Sawan, *Cogent Biology* (2016), 2: 1234959
http://dx.doi.org/10.1080/23312025.2016.1234959

cogent biology

PLANT SCIENCES | REVIEW ARTICLE

Plant density; plant growth retardants: Its direct and residual effects on cotton yield and fiber properties

Zakaria M. Sawan[1]*

Received: 14 June 2016
Accepted: 29 August 2016
First Published: 16 September 2016

*Corresponding author: Zakaria M. Sawan, Cotton Research Institute, Agricultural Research Center, Ministry of Agriculture and Land Reclamation, 9 Gamaa street, 12619, Giza, Egypt
E-mail: zmsawan@hotmail.com

Reviewing editor:
Raffaele Dello Ioio, Universita degli Studi di Roma La Sapienza, UK

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Abstract: Foliar sprays of (PGR's) Cycocel and Alar were applied at concentrations of 250, 500, and 750 ppm after 105 days after plantation (square and boll setting stage) to Egyptian cotton cultivar planted at three plant densities (166.000, 222.000, and 333.000 plant ha^{-1}). Number of opened bolls $plant^{-1}$, seed-cotton yield $plant^{-1}$, and earliness increased as plant density decreased in both years, as did seed-cotton and lint yield ha^{-1} in the second season. In the first year, the intermediate plant density gave highest yields. Plant density had no significant effect on lint percentage or fiber properties. Both Cycocel and Alar increased the number of opened bolls $plant^{-1}$, boll weight, seed and lint indices, seed-cotton yield $plant^{-1}$ and both seed-cotton and lint yield ha^{-1}, but effects were not always significant and response varied for different traits. Neither Cycocel nor Alar affected lint percentage, yield earliness or fiber properties at any plant density.

Subjects: Bioscience; Environment & Agriculture; Environmental Studies and Management

Keywords: alar; boll weight; cycocel; lint yield; micronaire readings; seed and lint indices; yield earliness

ABOUT THE AUTHOR

Effect of different rates and application systems of nitrogen fertilization and indole-3-butyric acid on Egyptian cotton growth and yield. Effect of organic fertilizer and micro-nutrient treatments on cotton agronomy and fiber characteristics of Giza 69. Effect of concentration and time of application of the defoliant Harvade on the lint, seed, protein and oil yields, and oil properties of cottonseed. Effect of 1-naphthalene acetic acid and Kinetin on yield and fiber properties, seed, protein, oil, and fatty acids of Egyptian cotton. Plant growth retardants, plant nutrients, and cotton production. Plant density; plant growth retardants: its direct and residual effects on cotton yield and fiber properties. Plant nutrition and plant growth retardants: their effects on cottonseed, protein, oil yields, and oil properties. Direct and Residual affects of Plant Nutrition's and Plant Growth Retardants, on Cottonseed. Studying the nature relationships between climatic factors and cotton production by different applied statistical methods.

PUBLIC INTEREST STATEMENT

This work confirmed the applicability of some other reports on PGR under Egyptian conditions and indicated that yield components and yield could be improved without affecting fiber properties by applying Cycocel at 500 or 750 ppm or Alar at 250 ppm to a plant density of 166,000 plants ha^{-1}. Yields at higher plant densities could be enhanced by either treatment, but were less than those observed at a plant density of 166,000 plants ha^{-1}. There was a definite correlation between plant density and growth and growth retardants, which suggested that cotton plants produced more when each plant had optimum growing space, that maximum yield depended on an optimum balance of space $plant^{-1}$ *vs.* number of plants ha^{-1}, and that the yield effect of wider spacing can be enhanced by treatment with growth retardants.

http://dx.doi.org/10.1080/23312025.2016.1234959

1. Introduction

Chemical may be used to reduce plant size in cotton (*Gossypium barbadense*, L.), which can increase cotton yield by allowing an increased number of plants per unit area. Mondino, Peterlin, and Garay (1999) indicated that to optimize yield, it is necessary to establish a balance between biomass production and harvest index. Short cotton plants necessitate the use of higher plant densities per area unit. Plant size may be reduced genetically or chemically. Plant Growth Regulators, which affects physiological processes using hormones in the plant, can be used to modify plant size. Also, an important objective for using PGR's in cotton is to balance vegetative and reproductive growth as well as to improve lint yield and fiber quality (Zhao & Oosterhuis, 2000). Application of Cycocel and Alar, when plants had at least four fruiting branches, reduced plant height and length of lateral branches (Wang, Chem, & Yu, 1985) They have also been shown to enhance yield-related physiological functions by increasing gross plant photosynthesis or by increasing the retention of bolls by enhanced partitioning of photosynthates to fruiting forms (Guinn, 1984). Treated plants are compact, conical in form (Wang et al., 1985; Zhao & Oosterhuis, 2000) and can be spaced closer to achieve higher plant populations. Also, short, compact, open-canopy plants resulting from such treatments conceivably could improve energy distribution through better light penetration and improve insect control through better insecticide coverage thereby increasing yield.

Koraddi, Modak, Guggari, and Kamath (1993) found that application of 60 ml Cycocel ha^{-1} at 90, 105, and 120 days after sowing increased mean yield of cotton plants. Pipolo, Athayde, Pipolo, and Parducci (1993) found that single and double applications of 25 g ha^{-1} of Cycocel resulted in yield increases of 11.5% and 11.6%, respectively. These treatments also enhanced earliness and seed weight and micronaire. More, Waykar, and Choulwar (1993) found plant height, number of branches, number of leaves plant^{-1}, and number of internodes and internodal length to be significantly decreased when plants were treated with 100, 150, and 200 ppm of Cycocel. Singh and Chouhan (1993) reported cotton yield of a control treatment to be 1.06 t ha^{-1} and to have increased to 1.14 t ha^{-1} when 80 ppm of Cycocel was sprayed once at flower initiation and again 20 days later. Cycocel decreased the percentage of boll shedding and increased net economic return Sawan (2013). Mahmoud, Bondok, and Abdel-halim (1994) found that Cycocel and Alar decreased plant height with application rates of 500 and 5,000 ppm, respectively, when applied at-early growth stages, while late application increased plant height and leaf abscission, but decreased the number of nodes plant^{-1} and number of leaves plant^{-1}.

Bednarz, Bridges, and Brown (2000) indicated that lower cotton population densities resulted in plants with more main-stem nodes and monopodial branches with increased fruit retention, resulting in greater fruit production per plant. They added that mean net assimilation rate from first flower to peak bloom was inversely related to population density. Mohamed, El-Din, and Ragab (1991) and Sawan (2013) found, when cotton was grown at 2, 3, or 4 plants hill^{-1} (166.000, 222.000, and 333.000 plants ha^{-1}, respectively), that increasing plant density decreased number of bolls plant^{-1}, and seed-cotton yield plant^{-1}, but increased yield ha^{-1}. Fiber quality was not significantly affected by plant density. Gannaway, Hake, and Harrington (1995) found that when cotton was grown at 6, 12, 18, and 24 plants m^{-1} of a row, lint gin turnout and boll size decreased, as population increased. Plant population had essentially no effect on fiber length, strength and elongation, but micronaire reading decreased as the population increased. Campanella and Hood (2000) indicated that plots sown at a rate of nine seeds m^{-1} (90.000 ha^{-1}) produced 2–10% more yield, saved 31–66% in sowing costs, and increased profit margins by 7–13%, when compared to sowing rates of 12 and 15 seeds m^{-1}.

Considerable research with Cycocel effects on cotton has been widely reported, but little work has been carried out with Alar. Inadequate information is available on cotton's response to these chemicals under Egyptian growing conditions. Little or no literature was found on interactions between plant density and growth retardant treatments. To fill this gap and confirm the applicability of other work, this study was designed to evaluate the effects of Cycocel and Alar (PGR's) on cotton yield and fiber properties as inter-related to plant density of an Egyptian variety of *G. barbadense* under Egyptian field conditions.

2. Materials and methods

Two field experiments in two consecutive years, I and II) were conducted at Giza Agricultural Research Station (30°N, 31°: 28’E and 19 m altitude), Agricultural Research Center, Egypt, with the Egyptian cotton cv. Giza 75 (*Gossypium barbadense*, L.). The soil texture in both seasons was a clay loam, with an alluvial substratum, (pH = 8.10, 43.0% clay, 28.40% silt, 19.33% fine sand, 4.31% coarse sand, 3.00% calcium carbonate, and 1.83% organic matter). Treatments were arranged in a randomized complete-block design with four replications. Each experiment included 21 treatments, i.e. 3 plant densities × 6 growth retardant concentrations + 1 (0 concentrations as control). The plot size was 3 rows, 4 m long × 0.6 m wide. Plots were planted on April 8 in season I and on April 15 in season II. Seeds were planted in hills 20, 15, and 10 cm apart within the row and thinned to 2 plants hill^{-1} six weeks after planting to achieve plant densities of 166.000, 222.000, and 333.000 plants ha^{-1}, respectively. Plots were foliar-sprayed with 250, 500, and 750 ppm of either 2-chloroethyl trimethyl ammonium chloride (chlormequat chloride, Cycocel, or CCC) or succinic acid 2,2-dimethyl hydrazide (daminozide, SADH, B-Nine, Kylar or Alar). Water alone was sprayed as a control and 166.000 plants ha^{-1} was the control for plant density. This concept is based on the fact that the plant density of 166.000 plants ha^{-1} is the recommended density in Egypt. Treatments were foliar-sprayed 105 days after planting, which was during the square-and-boll setting stage. The Cycocel and Alar were both applied to the leaves with uniform coverage using a knapsack sprayer. The solution volume was 960 L ha^{-1} for all treatments. The application was carried out between 09.00 and 11.00 h. Total irrigation amount during both growing seasons (surface irrigation) was about 6,000-m^3 ha^{-1}. No rainfall occurred during the two growing seasons. The first irrigation was applied 3 weeks after sowing, and the second one was 3 weeks after that. Thereafter, the plots were irrigated every 2 weeks until the end of the season, thus providing a total of nine irrigations. Phosphorus fertilizer was applied at the rate of 24 kg P ha^{-1} as calcium super-phosphate during land preparation (the recommended level for semi-fertile soil). Potassium fertilizer was applied at the rate of 47 kg K ha^{-1} as potassium sulfate before the first irrigation. Nitrogen fertilizer was applied at the rate of 144 kg N ha^{-1} as ammonium nitrate in two equal doses; the first one was applied after thinning just before the second irrigation and the other one was applied before the third irrigation. Fertilizer application (N, P, and K), along with pest and weed management was carried out according to local practices performed at the Experiment Research Station.

Ten plants were randomly chosen from the central row of each plot to determine plant height and the number of opened bolls per plant and boll weight (g seed cotton boll^{-1}), seed-cotton yield (g plant^{-1}), and plant height (cm). Earliness as percentage of the yield harvested in the first picking was calculated as follows: seed-cotton yield in first picking divided by the total seed cotton yield and multiplied by 100. First hand-pickings took place on September 25th and 30th and the final pickings on October 10th and 15th in seasons I and II, respectively. Total seed cotton yield of each plot (including the 10 plant sub samples) was ginned on a laboratory roller gin stand to determine lint yield (kg lint he^{-1}), lint percent, seed index (g per100 seeds), and lint index (g of lint per100 seeds). Fiber tests were made using single instrumentation at a relative humidity of 65 ± 2% and a temperature of 20 ± 1°C. A digital fibrograph was used to determine fiber length in terms of 2.5 and 50% span length (millimeters) and uniformity ratio. Micronaire readings, including a measurement of fiber fineness and maturity, were done on a Micronaire instrument, on harvested fiber. Flat bundle strength (in g tex^{-1}) was determined using a Pressly tester (according to the method of the American Society for Testing Materials (ASTM), 1979) (Sawan, Mahmoud, & Fahmy, 2011).

Results were statistically analyzed as a factorial experiment in a randomized complete-block design with four replications for the studied characters each year, following the procedure outlined by Snedecor and Cochran (1980). The Least Significant Difference (LSD) test method, at 5% level of significance, was used to verify the significance of differences among treatment means and the interactions.

Table 1. Average values of plant height and yield components as affected by plant densities and plant growth retardants

Character	Plant height (cm)		Number of open bolls m^{-2}		Number of open bolls $plant^{-1}$		Boll weight (g)	
Season	I	II	I	II	I	II	I	II
Treatments:								
Plant density (plant ha^{-1})								
166	108.4	105.6	121.7	131.2	10.52	10.99	2.232	2.396
222	111.8	107.2	125.2	125.9	8.21	8.43	2.205	2.356
333	114	109.6	119.3	123.8	7.4	7.27	2.162	2.291
LSD (p = 0.05)	0.75	0.87	5.01	4.96	0.36	0.37	0.037	0.039
Cycocel & Alar concentration (ppm)								
Control, 0	117.5	112	113.1	116.4	7.96	8.18	2.164	2.297
Cycocel, 250	113.4	108.5	121.4	128.3	8.57	9	2.191	2.299
Cycocel, 500	110.1	106.9	121	130	8.55	9.24	2.198	2.308
Cycocel, 750	106.2	103.6	128.7	132.3	8.97	9.28	2.208	2.355
Alar, 250	114.1	109.3	129.1	127	9.02	8.96	2.19	2.42
Alar, 500	111.3	107.2	120.9	127.4	8.52	8.86	2.218	2.378
Alar, 750	107.1	104.8	120.3	127.3	8.51	8.78	2.226	2.376
LSD (p = 0.05)	1.15	1.33	7.66	7.57	0.55	0.57	NS	0.06

3. Results and discussion

3.1. Plant height

Both Cycocel and Alar significantly decreased plant height in both years (Table 1), with the most pronounced effect at the highest concentration (750 ppm). Cycocel and Alar, therefore, could be used to control the vegetative development of cotton plants. This corroborates the research of Wang et al. (1985), who report that these two PGRs reduce plant height and length of lateral branches. Plant height significantly increased as plant density increased in both years (Table 1). Similar results were obtained by Alfageih, Baswaid, and Atroosh (2001).

3.2. Yield components

3.2.1. Number of open bolls m^{-2} and $plant^{-1}$

Number of opened bolls m^{-2} and $plant^{-1}$ were significantly greater on plants treated with Cycocel and Alar in both years, compared with the untreated control (Table 1), but there was no difference between application rates. Increased number of opened bolls m^{-2} and $plant^{-1}$ may be due to increased photosynthetic activity of leaves following application of Cycocel and Alar (Gardner, 1988; Wu, Chen, Yuan, & Hu, 1985). Increased photosynthesis has been shown to greatly increase flowering and boll retention (Kler, Raj, & Dhillon, 1989; Wang et al., 1985). Also, favorable metabolite balance may suppress vegetative growth, which increases penetration of photosynthetically active radiation into the canopy. These results agree with those of Singh and Chouhan (1993), where Cycocel decreased percentage of boll shedding and increased net economic return after its application at 80 ppm at flower initiation and 20 days later. Our findings also agree with those of Sawan, Mahmoud, and Momtaz (1997), when Cycocel and Alar were sprayed at 300 ppm 75 days after plantation, and Sawan (2013).

Plant density was significantly and inversely related to the number of opened bolls m^{-2} and $plant^{-1}$ in both years, except in the first year when the highest number of opened bolls m^{-2} was obtained at the intermediate plant density, followed by the lowest density. As to reduce plant density increasing the number of opened bolls m^{-2} and $plant^{-1}$, Guinn (1984), studying factors influencing abscission of floral buds and bolls, found that conditions that decrease photosynthesis might delay fruiting and reduce retention of squares and bolls. Bednarz et al. (2000) found lower cotton population densities lead to the production of plants with more main-stem nodes and monopodial branches with increased fruit retention, resulting in greater fruit production per plant. More opened bolls $plant^{-1}$ has been reported at low population levels by Abd-El-Malik and El-Shahawy (1999), and Palomo Gil, Gaytan Mascorro, and Godoy Avila (2000).

3.2.2. Boll weight

Alar increased boll weight above the control in second year at all rates; Cycocel did not show significant effects (Table 1). Similar results were obtained by Sawan et al. (1997) and Sawan (2013) with Cycocel and Alar, and by Karthikeyan and Jayakumar (2001) and Lamas (2001) with Cycocel.

Decreasing plant density was accompanied by an increase in boll weight in both years. The effects of plant density may be due to heavy shading by upper leaves in high plant populations, which could limit photosynthate availability to, and growth of, bolls on the lower portion of the plant. In this connection, Bednarz et al. (2000) stated that mean net assimilation rate from first flower to peak bloom and boll size were inversely related to population density. These results agree with those of Gannaway et al. (1995) and Abd-El-Malik and El-Shahawy (1999).

3.2.3. Lint percentage

Lint percentage was not affected by Cycocel or Alar (Table 2). This result agrees with the finding of Sawan et al. (1997) and Sawan (2013) for Cycocel and Alar, and Lamas (2001) for Cycocel, although a reduction in lint percentage due to Cycocel application was observed by Carvalho et al. (1994). Plant density also had no significant effect in either year, supporting the results of Jones, Snipes, and Tupper (2000).

3.2.4. Seed index

Seed index significantly increased in both years due to both Cycocel and Alar applications compared with the control (Table 2). In the first year, there was no difference between rates of either PGR;

Table 2. Average values of yield components as affected by plant densities and plant growth retardants

Character	Lint (%)		Seed index (g)		Lint index (g)	
Season	**I**	**II**	**I**	**II**	**I**	**II**
Treatments:						
Plant density (plant ha^{-1})						
166.000	35.14	33.61	10.34	11.48	5.61	5.81
222.000	35.37	33.64	10.22	11.37	5.59	5.76
333.000	35.57	33.75	10.10	11.23	5.58	5.72
LSD (p = 0.05)	NS	NS	0.07	0.11	NS	NS
Cycocel & Alar concentration (ppm)						
Control, 0	35.13	33.66	10.09	10.95	5.46	5.56
Cycocel, 250	35.47	34.00	10.26	11.02	5.64	5.67
Cycocel, 500	35.12	33.60	10.23	11.02	5.54	5.58
Cycocel, 750	35.08	33.77	10.27	11.22	5.55	5.73
Alar, 250	35.37	33.40	10.20	11.64	5.59	5.84
Alar, 500	35.64	33.48	10.23	11.82	5.66	5.95
Alar, 750	35.73	33.78	10.26	11.82	5.70	6.03
LSD (p = 0.05)	NS	NS	0.10	0.17	0.12	0.17

however, in the second year, higher rates of both PGR's increased seed index. This indicates that treated cotton bolls had larger carbohydrates and other metabolites than untreated bolls (Gardner, 1988; Wu et al., 1985). This agrees with previous works of Pipolo et al. (1993) for Cycocel, Sawan et al. (1997) and Sawan (2013) for Cycocel and Alar, and Lamas (2001) for Cycocel.

Lower plant density significantly increased seed index in both years probably due to improved light penetration at the lower plant density (166.000 plants ha^{-1}). Similar results were obtained by Singh and Warsi (1985).

3.2.5. Lint index

Compared with the untreated control, lint index was significantly increased on plants treated with Alar in both years (Table 2), with the most pronounced effect being at the highest concentration of 750 ppm. Also, Cycocel significantly increased lint index when applied at 250 ppm in the first year and at 750 ppm in the second year. The significant increase in lint index due to both Cycocel and Alar application was similar to the results of Kler et al. (1989) for Cycocel and Sawan et al. (1997) and Sawan (2013) for both Cycocel and Alar. Lint index was not significantly affected by plant density in either year. Lack of effects due to plant density for lint index agreed with the findings of Singh and Warsi (1985).

3.3. Yield

Both Cycocel and Alar significantly increased seed-cotton yield plant^{-1} and seed-cotton and lint yields ha^{-1} in both years (Table 3), with no difference among application rates of either chemical. Increased seed-cotton yield plant^{-1}and seed-cotton and lint yields ha^{-1} due to Cycocel and Alar may be attributed to the stimulatory effect of these substances on certain physiological processes, leading to improvement of all the yield components. Cycocel and Alar have also been associated with increased photosynthesis (Gardner, 1988; Wu et al., 1985) through increased total chlorophyll concentration of plant leaves. In these studies, increased photosynthesis greatly increased flowering, boll retention, and yield. These results agree with those obtained by Sawan et al. (1997) and Sawan (2013) with Cycocel and Alar, and by Karthikeyan and Jayakumar (2001) and Lamas (2001) with Cycocel.

Table 3. Average values of yield and yield earliness as affected by plant densities and plant growth retardants

Character	Seed cotton yield (g plant^{-1})		Seed cotton yield (kg ha^{-1})		Lint yield (kg ha^{-1})		Yield earliness (%)	
Season	**I**	**II**	**I**	**II**	**I**	**II**	**I**	**II**
Treatments:								
Plant density (plant ha^{-1})								
166.000	23.48	26.29	2,717.6	3136.8	955.1	1053.8	83.13	78.89
222.000	18.10	19.86	2,759.8	2963.8	976.7	997.8	81.98	74.01
333.000	15.20	16.66	2,577.7	2836.9	917.7	965.4	75.18	68.94
LSD ($p = 0.05$)	0.88	0.92	116.3	123.0	42.5	43.8	6.02	4.73
Cycocel & Alar concentration (ppm)								
Control, 0	17.25	18.80	2,447.5	2,672.5	860.3	901.2	81.30	73.85
Cycocel, 250	18.78	20.72	2,660.4	2,948.1	943.7	1,002.8	79.02	72.99
Cycocel, 500	18.83	21.32	2,661.2	2,999.5	934.7	1,023.1	79.44	72.58
Cycocel, 750	19.86	21.94	2,843.6	3,117.9	997.7	1,053.4	81.12	72.53
Alar, 250	19.78	21.76	2,820.7	3,075.6	998.6	1,027.3	80.02	75.08
Alar, 500	18.96	21.13	2,684.2	3,023.9	956.7	1,012.4	79.14	74.86
Alar, 750	19.04	20.89	2,677.8	3,016.5	956.9	1,019.3	80.62	75.68
LSD ($p = 0.05$)	1.35	1.41	177.7	187.9	64.9	66.9	NS	NS

Seed-cotton yield plant^{-1}, and seed-cotton and lint yields ha^{-1} significantly decreased as plant density increased in both years, with two exceptions in the first year, where maximum seed-cotton and lint yields ha^{-1} were obtained from the intermediate plant density, followed by the lowest density. Increase in plants per unit area with dense planting did not nullify the increase in seed-cotton yield plant^{-1} under wide hill spacing. Decreased seed-cotton yield plant^{-1}, and seed-cotton and lint yields ha^{-1}, as plant density increased, may be due to the fact that the increase in plants per unit area with dense planting could not compensate for the decrease in yield components plant^{-1} under narrow hill spacing. A consequence of high plant densities was that many plants were barren of bolls, which decreased fruiting efficiency; such decrease due to a lower percentage of assimilates being converted into fruits. Chhabra and Bishnoi (1993), when planting two cotton cultivars at spacing of 60 × 30, 60 × 22.5 and 60 × 15 cm, found that with narrow spacing, dry matter accumulation in stems, leaves and reproductive parts at all the crop stages was decreased. Increased seed-cotton yield under low plant density was reported by Abd-El-Malik and El-Shahawy (1999), Campanella and Hood (2000), and Palomo Gil et al. (2000).

3.4. Yield earliness

No significant difference was noted in yield earliness (as percentage of the yield harvested in the first picking) due to Cycocel or Alar in either year (Table 3). Similar lack of influence on yield earliness for Cycocel or Alar was obtained by Sawan et al. (1997) and Sawan (2013), but Abdel Al and Eid (1985) found that in one out of two seasons, Alar increased earliness; however, Pipolo et al. (1993) indicated that application of Cycocel 70 days after emergence with 25–100 g ha^{-1} and given also two extra sprays 15 days apart (85 and 100 days after emergence) increased earliness of yield.

Yield earliness was inversely related to plant density probably due to more light penetration to, and air movement around, plants, thus causing earlier boll opening. Abd-El-Malik and El-Shahawy (1999) and Alfageih et al. (2001) reported a similar inverse relationship of yield earliness to plant density.

3.5. Fiber properties

Neither PGRs (Cycocel and Alar) nor plant density had a significant effect on any of the fiber properties investigated (Table 4). There may be specific hormones for cotton fiber, so failure to improve fiber properties consistently may simply be due to failure to test the right compound; potential chemical improvement of fiber length should not be ignored. These results agree with those of Sawan et al. (1997) and Sawan (2013) who reported that Cycocel and Alar did not affect cotton fiber quality. Karthikeyan and Jayakumar (2001) suggested that fiber quality parameters were unaffected by Cycocel application. Mohamed et al. (1991) found that fiber quality was not affected by plant density. Gannaway et al. (1995) found that plant population had essentially no effect upon fiber length and strength, but micronaire reading decreased as population increased. Pettigrew and Johnson (2005) stated that few fiber quality differences were detected among PGR application rates and seedling rates.

3.6. Interactions

Interactions effects between plant density and Cycocel or Alar relative to number of opened bolls m^{-2} and plant^{-1}, seed-cotton yield plant^{-1}, seed-cotton, and lint yield ha^{-1} in both years were noted (Tables 5 and 6), but not for the other measured properties (Tables 7–10). The highest number of opened bolls m^{-2} and plant^{-1}, seed-cotton yield plant^{-1}, seed-cotton, and lint yield ha^{-1} was obtained at the lowest plant densities when either Cycocel or Alar was applied. The plant density × growth retardants interaction implies that effects on cotton yield depend essentially on the space available to each plant, and that optimum plant spacing exists and cotton yield can be affected by growth retardant treatment. Favorable effects of low plant density on number of opened bolls plant^{-1} and seed-cotton yield plant^{-1}, and low or intermediate plant density on number of opened bolls m^{-2}, seed-cotton and lint yields ha^{-1} were greater when treated with Cycocel or Alar, especially Cycocel at 500 or 750 ppm or Alar at 250 ppm. The interaction of plant density × growth retardants was significant for number of opened bolls m^{-2} and plant^{-1} seed-cotton yield plant^{-1} and ha^{-1} and lint

Table 4. Average values of fiber properties as affected by plant densities and plant growth retardants

Character	2.5% span length (mm)		50% span length (mm)		Uniformity ratio (%)		Micronaire reading		Flat bundle strength (g tex^{-1})	
Season	**I**	**II**	**I**	**II**	**I**	**II**	**I**	**II**	**I**	**II**
Treatments:										
Plant density (plant ha^{-1})										
166.000	30.99	30.89	14.78	14.35	47.70	46.48	4.38	4.46	10.55	10.72
222.000	31.09	31.01	15.01	14.63	48.27	47.19	4.34	4.45	10.64	10.75
333.000	31.14	31.04	14.86	14.48	47.72	46.60	4.35	4.38	10.47	10.68
LSD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cycocel & Alar concentration (ppm)										
Control, 0	30.96	30.89	14.78	14.38	47.70	46.53	4.32	4.38	10.37	10.62
Cycocel, 250	31.22	30.89	14.86	14.33	47.58	46.40	4.42	4.42	10.42	10.80
Cycocel, 500	31.06	30.99	14.96	14.53	48.16	46.85	4.33	4.38	10.57	10.72
Cycocel, 750	31.16	30.91	14.91	14.43	47.81	46.64	4.38	4.39	10.52	10.84
Alar, 250	31.19	31.01	14.99	14.58	48.05	47.03	4.31	4.46	10.66	10.69
Alar, 500	30.96	31.16	14.91	14.55	48.11	46.74	4.40	4.46	10.65	10.68
Alar, 750	30.96	31.06	14.81	14.66	47.84	47.14	4.36	4.54	10.68	10.63
LSD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 5. Effect of interaction between plant densities and plant growth retardants on number of open bolls m^{-2} and plant^{-1}

Character	Number of open bolls m^{-2}			Number of open bolls plant^{-1}		
Cycocel and Alar concentration (ppm)	**Plant density (plants ha^{-1})**					
	166.000	**222.000**	**333.000**	**166.000**	**222.000**	**333.000**
Season I						
Control, 0	115.75	109.33	114.08	9.98	7.16	6.74
Cycocel, 250	127.05	113.63	123.58	10.99	7.44	7.26
Cycocel, 500	126.78	114.93	121.33	10.96	7.75	7.16
Cycocel, 750	117.10	144.98	123.93	10.12	9.50	7.30
Alar, 250	118.38	147.10	121.68	10.22	9.66	7.18
Alar, 500	121.80	126.33	114.70	10.52	8.28	6.76
Alar, 750	125.20	120.13	115.58	10.83	7.88	6.83
LSD (p = 0.05)		13.26			0.97	
Season II						
Control, 0	120.08	119.55	109.60	10.08	8.01	6.44
Cycocel, 250	134.70	125.28	124.80	11.28	8.40	7.32
Cycocel, 500	147.63	132.75	109.73	12.36	8.91	6.44
Cycocel, 750	141.40	122.95	132.58	11.85	8.22	7.78
Alar, 250	138.45	122.50	119.98	11.61	8.22	7.04
Alar, 500	120.78	131.20	130.10	10.14	8.79	7.64
Alar, 750	115.15	126.80	140.05	9.63	8.49	8.24
LSD (p = 0.05)		13.11			0.99	

http://dx.doi.org/10.1080/23312025.2016.1234959

Table 6. Effect of interaction between plant densities and plant growth retardants on cotton yield

Character	Seed cotton yield (g plant^{-1})			Seed cotton yield (kg ha^{-1})			Lint yield (kg ha^{-1})		
Cycocel & Alar concentration (ppm)	Plant density (plants ha^{-1})								
	166.000	222.000	333.000	166.000	222.000	333.000	166.000	222.000	333.000
Season I									
Control, 0	21.78	15.52	14.45	2525.9	2370.6	2446.0	881.6	840.2	859.1
Cycocel, 250	24.11	16.33	15.89	2785.7	2492.9	2702.4	976.4	887.2	967.4
Cycocel, 500	24.23	16.68	15.57	2803.0	2541.3	2639.2	977.0	891.1	936.1
Cycocel, 750	22.54	21.34	15.70	2608.8	3258.8	2663.2	903.5	1144.4	945.2
Alar, 250	22.90	21.17	15.27	2652.3	3222.7	2587.0	941.2	1144.8	909.7
Alar, 500	23.70	18.44	14.72	2745.2	2810.6	2496.9	967.2	1007.9	895.2
Alar, 750	25.11	17.19	14.82	2902.6	2621.6	2509.3	1038.5	921.1	911.1
LSD (p = 0.05)		2.35			307.8			112.4	
Season II									
Control, 0	23.40	18.40	14.60	2788.4	2745.2	2484.1	948.4	925.5	829.8
Cycocel, 250	26.22	19.37	16.58	3130.5	2889.3	2824.4	1056.9	982.9	968.7
Cycocel, 500	28.63	20.58	14.76	3418.9	3066.5	2513.2	1135.2	1037.6	896.7
Cycocel, 750	28.44	19.52	17.85	3393.1	2917.3	3043.3	1135.1	988.4	1036.6
Alar, 250	28.76	19.83	16.68	3429.9	2956.0	2841.0	1145.8	987.6	948.6
Alar, 500	25.07	20.97	17.35	2987.4	3130.7	2953.7	1005.9	1038.3	992.6
Alar, 750	23.50	20.36	18.80	2809.7	3041.4	3198.6	949.0	1024.1	1084.8
LSD (p = 0.05)		2.44			325.4			115.9	

Table 7. Mean squares from analysis of variance of plant height and yield components

Source	d.f.	Plant height (cm)		Number of open bolls m^{-2}		Number of open bolls $plant^{-1}$		Boll weight (g)	
		I	II	I	II	I	II	I	II
Replicates	3	0.87	2.70	515.8**	1210.9**	2.93**	7.06**	0.0048	0.0134
PD	2	223.59**	110.67**	249.1	401.8*	87.79**	101.44**	0.0345**	0.0777**
GR	6	192.79**	93.23**	359.1**	302.7**	1.49**	1.62**	0.0051	0.0272**
PD × GR	12	1.73	1.31	365.5**	469.2**	1.74**	4.48**	0.0038	0.0061
Error	60	1.99	2.66	88.0	85.9	0.47	0.49	0.0050	0.0056

*Significant at 0.05 probability level.

**Significant at 0.01 probability level.

Table 8. Mean squares from analysis of variance of yield components

Source	d.f.	Lint percentage (%)		Seed index (g)		Lint index (g)	
		I	II	I	II	I	II
Replicates	3	6.457**	0.798	0.2114**	1.7103**	0.1347**	0.1931*
PD	2	1.309	0.152	0.3904**	0.4275**	0.0050	0.0507
GR	6	0.844	0.489	0.0482*	1.8459**	0.0840**	0.3911**
PD × GR	12	0.419	0.275	0.0080	0.0470	0.0294	0.0274
Error	60	0.474	0.515	0.0174	0.0457	0.0249	0.0469

**Significant* at 0.05 probability level.

**Significant at 0.01 probability level.

Table 9. Mean squares from analysis of variance of on yield and yield earliness in cotton

Source	d.f.	Seed cotton yield (g $plant^{-1}$)		Seed cotton yield (kg ha^{-1})		Lint yield (kg ha^{-1})		Yield earliness (%)	
		I	II	I	II	I	II	I	II
Replicates	3	10.76*	29.11**	166076*	497098**	41404**	70743**	548.2**	1875.0**
PD	2	494.27**	673.27**	254390**	634835**	24955*	55925**	517.2*	692.1**
GR	6	8.92**	12.97**	202407**	254719**	26076**	28391**	10.6	19.9
PD × GRP	12	9.64**	11.10**	2022300**	205445**	26396**	18851**	43.7	26.3
Error	60	2.77	2.99	47385	52962	6318	6717	126.9	78.6

**Significant* at 0.05 probability level.

**Significant at 0.01 probability level.

Table 10. Mean squares from analysis of variance of fiber properties of cotton

Source	d.f.	2.5% span length (mm)		50% span length (mm)		Uniformity ratio (%)		Micronaire reading		Flat bundle strength (g tex^{-1})	
		I	II	I	II	I	II	I	II	I	II
Repli-cates	3	0.0024**	0.0020**	0.0034**	0.0015**	8.15**	4.54*	0.025	0.018	1.322**	0.147
PD	2	0.0002	0.0003	0.0006	0.0009	2.92	4.02	0.016	0.061	0.189	0.033
GR	6	0.0002	0.0002	0.0001	0.0003	0.57	0.84	0.024	0.042	0.180	0.079
PD × GR	12	0.0003	0.0004	0.0002	0.0004	0.87	2.59	0.001	0.019	0.218	0.084
Error	60	0.0002	0.0002	0.0004	0.0003	1.56	1.32	0.012	0.030	0.182	0.154

*Significant at 0.05 probability level.

**Significant at 0.01 probability level.

yield ha^{-1}. The lowest plant density of 166.000 plants ha^{-1} produced higher seed-cotton yield plant^{-1} when either Cycocel or Alar was applied. The highest seed-cotton yield plant^{-1} was actually obtained in the first year when 750 ppm Alar was applied to plant density of 166.000 plants ha^{-1} (Table 6). In the second year, the highest seed-cotton yield plant^{-1} was attained from 250 ppm Alar applied to plant density of 166.000 plants ha^{-1}. Highest seed-cotton yield ha^{-1} in the first year was from Cycocel at 750 ppm applied to plant density of 222.000 plants ha^{-1}. Highest lint yield ha^{-1} in the first year was from Alar at 250 ppm or Cycocel at 750 ppm applied to plant density of 222.000 plants ha^{-1}. In the second year, highest seed-cotton yield ha^{-1} and lint yield ha^{-1} were from applying Alar at 250 ppm and Cycocel at 500 ppm, respectively, to the lowest plant density of 166.000 plants ha^{-1} (Table 6).

Interactions effects between plant density and Cycocel or Alar (highest yields at lowest plant density combined with Cycocel or Alar) on seed-cotton yield plant^{-1} and seed-cotton and lint yields ha^{-1}, could logically be expected, as the growth retardants should have the effect of adding extra space between plants while maintaining the optimum population for best yield.

4. Conclusions

This work confirmed the applicability of some other reports on PGR under Egyptian conditions and indicated that yield components and yield could be improved without affecting fiber properties by applying Cycocel at 500 or 750 ppm or Alar at 250 ppm to a plant density of 166.000 plants ha^{-1}. Yields at higher plant densities could be enhanced by either treatment, but were less than those observed at a plant density of 166.000 plants ha^{-1}. There was a definite correlation between plant density and growth and growth retardants, which suggested that cotton plants produced more when each plant had optimum growing space, that maximum yield depended on an optimum balance of space plant^{-1} *vs*. number of plants ha^{-1}, and that the yield effect of wider spacing can be enhanced by treatment with growth retardants.

Funding
The authors received no direct funding for this research.

Competing Interests
The authors declare no competing interest.

Author details
Zakaria M. Sawan[1]
E-mail: zmsawan@hotmail.com
[1] Cotton Research Institute, Agricultural Research Center, Ministry of Agriculture and Land Reclamation, 9 Gamaa Street, 12619, Giza, Egypt.

Citation information
Cite this article as: Plant density; plant growth retardants: Its direct and residual effects on cotton yield and fiber properties, Zakaria M. Sawan, *Cogent Biology* (2016), 2: 1234959.

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