
32. Jie KUAI, Li XY, Yang YANG, Zhou GS. Effects of paclobutrazol on biomass production in relation to resistance to lodging and pod shattering in *Brassica napus* L. J Integr Agric. 2017;16(11):2470-81.