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Studies on the efficacy of plant density and growth regulators on vegetative growth of potted annual zinnia (*Zinnia elegans* Jacq.)

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Abstract
In an experiment carried out at College of Horticulture, Mojerla, SKLTSHU, during December 2022 to March 2023, laid out in FCRD with two factors of which first factor consists of two levels of plant densities and second factor consists of seven levels of sprays of growth regulators, the results revealed that four plants per pot with cycocel at 1500 ppm reduced the plant height, internodal length to maximum extent and increased number of nodes, number of branches per plant, plant spread in both directions (East-West & North-South). Four plants per pot with cycocel at 1500 ppm was found best for all vegetative growth parameters.

Keywords: Plant density, cycocel, Paclobutrazol, zinnia, anti-gibberellins

Introduction
A member of Asteraceae family, *Zinnia* is a genus of annual and perennial flowering plants with roughly 20 species. The most popular and quite well known annual in the genus is *Zinnia elegans* (syn. *Zinnia violacea*). Zinnia flowers have vivid, single colour with strong stalks and extended vase life.

Zinnia elegans is also known as the youth and age plant, common zinnia, and elegant zinnia. The genera bear the name of Johann Gottfried Zinn, a German botanist, and it represents tenacity, generosity, and friendliness. It is believed that it originated in Mexico and regions of Central and South America.

Rapid urbanization, lack of free space for planting and changing lifestyles has increased the demand for potted plants in India. It is important to study the performance of existing varieties available in market and to identify the precise number of plants per pot to look attractive. Increasing the number of plants per pot gives a bushy appearance which makes the pot more appealing. Number of branches per pot increased significantly as number of cuttings per pot increased. (Rezazadeh *et al*., 2015) [14].

Controlling plant size is one of the most important aspects in ornamental plant production. Plant size can be limited by various methods such as genetic control, environmental conditions and use of plant growth retardants (Cowling, 2010) [2]. Plant growth retardants are commonly applied to limit stem elongation and to produce more compact plants.

Cycocel (CCC) is a quaternary ammonium compound that prevents gibberellin biosynthesis (Megersa *et al*., 2018) [8] resulting in reduction in vegetative growth. The use of such growth retardants is recommended to reduce the height. (Karimi *et al.,* 2020) [5]. Paclobutrazol has been reported to be very effective for dwarfing a wide range of crops (Lever *et al*., 1982; Menhenett and Hanks, 1982) [7, 9]. It is used primarily for the reduction in extension of shoot growth, increase the root growth, produce uniform compact plants, with enhancement of foliage colour and flowering in certain species.

Materials and Methods
The experiment was conducted in a polyhouse at Floriculture block of College of Horticulture, Mojerla, Wanaparthy district in Factorial Completely Randomized Design with two replications and two factors with the first factor consisting of two levels of Plant densities (P1-Three plants per pot, P2-Four plants per pot) and second factor comprising of seven levels of growth regulators (R0-No spray, R1-Cycocel @ 1000 ppm, R2-Cycocel @ 1500 ppm, R3-Cycocel

@ 2000 ppm, R4-Paclobutrazol @ 60 ppm, R5-Paclobutrazol @ 90 ppm and R6-Paclobutrazol @ 120 ppm).

Seed was sown in plug trays filled with a mixture of cocopeat and vermicompost and seedlings were transplanted after 21 days of sowing into pots containing potting mixture of red earth, vermicompost, FYM and cocopeat in the ratio of 1:1:1:1. First spray of growth regulators was done at 3-4 leaf stage and second spray was done 25 days after first spray. Data was recorded to record the influence of growth regulators and plant densities on vegetative growth.

Results and Discussion

Plant height (cm)

Higher plant height with longer internodal length is a main hindrance for potted zinnias to attain good pot presentability score. It was observed that the four plants per pot significantly reduced overall plant height (13.26 cm, 16.26 cm) at 45 and 60 DAT compared to three plants per pot in the present experiment (table 1). The reduction in plant height at higher plant density might be due to increased competition among the plants for moisture, nutrients, sunlight, etc.

Cycocel @ 1500 ppm reduced the plant height (12.78 cm, 15.12 cm) at 45 and 60 DAT to the maximum extent. The retarding effect of cycocel is due to its opposing effect to gibberellin biosynthesis by blocking the conversion of geranyl pyrophosphate to copalyl diphosphate causing reduction in cell elongation (Rademacher, 2000). Among the interactions, four plants per pot + cycocel @ 1500 ppm concentration controlled the plant height effectively (14.00 cm) at 60 DAT.

Stem diameter (cm)

Stem diameter in three plants per pot is higher (0.45 cm, 0.53 cm) at 45 and 60 DAT compared to four plants per pot (table 2). Thicker stems at lower plant density might be due to lack of competition for nutrients, water and light (Abdulrahman *et al*., 2011) [1].

Cycocel @ 1500 ppm resulted in maximum stem diameter (0.49 cm, 0.57 cm) at 45 and 60 DAT. The plants treated with cycocel produced thicker stems because cycocel acts as anti-gibberellin and inhibits cell elongation which resulted in shorter plants with more stem thickness.

Among the interactions, the combination of three plants per pot + cycocel at 1500 ppm resulted in plants with higher stem diameter (0.54 cm, 0.66 cm) at 45 and 60 DAT.

Table 1: Effect of plant density and growth regulators on plant height (cm) at 45 and 60 days after transplanting in zinnia

45 Days after transplanting					60 Days after transplanting		
Growth		Plant density	Mean	Growth		Plant density	
Regulators	P1	P2		Regulators	P1	P2	Mean
R0	15.11	13.78	14.45a	R0	18.03a	17.10bc	17.57a
R1	14.44	13.36	13.90a	R1	17.05bc	17.31abc	17.18a
R2	13.59	11.96	12.78b	R2	16.23de	14.00f	15.12c
R3	13.20	12.99	13.50ab	R3	15.80e	15.80e	15.80bc
R4	13.99	13.75	13.87ab	R4	17.83ab	16.92cd	17.38a
R5	13.98	13.78	13.88a	R5	17.13bc	16.92cd	17.03a
R6	14.80	13.21	14.01a	R6	16.53cde	15.78e	16.16b
MEAN	14.28a	13.26b		MEAN	16.94a	16.26b	
	S.E (m)±		C.D. at 5%		S.E (m)±		C.D. at 5%
P		0.13	0.35	P		0.09	0.27
R		0.23	0.70	R		0.17	0.51
P*R		0.33	NS	P*R		0.23	0.72

Table 2: Effect of plant density and growth regulators on stem diameter (cm) at 45 and 60 days after transplanting in zinnia

45 Days after transplanting					60 Days after transplanting		
Growth	Plant density			Growth	Plant density		
Regulators	P1	P2	Mean	Regulators	P1	P_2	Mean
R0	0.41f	0.33^{h}	0.33h	R0	0.47^{ef}	0.41^{g}	0.44^{b}
R1	0.36g	0.41^{f}	0.41f	R1	0.45^{fg}	0.49^{def}	0.47^{b}
R2	0.54a	0.44^{e}	0.44e	R2	0.66^{a}	0.48^{ef}	0.57^{a}
R3	0.45de	0.47^{cd}	0.47cd	R3	0.51^{cde}	0.56^{b}	0.54^{a}
R4	0.46de	0.36^{g}	0.36g	R4	0.53^{bcd}	0.54^{bc}	0.53^{a}
R5	0.49bc	0.47^{cd}	0.47cd	R5	0.57^{b}	0.54^{bc}	0.56^{a}
R6	0.41f	0.50^{b}	0.50b	R6	0.49^{def}	0.51^{cde}	0.50^{b}
Mean	0.45a	0.43^{b}	0.43b	Mean	0.53^{a}	0.51^{b}	0.53a
	S.E (m)±	C.D. at 5%			S.E (m)±	C.D. at 5%	
P		0.003	0.009	P	0.006	0.017	
R		0.005	0.017	R	0.01	0.032	
P*R		0.008	0.024	P*R	0.015	0.045	

Number of nodes

Table (3) reveals that maximum number of nodes (10.53, 12.15) were recorded at higher plant density of 45 and 60 DAT. At lower plant density the plants were tall with lesser number of nodes and internodal length.

Among the growth regulators, cycocel @ 1500 ppm resulted in higher number of nodes (10.53, 13.20) at 45 and 60 DAT with decreased internodal length which is due to the effect of growth regulators resulting in increased number of nodes. Sasikumar *et al*. (2015) [15] reported production of higher number of nodes in plants treated with cycocel at higher concentration in marigold. Among the interactions, four plants per pot + cycocel @ 1500 ppm produced maximum number of nodes (10.80, 13.45) at 45 and 60 DAT.

Table 3: Effect of plant density and growth regulators on number of nodes at 45 and 60 days after transplanting in zinnia

45 Days After Transplanting					60 Days After Transplanting		
Growth Regulators	Plant Density P1	Plant Density P2	Mean	Growth Regulators	Plant Density P1	Plant Density P2	Mean
R0	8.40g	8.55fg	8.48c	R0	11.05de	10.75e	10.90c
R1	9.85cd	9.00ef	9.43b	R1	12.25b	11.40cd	11.83b
R2	10.25abc	10.80a	10.53a	R2	12.95a	13.45a	13.20a
R3	8.55fg	10.10bc	9.33b	R3	11.05de	13.00a	12.03b
R4	8.55fg	8.40g	8.48c	R4	11.25de	11.15de	11.20c
R5	9.30de	9.30de	9.30b	R5	11.95b	11.90bc	11.93b
R6	9.90c	10.50ab	10.20a	R6	12.40b	13.35a	12.88a
Mean	9.26b	9.53a		Mean	11.85b	12.15a	
	S.E (m)±		C.D. at 5%		S.E (m)±		C.D. at 5%
P		0.07	0.21	P	0.07		0.20
R		0.13	0.38	R	0.13		0.38
P*R		0.18	0.54	P*R	0.18		0.53

Internodal length (cm)

Higher plant density reduced the internodal length (1.88 cm, 2.24 cm) at 45 and 60 DAT compared to lower plant density (table 4). This decrease in internodal length in plants with higher number of plants per pot might be due to increased competition among the plants for moisture, nutrients and sunlight.

Cycocel @ 1500 ppm resulted in minimum internodal length (1.79 cm, 2.19 cm) at 45 and 60 DAT. Cycocel decreases cell elongation and reduce plant height by acting in sub-apical system and consequently the plant becomes dwarf as the internodes fail to elongate. Similar observations were recorded by Patel *et al*., (2022) [12] in bougainvillea. The interactions among the factors indicated that the combination of four plants per pot + cycocel at 1500 ppm reduced the internodal length to the maximum extent (1.55 cm, 2.01 cm) at 45 and 60 DAT.

Table 4: Effect of plant density and growth regulators on internodal length (cm) at 45 and 60 days after transplanting in zinnia

45 Days After Transplanting					60 Days After Transplanting		
Growth Regulators	Plant density P1	Plant density P2	Mean	Growth Regulators	Plant density P1	Plant density P2	Mean
R0	2.45a	2.30b	2.38a	R0	2.80a	2.72a	2.76a
R1	2.06c	1.86hi	1.96b	R1	2.50b	2.32ef	2.41b
R2	2.03cd	1.55j	1.79c	R2	2.37cde	2.01g	2.19c
R3	1.95efg	1.93fgh	1.94b	R3	2.38cde	2.05g	2.22c
R4	2.01cde	1.99cdef	2.00b	R4	2.46bc	2.29ef	2.37b
R5	1.89ghi	1.97def	1.93b	R5	2.43bcd	2.25f	2.34b
R6	1.85i	1.56j	1.71d	R6	2.35def	2.06g	2.20c
Mean	2.04a	1.88b		Mean	2.47a	2.24b	
	S.E (m)±		C.D. at 5%		S.E (m)±		C.D. at 5%
P		0.008	0.025	P	0.013		0.040
R		0.015	0.047	R	0.025		0.075
P*R		0.022	0.066	P*R	0.035		0.107

Number of branches per plant

The results (fig. 1), shows that maximum number of branches (9.38, 12.36) at 45 and 60 DAT were observed at higher plant density and the number of branches decreased with decreasing plant density. Increased number of branches per plants were observed at higher plant density by Rezazadeh *et al*. (2015) [14] in purple fire spike. It was observed that cycocel @ 1500 ppm increased number of branches (10.33, 13.25) at 45 and 60 DAT in zinnia and the lower number of branches per plant were recorded in control (no spray). This response may be due to inhibition of GA synthesis and breakdown of apical dominance, thereby resulting in auxin balance and enhanced differentiation of branching caused by CCC, as proposed by (Ninnemann *et al*., 1964) [10].

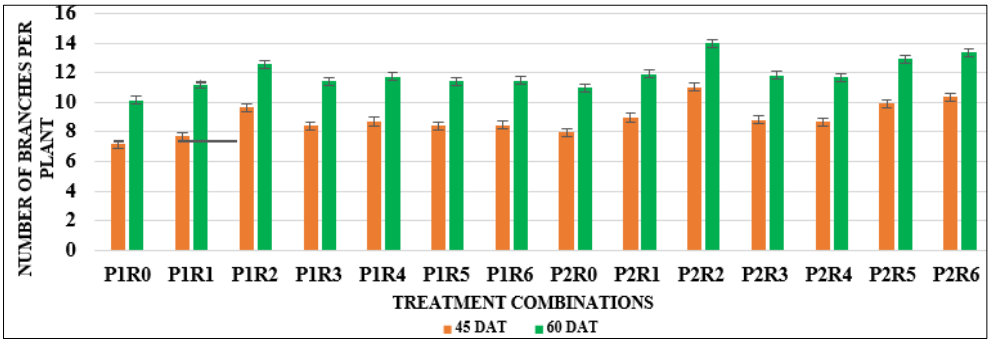

Fig 1: Effect of plant density and growth regulators on number of branches per plant at 45 and 60 days after transplanting in zinnia.

Plant spread (East-West & North-South direction) (cm)

Higher plant density resulted in maximum plant spread in both East-West and North-South directions (12.56 cm, 13.55 cm) and (12.50 cm, 13.05 cm) at 45 and 60 DAT. It might be due to increased number of branches and decreased plant height that covered the whole pot.

Cycocel at 1500 ppm recorded plant spread in both East-West and North-South directions (12.90 cm, 13.84 cm) and (12.90 cm, 14.06 cm) at 45 and 60 DAT. The increased plant spread both in East-West and North-South directions might be due to the inhibition of apical dominance by cycocel which results in the production of a greater number of branches. Similar reports were recorded by Patel *et al*. (2022) [12] in bougainvillea in plants treated with cycocel.

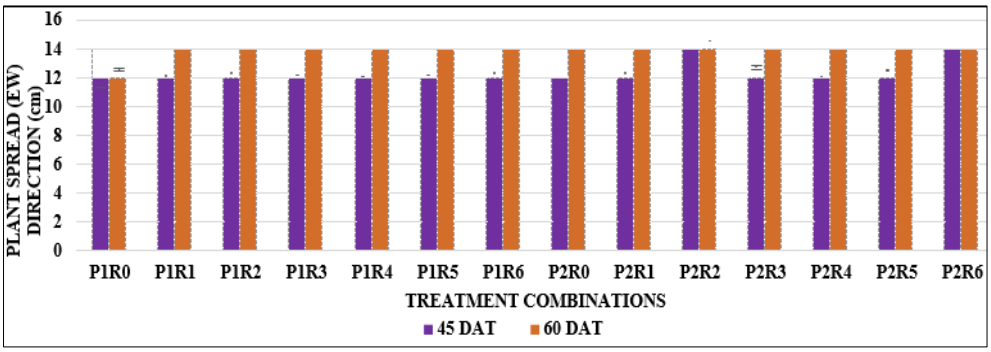

Fig 2a: Effect of plant density and growth regulators on plant spread (EW) (cm) at 45 and 60 days after transplanting in zinnia

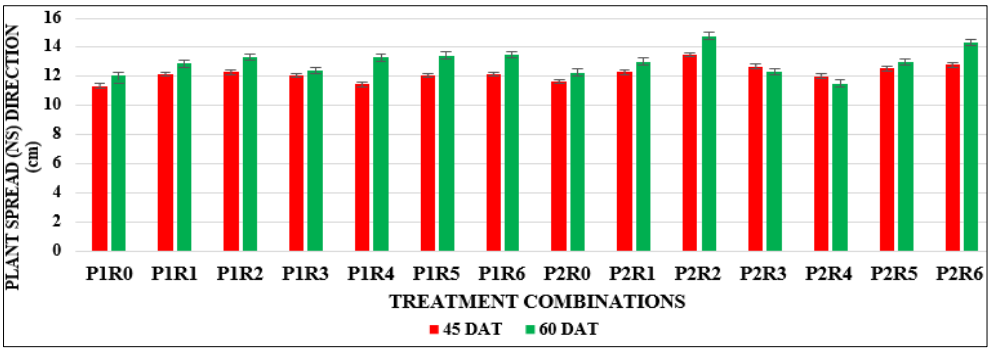

Fig 2b: Effect of plant density and growth regulators on plant spread (NS) (cm) at 45 and 60 days after transplanting in zinnia

Number of leaves per plant

Maximum number of leaves per plant (72.95) were produced by cycocel @ 1500 ppm. This might be due to inhibition of gibberellin synthesis at the apical region of the plant which resulted in increased cytokinin levels thus produced a greater number of lateral branches resulting in a greater number of leaves. Kumar *et al*. (2019) [6] observed a greater number of branches in *Nerium* plants treated with cycocel.

Table 5: Effect of plant density and growth regulators on number of leaves per plant at 45 and 60 days after transplanting in zinnia

45 Days After Transplanting					60 Days After Transplanting		
Growth	Plant density			Growth	Plant Density		
Regulators	P1	P2	Mean	Regulators	P1	P2	Mean
R0	51.00	49.50	50.25	R0	59.00	58.90	58.95b
R1	50.60	52.70	51.65	R1	59.70	64.90	62.30ab
R2	67.30	60.40	63.85	R2	76.40	69.50	72.95a
R3	50.50	64.50	57.50	R3	63.10	72.90	68.00ab
R4	50.30	61.20	55.75	R4	59.30	70.60	64.95ab
R5	59.10	63.00	61.05	R5	67.60	71.60	69.60ab
R6	68.30	55.20	61.75	R6	75.50	64.50	70.00ab
Mean	56.73	58.10		Mean	65.80	67.56	
	S.E (m)±		C.D. at 5%		S.E (m)±		C.D. at 5%
P	1.73		NS	P	1.37		NS
R	3.23		NS	R	2.56		7.76
P*R	4.56		NS	P*R	3.62		NS

Leaf width (cm)

Minimum leaf width (1.74 cm, 1.89 cm) was recorded at plant density of four plants per pot at 45 and 60 DAT. Cycocel @ 1500 ppm resulted in lower leaf width (1.58 cm, 1.69 cm) at 45 and 60 DAT. The interactions revealed that the combination of four plants per pot + cycocel at 1500 ppm produced leaves with small width (1.51 cm, 1.60 cm) at 45 and 60 DAT.

Among the two different plant densities, four plants per pot resulted in minimum leaf length (3.89 cm, 4.04 cm) at 45 and

60 DAT. Cycocel @ 1500 ppm reduced the leaf length to the maximum extent (3.61 cm, 3.79 cm) at 45 and 60 DAT. The interactions showed that the combination of four plants per pot + cycocel at 1500 ppm produced leaves with lesser length (3.52 cm) at 45 DAT.

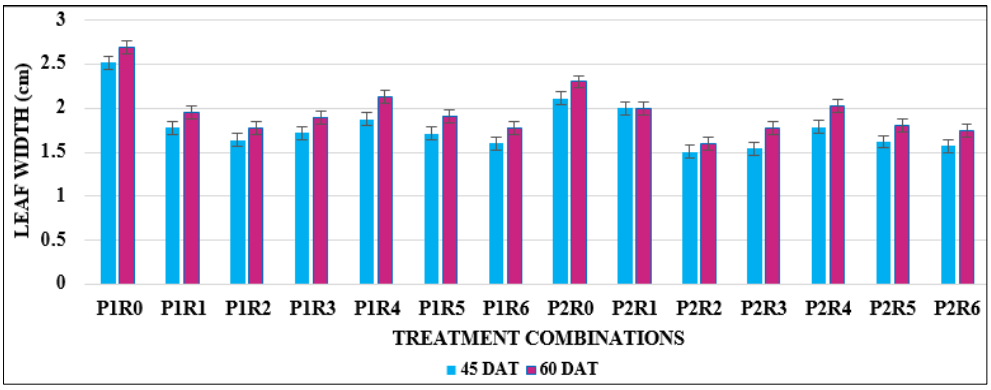

Fig 3: Effect of plant density and growth regulators on leaf width (cm) at 45 and 60 days after transplanting in zinnia

Leaf length (cm)

Among the two different plant densities, four plants per pot resulted in minimum leaf length (3.89 cm, 4.04 cm) at 45 and 60 DAT. Cycocel @ 1500 ppm reduced the leaf length to the maximum extent (3.61 cm, 3.79 cm) at 45 and 60 DAT. The interactions showed that the combination of four plants per pot + cycocel at 1500 ppm produced leaves with lesser length (3.52 cm) at 45 DAT.

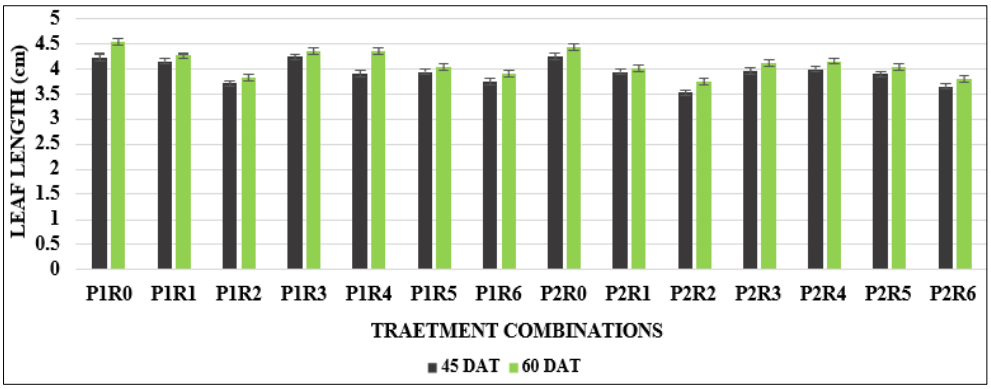

Fig 4: Effect of plant density and growth regulators on leaf length (cm) at 45 and 60 days after transplanting in zinnia

Leaf area (cm2)

Minimum leaf area (4.00 cm2, 4.22 cm2) was observed at plant density of four plants per pot at 45 and 60 DAT. Reduced leaf area in plants at higher plant density might be due to increased competition for nutrients, sunlight and space. Osman *et al*. (2014) [11] reported such lesser leaf area in plants planted at closer spacing in solidago.

Lowest leaf area (3.63 cm2, 3.96 cm2) was noticed with cycocel @ 1500 ppm at 45 and 60 DAT which might be due to cycocel, an anti-gibberellin dwarfing agent, may cause a lack of gibberellins in the plant and inhibit growth. Reduced leaf area upon treatment with cycocel at 2000 ppm was reported by El-Sharhorey *et al*. (2022) [3] in zinnia plants. Among the interactions, the combination four plants per plant + cycocel at 1500 ppm recorded lowest leaf area (3.34 cm2, 3.89 cm2) at 45 and 60 DAT.

Table 6: Effect of plant density and growth regulators on leaf area (cm2) at 45 and 60 days after transplanting in zinnia

45 Days After Transplanting					60 Days After Transplanting		
Growth Regulators	Plant density			Growth Regulators	Plant density		
	P1	P2	Mean		P1	P2	Mean
R0	4.75a	4.75a	4.75a	R0	4.90a	4.57b	4.74a
R1	4.14cd	3.99ef	4.07c	R1	4.30de	4.07fg	4.18c
R2	3.91fg	3.34i	3.63e	R2	4.03fg	3.89h	3.96d
R3	4.18cd	4.19c	4.19b	R3	4.10f	4.28e	4.19c
R4	4.37b	4.08de	4.22b	R4	4.45c	4.35cde	4.40b
R5	4.19c	3.86gh	4.03c	R5	4.26e	4.40cd	4.33b
R6	4.02e	3.79h	3.90d	R6	4.28e	3.97gh	4.13c
Mean	4.22a	4.00b		Mean	4.33a	4.22b	
	S.E (m)±		C.D. at 5%		S.E (m)±		C.D. at 5%
P		0.011	0.034	P	0.012		0.037
R		0.021	0.063	R	0.22		0.068
P*R		0.029	0.089	P*R	0.032		0.097

Chlorophyll content in leaves (SPAD chlorophyll meter)

Fig. 5 reveals that the highest chlorophyll content in leaves (15.29, 16.01) was observed at plant density of three plants per pot compared to four plants per pot at 45 and 60 DAT. Widely spaced plants might have received more nutrition in terms of moisture, light and space thus produced wider leaves with more chlorophyll content.

Maximum chlorophyll content (17.61, 18.39) was noticed with cycocel at 2000 ppm at 45 and 60 DAT. Increase in chlorophyll content is influenced by growth retardants which causes increase in cytokinin levels, (Gopi *et al*., 2005; Zhang *et al*., 2007) [4, 16]. Among the interaction effects, the combination three plants per pot + cycocel at 2000 ppm resulted in higher chlorophyll content in leaves (18.26, 18.85) at 45 and 60 DAT.

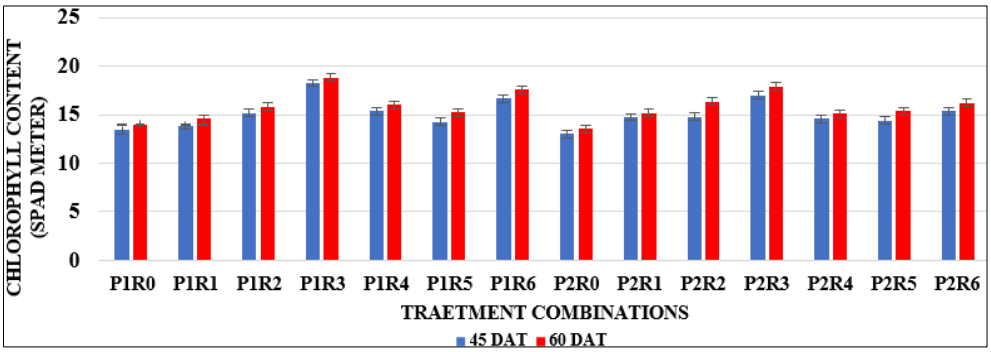

Fig 5: Effect of plant density and growth regulators on chlorophyll content in leaves at 45 and 60 days after transplanting in zinnia

Conclusion

Compactness is desirable character for pot plants being a combination of reduced plant height, less internodal length, greater number of branches per plant and higher plant spread which was achieved with the treatment combination of Four plants per pot + Cycocel spray @ 1500 ppm followed by Four plants per pot + Paclobutrazol spray @ 120 ppm

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