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Effects of sequentially applied growth regulators on growth and development of apple-trees variety Wealthy

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INTRODUCTION

Information concerning the effects of growth regulators on fruit trees has sometimes been controversial. The well known growth retardant B-9 (N-dimethylaminosuccinamic acid) was regarded by Everest (1966) as an inhibitor of growth extension and flower bud initiation in apples, cherries and pears, while Modlibowska (1965) and Loonney (1967) obtained a great improvement in the blossoming of apple trees in the subsequent year after B-9 treatment.

Besides B-9, flower-bud setting in apple-trees can also be stimulated by benzyloaminopurine (Tomaszewski and Chvojka 1967) and by naphthaleneacetic acid (Grochowska 1963, 1968). Gibberellins exert quite the opposite effect on apple trees, strongly inhibiting flower--bud formation and greatly increasing shoot growth and apical meristem activity (Greenhalgh and Edgerton 1967).

It was interesting to know whether the combined effects of these substances, applied successively, would be able to increase the growth of very young apple trees and then to inhibit it, thus obviating pruning and enhancing fruit-bud differentiation.

MATERIAL AND METHODS

In autumn 1966, 80 trees of apple variety 'Wealthy' were potted in their first year after budding. In early spring 1967 these trees were placed in the greenhouse and then the foliage sprayed with various growth regulators, sequentially applied at one month intervals.

Four growth regulators were used:

1. Gibberellic acid (GA) at 2500 mg/l ("Gibrescol" — Kutnowskie Zakłady Farmaceutyczne "Polfa", Kutno, Poland).

2. N-dimethylaminosuccinamic acid (B-9) at 2000 mg/l ("Alar", U.S. Rubber Company, Naugatuck U.S.A.).

3. N6-benzyloaminopurine (BA) at 50 mg/l ("Permedia", Lublin, Poland).

4. Naphthaleneacetic acid (NAA) at 10 mg/l ("Pomonit", Rokita, Brzeg Dolny, Poland).

Groups of ten trees were treated with 1, 2 or 3 growth regulators in following combinations:

I — Control (water)
II — GA
III — B-9
IV — NAA
V — GA+NAA
VI — GA+B-9
VII — GA+B-9+BA
VIII — GA+B-9+NAA

A single spray with each substance was performed on the trees in the first year of the experiment. In 1968, sprays were applied twice with a two week interval between sprayings but concentrations of GA and B-9 were halved. The concentrations of NAA and BA were unchanged. Ten millilitres glycerin and 2 millilitres triethanolamine were added per litre of spray to improve absorption.

GA was always applied at the very beginning of vegetative growth, in the middle of April, and the remaining substances subsequently: B-9 in May, NAA in June and BA in July.

The trees were fed with a full-nutrient solution every two weeks throughout the vegetative period. In winter, the trees were kept outside.

In 1968, after the blooming had been estimated, all flowers were removed.

Several features were studied to estimate the effect of the treatments on growth and development of the trees. All these features in the second year of the experiment were tested statistically with Duncan's Range Test (regression analysis). Results are presented graphically as well as in corresponding tables containing the average values grouped with a common line in cases where they were not statistically different at 5% level of significance.

RESULTS

In 1967 — the first year of experiment — growth of the trees sprayed with single growth regulators did not differ markedly except for two combinations: with GA, which enhanced total growth about 14% in comparison with controls, and with B-9, which lowered it slightly (Fig. 1). The treatment with several regulators sequentially applied did not

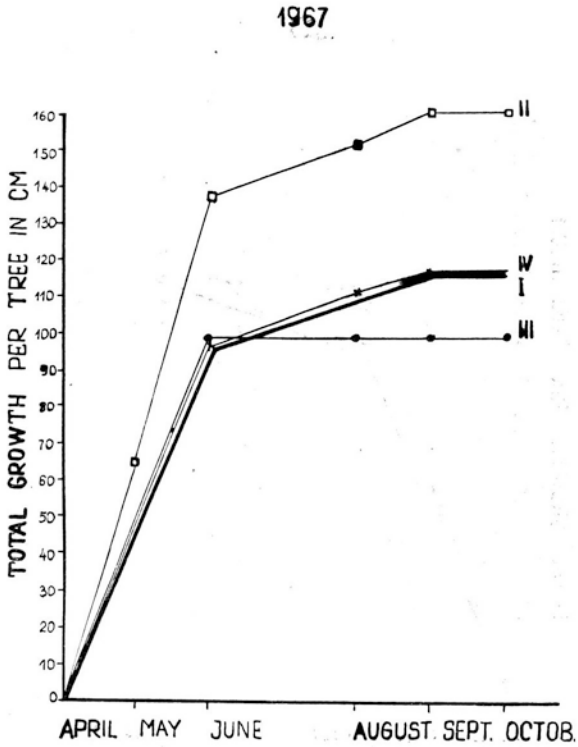


Fig. 1. Effect of growth regulators on total growth of trees in first year of treatment
I — control, II — GA, III — B-9, IV — NAA

apparently influence the total growth of the trees (Fig. 2). A small enhancement seen in May in almost all combinations may be due to the earlier GA applications. NAA spray at 10 mg/l applied after GA treatment suppresed growth for two months. After that time, growth of the trees resumed.

Enlargement of the leaf surface on the trees treated with GA followed their total growth enhancement. A slightly smaller enlargement of the leaf blade was observed on the trees sequentially treated with growth regulators, when GA was a first spray.

Table 1

Mean surface of the leaf blade in cm (length times width) in 1967

GA	GA+ B-9+ NAA	GA+ B-9 BA	GA+ B-9+	GA+ NAA	NAA	Control	B-9
68,4	64,3	60,7	57,9	57,3	51,9	51,4	51,2

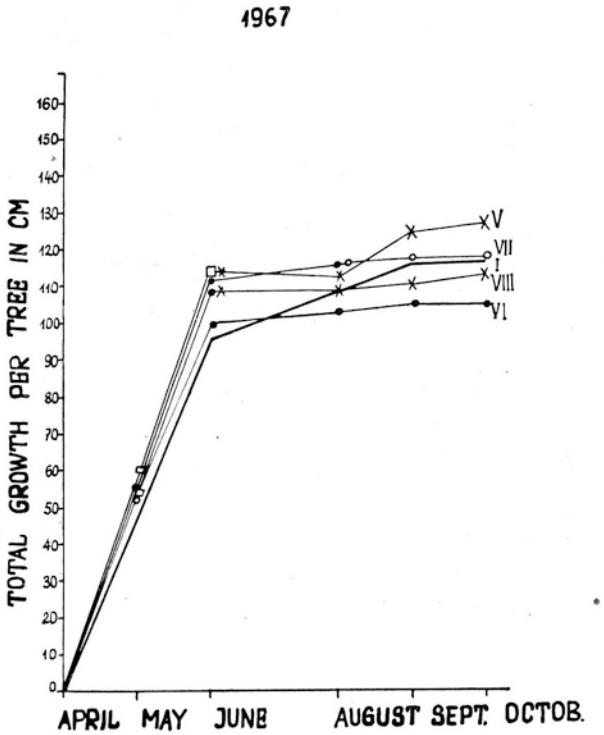


Fig. 2. Effect of growth regulators applied sequentially on total growth of trees in first year of treatment
I — control, V — GA+NAA, VI — GA+B-9, VII — GA+B-9+BA, VIII — GA+B-9+NAA

The following spring, flowering of the trees was estimated. The results indicated that the trees responded to the treatments.

Inhibition of flower-bud setting occurred on the trees with GA while B-9 treatment doubled flowering in comparison with controls. The best result in the stimulation of flower-bud setting occurred in combination VIII when 3 growth regulators were applied sequentially at one month intervals (GA + B-9 + NAA). The number of flowering spurs in this combination almost trebled (Table 2).

However, in the third year of the experiment, after two years of growth-regulator application, the flowering of the trees changed mark-

Table 2
Total flowering spurs in 1968

I, Control — 12	V, GA + NAA — 10
II, GA — 2	VI, GA + B-9 — 23
III, B-9 — 28	VII, GA + B-9 + BA — 29
IV, NAA — 15	VIII, GA + B-9 + NAA — 33

edly. The number of flowering spurs decreased, unexpectedly, on the trees treated with B-9 as compared with controls (Table 3).

The results received in flower-bud setting after B-9 application were very similar to those obtained with GA (Table 3). When these substances were applied separately or together as sequential sprays, the number of flowering spurs was reduced to about half of that of controls.

Table 3

The flowering of the trees in the third year of experiment

Treatment	Total number of flowering spurs in 1969	Growth in centimeters per flowering spur on the three
Control	124	30,61
GA	50	94,66
B-9	68	40,80
NAA	192	17,87
GA + NAA	166	25,53
GA + B-9	76	56,67
GA + B-9 + BA	52	91,56
GA + B-9 + NAA	105	39,47

NAA was the only substance which increased the flowering the trees (Table 3). It seemed to counteract the inhibition exerted by GA when applied as a successive spray. The best rate of vegetative growth relative to flower-bud setting in the apple trees occurred after the NAA spray (Table 3). There was one flowering spur for every 17,8 cm of the growth increment on the trees sprayed with NAA. In control trees this relationship was one to 30,6 but in the most unfavourable case, after GA treatment it rose to one to 94,6.

In 1968 — the second year of treatment — the differences in total growth that occurred between the trees considerably increased (Fig. 3). As expected, the highest increase occurred on GA treated trees and the the lowest on the ones sprayed with B-9, 120% and 70% of controls, respectively.

Double spray of the trees with NAA at a concentration of 10 mg/l resulted in about 15% inhibition of their growth in comparison with controls. The same compound applied as a sequential spray caused the trees to grow similarly to those treated with B-9 as a second spray (Fig. 4). However, the earlier treatment with GA caused all the trees sprayed with more than one regulator growing more intensively than controls.

There was an unexpected tendency, statistically non-significant, towards growth stimulation on the trees which received BA after B-9

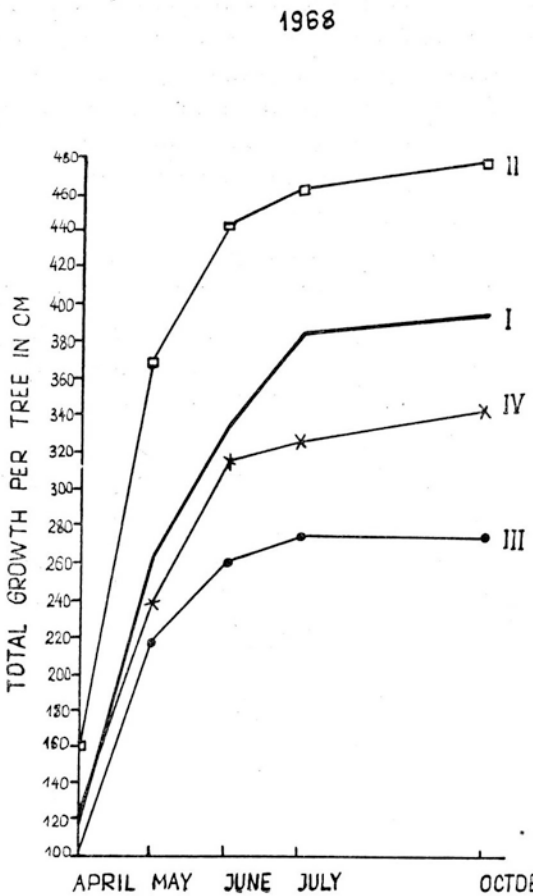


Fig. 3. Effect of growth regulators on total growth of the trees in second year of treatment
Other details as in Fig. 1

spray. Their total growth was almost equal to that of the trees sprayed with GA.

Table 4
Mean total growth per tree in cm

AG	GA+ B-9 + BA	GA + B-9	GA + B-9 NAA	GA + NAA	Control	NAA	B-9
473,3	467,1	430,7	414,4	411,0	397,6	343,1	277,4

Intensity of growth (increase of shoot per unit time) of the sprayed trees with single growth regulators was somewhat different from that

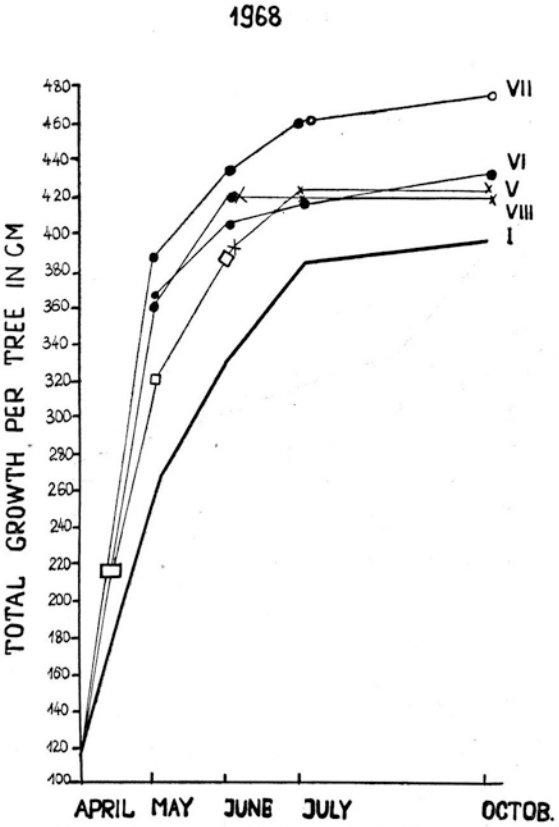


Fig. 4. Effect of growth regulators applied sequentially on total growth of the trees in second year of treatment
Other details as in Fig. 2

of controls (Fig. 5). The very intensive growth of the shoots which occurred at the beginning of the vegetative period on the trees treated with GA, dropped sharply in July, while control trees grew moderately until October. Similar breakdown in growth intensity was observed on the trees sprayed with NAA and B-9, though at the beginning of vegetative growth they developed in much the same way as controls.

The trees varied in some other features besides their growth intensity:

Table 5

Mean number of shoots per tree. Values presented are transformed according to $y = \sqrt{x}$, when x eaquals number of shooth

GA + B-9 + BA	GA + B-9 + NAA	GA + B-9	GA	GA + NAA	Control	B-9	NAA
3,20	3,15	3,13	3,10	2,91	2,87	2,67	2,59

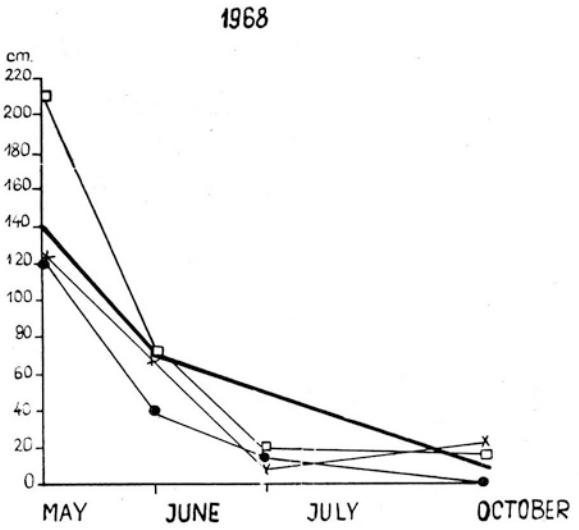
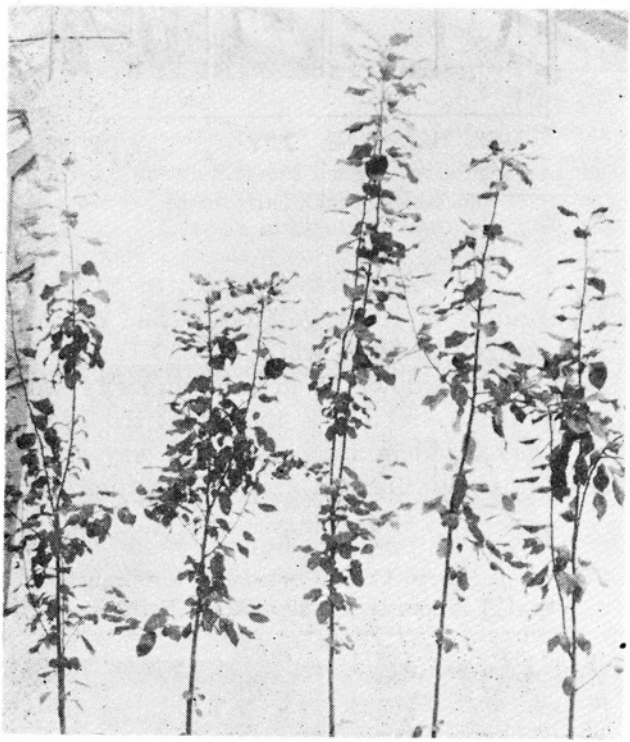


Fig. 5. Intensity of the total growth of the trees per month (in cm)
Other details as in Fig. 1



Fot. 1. Shape and height of the trees sprayed with growth regulators
From left to right: Control, B-9, GA, GA+B-9, GA+B-9+NAA

number of shoots and width of crotch angles per tree. Total growth when compared with the number of shoots over 5 cm in length gave a general idea about the tree shape (Fig. 6).

In general, the trees sprayed with more than one growth regulator had a much better shape because of their better branching than did ones treated with single substances. Of all combinations, VI — (GA + B-9) appeared to be the best. These trees had intermediate height relative to others and good branching with a more horizontal habit (Fot. 1).

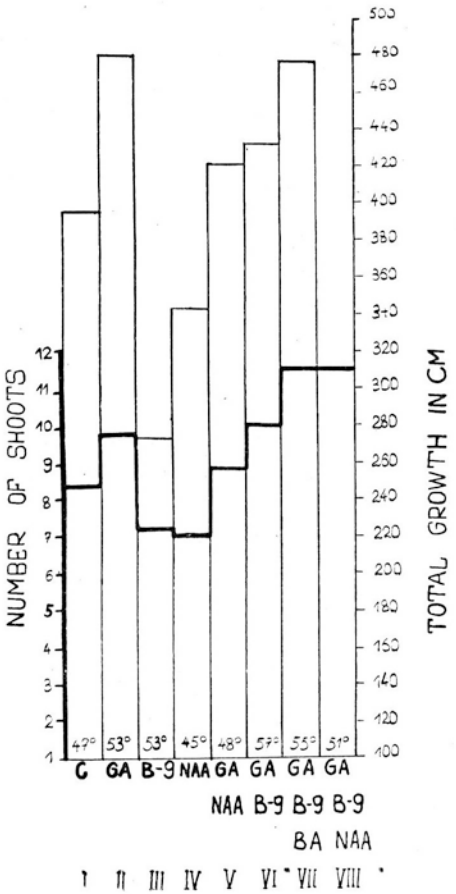


Fig. 6. Characteristic features of the tree shape after treatment with growth regulators. Averages: total growth (presented on the left side of the diagram), number of shoots (on the right side) and width of crotch angles (at the bottom of every diagram)

Length of internodes on the main shoot of the trees changed in two combinations only: after B-9 treatment when its mean length was reduced to 2,6 cm, and it was extended to 3,2 cm on the trees sprayed sequ-

entially with GA + B-9 + BA. Mean internode length of control trees was 2,9 cm. No distinct increase in internode length was observed on the trees sprayed with GA.

Similarly to the previous year results, the subsequent sprays with growth regulators contributed to the enlargement of the leaf blade. Again GA in combination with some other growth regulators exerts a stimulating effect in this process.

Table 6

Mean surface of the leaf blade in cm (length times width) in 1968

GA + B-9	GA + NAA	GA + B-9 + NAA	GA + B-9 + BA	GA	NAA	B-9	Control
104,1	102,2	101,8	98,9	97,8	93,3	93,2	88,6

DISCUSSION

Treatment of the apple trees with GA increased their shoot growth and greatly inhibited flower-bud setting, but it did not bring about the leaf blade narrowing or reduction which was suggested by Phinney (1960). On the contrary, in our experiments GA contributed to a significant enlargement of the leaf blade surface which occurred in both years of treatment. These results were in good agreement with the observations of Kuraishi and Muir (1962).

The improvement of crotch angle that occurred on the trees sprayed with GA was most unexpected. The rapid growth of the primary shoots rather favored narrowing of their crotch angles (Bukovac 1965). However, the high temperature of greenhouse together with the very high daily increase of shoot growth (about 0,9 cm) made them very week and they tended to bend downwards probably causing the more horizontal growth habit.

The number of shoots which sprouted on the trees showed that B-9 and NAA had no effect on apical dominance, while GA, especially when combined with other growth regulators, destroyed it, greatly improving the branching of the trees. Luckwill (1968) suggested that GA is assumed to increase the diffusible auxin in the shoot apices to the point where all shoots on the tree could compete for the available nutrients on equal terms. On the other hand, maintenance of apical dominance suggests that B-9 can have no direct effect on auxin production and GA synthesis at the apical meristems.

The results obtained in the flowering of the trees, variety 'Wealthy' in this experiment supported Everest's observations, that B-9 can inhibit

flower-bud setting in some apple cultivars when they are treated every year. This may be attributed to the fact, pointed out by several authors (Martin, Williams 1966, Martin et al. 1964), that B-9 is very resistant to inactivation in plant tissues. Every year the accumulation of this substance in the tree increases the obstacle to flower-bud formation.

According to Williams and Stahly (1968), cytokinins are limiting factors for apple bud development and growth. In our experiments, BA showed a tendency (differences were not statistically significant) to incerase the total growth of the trees. This enhanced growth effect was probably realised by the ability of BA to break the buds and to promote the lateral shoot development. It should be pointed out that BA was applied as a foliar spray instead of to the buds or to peduncles. However, the high temperature which greatly improves BA action and absorption (Poll 1968) was secured in our experiments by placing the trees in greenhouse.

After the second year of treatment, BA failed to influence the flower-bud setting. In combination with GA and B-9, which both exerted inhibiting effect on flower-bud formation, BA could not conteract their action. There was no flower stimulation as suggested by Tomaszewski and Chvojka (1966), the result dues possibly to too low concentration of BA when applied as a subsequent spray.

The bahaviour of the trees under NAA treatment caused many difficulties in the attempt to rank it with either stimulator or inhibitor-like substances. NAA showed a tendency towards inhibition of growth of apple trees even when very low concentration (10 mg/l) was used. It was followed by a bad branching of the trees, with a tendency towards narrowing of their crotch angle. On the other hand, NAA did not show an inhibitory effect in flower-bud formation but, contrarwise, even stimulated this process especially after the second year of treatment when applied as a single spray or in combination with GA.

This confirmed our previous observations (Grochowska 1963, 1968).

From the viewpoint of the most favorable feature required for productivity of the apple tree, the combination VIII (GA + B-9 + NAA) appeared to be the best one. The trees had characteristically moderate growth and very good branching with the crotch angle better than in control trees, see Fig. 6. Although the number of flowering spurs on the trees was slightly lower in the second year of treatment than on control ones, it was followed by the significant leaf blade enlargement which might secure the good cropping of thus treated trees.

In conclusion, 2 or 3 growth regulators sequentially applied resulted in a greater effect on growth and development of apple trees, variety "Wealthy" than the same compounds used individually. The combined

effect of a few growth regulators applied sequentially seemed to infuence the growth and development of the tree on a large scale including its shape and productivity. It must be remembered, however, that these results were obtained under greenhouse conditions and they need confirmation in the field.

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SUMMARY

Two or three growth regulators applied sequentially at one month intervals resulted in a greater effect on growth and development of apple trees, variety "Wealthy" than the same compounds used as single sprays. The combined effects of several growth regulators seemed to be to influence growth and development of the trees on a large scale including their shape, leaf surface, crotch angle, and flowering.

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Streszczenie

Regulatory wzrostu roślin (kwas giberelinowy — GA, retardant — B-9, benzyloaminopuryna — BA, i kwas naftalenooctowy — NAA) zastosowane w formie opryskiwań, pojedynczo lub kilka związków następczo po sobie, w miesięcznych odstępach czasu, na jabłonie odmiany 'Wealthy', wpłynęły modyfikująco na szereg cech wzrostowych i rozwojowych drzew. GA zwiększył ogólny wzrost drzew, ilość rozgałęzień, kąt ich rozwidleń oraz wielkość liści, natomiast znacznie zredukował ilość zakładanych pąków kwiatowych. Długość międzywęźli nie uległa jednak zmianie. B-9 wpłynął hamująco na wzrost drzew, zmniejszył długość międzywęźli oraz nieoczekiwanie obniżył ilość tworzonych kwiatów. Jedynym związkiem stymulującym kwitnienie okazał się NAA, który również osłabił wzrost drzew.

Połączone działanie kilku regulatorów wzrostu zastosowanych następczo wywołało większe i bardziej korzystne zmiany w rozwoju drzew niż te same związki użyte pojedynczo. Obiecującą z praktycznego punktu widzenia wydaje się kombinacja, której drzewa opryskano następczo: GA+B-9+NAA. Charakteryzował je umiarkowany wzrost, dobre rozgałęzienie oraz stosunkowo obfite kwitnienie. Ponieważ doświadczenie wykonano w warunkach szklarniowych wyniki otrzymane wymagają potwierdzenia w badaniach polowych.