The influence of KJ, CuSO_4 , and $\text{Mg}(\text{ClO}_3)_2$ on defoliation and subsequent frost resistance and growth of apple trees in nurseries*

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Abstract

In most cases 2-year-old trees of 3 cultivars responded better to defoliants than 1-year-old ones. Spraying with defoliants on September 25 - 28 was more effective than spraying 10 days earlier. There was also more bark injury in the autumn, and more frost injury on trees defoliated on the earlier date. $\text{Mg}(\text{ClO}_3)_2$ seemed to be the best defoliant but markedly decreased the frost resistance of McIntosh trees. Defoliants investigated may be applied to limited extent to 2-year-old trees but not to 1-year-old ones.

INTRODUCTION

Under the climatic conditions of Poland digging of nursery trees begins in the first decade of October. At that time trees of most varieties still have green foliage. Digging foliated trees would greatly decrease their value; therefore hand defoliation before digging is commonly practiced. Such defoliation is rather laborious and expensive. According to Ebetullaev (1967), 21 work-days are required for the hand defoliation of 1 ha of a nursery. Hand defoliation interrupts the physiological processes of plants leading to dormancy. Very often the shoots or buds are damaged, and the unhealed leaf scars become sites of infection by pathogenic fungi and bacteria.

Chemical defoliation on a commercial scale was started in several countries in the early fifties. Among many defoliants tried, chlorates were recognized as the best ones (Rakitin and Imamaliyev 1959a; Kuznecov 1965; Ebetullaev 1961, 1967; Sergeev and Daukaeva 1967, and others). Among chlorates, magnesium chlorate $\text{Mg}(\text{ClO}_3)_2$ and calcium chlorate-chloride $\text{Ca}(\text{ClO}_3)_2 + \text{CaCl}_2$ are used. Magnesium chlorate, because of its high effectiveness and low phyto-

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toxicity is commonly used to defoliate cotton plants in the Soviet Union. Good results have also been obtained with sodium chlorate (Furyova and Cervenka 1966).

Iodide ion also accelerates leaf abscission (Herrett et al. 1962; Larsen 1966; Macdonald and Kempton 1968; Ruckij and Nikolaev 1969). Potassium iodide is the most effective and the most commonly used for defoliation. The effectiveness of potassium iodide was increased when Nacconal NR was added (Larsen 1966). Interesting results were obtained by Larsen (1967a) who treated fruit and forest trees with potassium iodide alone and in mixtures with alanine.

Lane and Wayne (1962) showed that the addition of sucrose to defoliant increased the defoliation of cotton plants. According to Trusevich (1964), under the climatic conditions of south USSR, ammonium sulphate $(\text{NH}_4)_2\text{SO}_4$ appeared to be a satisfactory defoliant for nursery trees. Wanic (1964) indicates the possibilities of defoliating trees with CuSO_4 and CuCl_2 . Copper sulphate was used to defoliate tea shrubs (Acbar et al. 1967) and in physiological experiments with apple trees (Fulford 1970).

Calcium cyanamide $(\text{Ca}(\text{CN})_2)$ was used by Kuznecov (1961, 1965), Sergeev and Daukaeva (1967), Levin (1969). The chemical appeared to have a harmful effect on bud development the following spring.

The effectiveness of defoliant is closely related to the temperature (Imamaliyev 1960; Daukaeva 1964).

The date of application of defoliant is also of great importance. According to Kolesnikov (1970), the best defoliation of nursery trees is obtained if they are treated 10-14 days before digging. Ebetullaev (1968) reports that the best date of application of chemicals to defoliate apple seedlings in the region of Moscow is the second week of September.

It has been found that different plant species and varieties respond differently to the same defoliant (Imamaliyev 1960; Levin 1969; Polovnikov 1969). Trees of different ages also differ in their response to the same defoliant (Daukaeva 1964).

The speed with which defoliant penetrate plant tissues, their translocation and decomposition depends on their chemical structure and properties. It was found that chlorates do not spread easily within plants (Kraft and Bokarev 1967) whereas KJ absorbed by the roots is easily transported to the aboveground parts of plants, causing defoliation (Herrett et al. 1962).

According to Imamaliyev (1960) magnesium chlorate and Endothal applied to fruit trees under severe climatic conditions increase the frost resistance of trees because shoots mature earlier and transpiration

is lowered. Kuznietsov (1961) on the other hand, has found a reduced frost resistance in defoliated trees and considers this as a result of incomplete shoot lignification and reduced translocation of nutrients from leaves. Larsen (1966, 1967 b, 1970) indicates the possibility of injuring shoots and hypertrophy of the tissues of apical buds after treatment with KJ and Bromodine. Daukaeva (1964) points out that early treatment with defoliant may cause injuries on the stems of one-year-old apple seedlings.

The aim of this work was to investigate inorganic defoliant for apple nursery trees under the climatic conditions of Poland. Experiments were made to find the best defoliant and optimal period of defoliation.

MATERIALS AND METHODS

Experiments on the chemical defoliation of nursery apple trees were carried out in 1969-1970 in the Experiment Station "Prusy" of the Research Institute of Pomology near Skierniewice, Central Poland. Defoliant for the experiments were chosen on the basis of results obtained in earlier work (Czynczyk and Basak—in preparation). These were: magnesium chlorate, potassium iodide and copper sulphate. Each defoliant was used at two concentrations: KJ—0.3% and 0.5%, CuSO_4 —1.0% and 2.0%, $\text{Mg}(\text{ClO}_3)_2$ —0.4% and 0.5%. In a few cases other concentrations were tried. Defoliant were applied on two dates: September 15-18 i.e. about 20 days before the expected date of digging trees, and on September 25-28 i.e. ten days after the first treatment. The concentrations were calculated using hydrated forms of CuSO_4 and $\text{Mg}(\text{ClO}_3)_2$.

Since the reaction of nursery trees to the application of defoliant could depend on the age of trees, one- and two-year-old trees were used for the experiment. The one-year-old trees were propagated on Antonovka seedlings while the two-year-old trees were double grafted on Antonovka seedling with Yellow Transparent interstock in 1969 and Hibernial interstock in 1970.

Three apple varieties were treated with defoliant: Yellow Transparent, which under our climatic conditions ceases growth earlier than other varieties, and McIntosh and Jonathan, which end their growth late and very late respectively.

Defoliant were applied with a hand-sprayer "Puzon" of 10 l capacity, using about 1 l of liquid per 10 trees. The weather during spraying in 1969 was warm and sunny. The average air temperature on September 15 was 25°C and on September 25 was 20.7°C. The day after the second treatment there was 1.7 mm of rain. In 1970 the temperature during spraying was much lower. On September 18 it was 17.6°C followed by 9.6 mm of rain a few hours after spraying. On September 28 it was only 9.8°C.

The experiment was designed in 4 randomized blocks. Each plot consisted of 6 equally treated trees of one variety and of the same age. The effects of defoliant were evaluated by counting the number of leaves fallen on 7, 13, 18, 21 and 28 days after spraying. Data on leaf drop after 13 days (about 2 weeks) and after 28 days (4 weeks) are presented as percent of fallen leaves and were calculated statistically using variance analysis. The values were transformed according to the Bliss function. Differences between treatments were evaluated with Duncan's test.

Bark injuries sometimes occurred on chemically defoliated trees. The injuries appeared mainly in the upper parts of current season shoots and sometimes in the lower parts around buds. The injured bark had a discolored and scaly epidermis. The degree of injury was estimated using a 4-class scale: class I—trees without evident injury, class II—light injury, class III—medium injury—6-10 nodes and internodes injured and class IV—severe injury, occurring on more than 10 nodes and internodes. In the case of two-year-old trees the injuries were counted on all branches while on one-year-old trees only on the leader. Statistical analysis of results was done using the χ^2 test.

The frost resistance of chemically defoliated trees was determined by the method of electric conductivity of electrolytes. Shoots frozen in a refrigerator at a controlled temperature were compared with non-frozen ones. Each apple variety treated with a given method was represented by 6 shoots. The shoots were collected in the middle of January. At the beginning, the shoots were held at a temperature of -2°C and then frozen to -33°C or -35°C for 16 h. After this period the temperature was gradually increased. The temperature drop was about 2.5°C per hour. Differences in electric conductivity were calculated statistically using Duncan's test.

Laboratory experiments on frost resistance were supplemented by field observations after the winter of 1969/70 and 1970/71. The extent of frost injury was estimated using a 4-class scale: 1—no frost injury, 2—shoots injured up to 1/4 of their length, 3—shoots injured up to 1/2 of their length and 4—shoots injured up to 2/3 of their length or more. Usually the distal part of the shoots was injured. Results were worked out statistically using the χ^2 test.

One and two-year-old Jonathan trees and two-year-old McIntosh trees, both those treated with defoliant and the untreated controls were dug out and planted in another field for observation of their growth the year after defoliation. The growth of one-year-old McIntosh and Yellow Transparent trees was checked on their original place in the nursery. Unfolding buds were counted on these trees next spring. On one-year-old trees, counts were made on the leader only, while on two-

-year-old trees buds were counted on all branches. The results are expressed as an average number of buds unfolding per shoot and as percent of buds unfolding on a shoot. Tree growth was determined from the increase in stem diameter and measurements of the total growth of one-year-old shoots. Measurements were carried out in late fall. Stem diameters were measured 30 cm above the point of budding. The results of these experiments were evaluated statistically using an analysis of variance and Duncan's test for the significance of differences.

RESULTS

Defoliation

The first symptoms of the activity of defoliant could be observed 3-4 days after treatment. The trees showed browning of the lower surfaces of leaves (induced by CuSO_4), leaf puckering and browning of leaf edges (induced by KJ) and interveinal browning of leaf lamina (induced by $\text{Mg}(\text{ClO}_3)_2$).

Jonathan

One-year-old trees. Leaf fall from one-year-old trees treated with defoliant in 1969 started on the 7-8 day after spraying (Fig. 1, Tab. 1). Differences in the effectiveness of the defoliant applied on the first date (September 15) were already visible two weeks later. Potassium iodide used at both concentrations was more efficient than CuSO_4 (Fig. 1). Four weeks after spraying with KJ 75% to 80% of leaves had

Fig. 1. Pattern of leaf drop from one-year-old Jonathan trees treated with defoliant. Results of 1969

Table 1

Per cent of leaves fallen from one-year-old Jonathan trees depending on the defoliant, its concentration and date of application

Treatment	Concen- tration %	1969		1970	
		per cent of leaves fallen after			
		2 weeks	4 weeks	2 weeks	4 weeks
		First spraying date September 15		First spraying date September 18	
Untreated control	—	5.0 a	14.7 a	1.3 a	6.1 a
Potassium iodide	0.3	56.4 f	74.9 de	2.2 ab	92.3 fg
	0.5	64.0 f	80.4 ef	4.4 abc	92.7 fg
Copper sulphate	1.0	7.1 ab	23.2 b	7.8 bc	69.0 c
	2.0	12.2 bc	39.4 c	11.8 cd	85.7 ef
Magnesium chlorate	0.4	—	—	11.4 cd	74.0 cd
	0.5	—	—	18.5 d	66.1 c
		Second spraying date September 25		Second spraying date September 28	
Untreated control	—	13.1 abc	21.2 ab	4.0 abc	18.4 b
Potassium iodide	0.3	28.5 d	86.1 fg	53.8 e	95.4 g
	0.5	41.2 e	91.8 g	51.2 e	81.0 de
Copper sulphate	1.0	18.0 cd	64.7 d	51.2 e	74.7 cd
	2.0	23.0 d	73.7 de	75.8 f	92.5 fg
Magnesium chlorate	0.4	—	—	74.3 f	95.3 g
	0.5	21.5 —	78.0 —	70.5 f	94.2 g

Means designated by the same letter do not differ significantly at $P = 0.05$. Separate statistical analysis was done for each of 4 columns.

fallen. At the same time only 23% to 39% of the leaves had fallen from the trees sprayed with CuSO_4 .

Second date spraying (September 25) was more effective and there were smaller differences in effectiveness among the defoliants used. Potassium iodide was more effective than CuSO_4 . Magnesium chlorate was as effective as CuSO_4 . During that period only 21% of the leaves dropped from untreated control trees.

In next year experiments (1970) heavy defoliation occurred with KJ later than in 1969, i.e. 16-17 days after the first spraying. In general, the pattern of defoliation in the years 1969 and 1970 was similar (Tab. 1), although the second part of September was warm and sunny in 1969 while cold and wet in 1970, with the first frost on September 29.

Potassium iodide applied on the first date of 1970 was very effective in defoliating Jonathan trees. Four weeks after spraying, it induced 92-93% defoliation. Copper sulphate was more active in 1970

than in 1969. When used at 1% concentration it was less efficient than KJ. Magnesium chlorate defoliated trees to the same degree as the lower concentration of CuSO_4 .

Chemical defoliants applied in 1970 on the second date induced heavy defoliation two weeks after spraying (51 - 76% of leaf fall). The differences in effectiveness between KJ and CuSO_4 were not as evident as in 1969 and in many cases were not significant. The higher concentration of KJ applied on the second date acted too strongly, leaving many dried leaves on the trees. When used at a lower concentration KJ induced 95% defoliation while at the higher concentration it defoliated trees to 81%.

Two-year-old trees. In both years two-year-old Jonathan trees showed a better response to treatment with defoliants than one-year-old trees (Tab. 1 and 2). There were only a few exceptions: trees sprayed with KJ in 1969 lost their leaves earlier than two-year-old ones (differences were visible 2 weeks after treatment). Also one-year-old trees

Table 2

Per cent of leaves fallen from two-year-old Jonathan trees depending on the defoliant, its concentration and date of application

Treatment	Concen- tration %	1967		1970	
		per cent of leaves fallen after			
		2 weeks	4 weeks	2 weeks	4 weeks
		First spraying date September 15		First spraying date September 18	
Untreated control	—	3.1 a	11.3 a	3.4 a	14.9 a
Potassium iodide	0.3	37.2 d	75.9 cd	27.6 b	92.0 cde
	0.5	42.7 d	87.1 d	46.3 c	89.8 bcde
Copper sulphate	1.0	18.0 bc	44.9 b	49.1 cd	86.9 bcd
	2.0	42.8 d	71.9 c	41.4 c	78.0 b
Magnesium chlorate	0.4	—	—	42.8 c	90.2 bcde
	0.5	—	—	50.9 cde	85.6 bcd
		Second spraying date September 25		Second spraying date September 28	
Untreated control	—	12.5 ab	16.6 a	6.7 a	23.6 a
Potassium iodide	0.3	26.7 cd	88.0 d	65.6 ef	96.0 e
	0.5	29.3 cd	99.5 e	65.8 ef	94.2 de
Copper sulphate	1.0	27.0 cd	74.1 cd	72.4 f	92.5 cde
	2.0	44.4 d	88.2 d	61.5 def	83.0 bc
Magnesium chlorate	0.4	—	—	75.3 f	95.6 de
	0.5	22.8 —	90.8 —	68.8 f	95.0 de

Means designated by the same letter do not differ significantly at $P = 0.05$. Separate statistical analysis was done for each of 4 columns.

sprayed with CuSO_4 2% in 1970 responded more strongly than two-year-old trees. The cold, wet weather during and after the spraying in 1970 seemed to favour the action of CuSO_4 and the 2% concentration was too high for two-year-old trees — dried leaves were retained on the branches. Magnesium chlorate used on second date in 1970 defoliated one-year-old trees, as well as two-year-old ones.

Yellow Transparent

On one-year-old trees of this variety, leaf fall began 2 - 3 days earlier than on Jonathan trees. There was also better defoliation of Yellow Transparent than of Jonathan trees. In general KJ was as effective or more effective than CuSO_4 (Tab. 3). Magnesium chlorate was highly effective, in some cases more so than CuSO_4 or even KJ.

Potassium iodide and CuSO_4 were often more effective at higher concentrations whereas $\text{Mg}(\text{ClO}_3)_2$ was similarly effective at both concentrations.

Table 3

Per cent of leaves fallen from one-year-old Yellow Transparent trees depending on the defoliant, its concentration and date of application

Treatment	Concentration %	1969		1970	
		per cent of leaves fallen after			
		2 weeks	4 weeks	2 weeks	4 weeks
		First spraying date September 15		First spraying date September 18	
Untreated control	—	6.5 a	13.7 a	2.2 a	24.1 a
Potassium iodide	0.3	66.6 cd	82.6 cde	29.0 b	98.7 d
	0.5	80.4 d	95.1 fg	46.6 c	98.8 d
Copper sulphate	1.0	40.9 b	75.6 c	22.3 b	76.6 b
	2.0	54.7 bc	88.9 def	42.0 c	90.4 c
Magnesium chlorate	0.4	—	—	—	—
	0.5	—	—	24.7 b	85.6 bc
		Second spraying date September 25		Second spraying date September 28	
Untreated control	—	16.7 a	28.3 a	10.8 a	31.5 a
Potassium iodide	0.3	20.0 a	81.5 cde	61.5 c	99.6 d
	0.5	48.7 bc	90.8 efg	81.4 d	98.6 d
Copper sulphate	1.0	18.5 a	79.8 cd	82.6 d	98.5 d
	2.0	44.3 bc	96.7 g	95.0 e	99.5 d
Magnesium chlorate	0.4	—	—	99.2 e	100.0 d
	0.5	37.3 —	81.3 —	98.5 e	100.0 d

Means designated by the same letter do not differ significantly at $P = 0.05$. Separate statistical analysis was done for each of 4 columns.

McIntosh

In most cases potassium iodide and CuSO_4 were more effective at

Fig. 2. Comparison of leaf drop from one-year-old (first column) and two-year-old (second column) Mc Intosh trees

higher concentrations than at lower ones. Magnesium chlorate was similarly effective at both concentrations. Results indicate that defoliant applied to McIntosh trees on the second date were usually more effective than on the first date of treatment.

Two-year-old McIntosh trees responded to the various defoliant, their concentrations and date of treatment in a similar way as the one-year-old trees (Fig. 2). Often greater leaf fall occurred on two-year-old than on one-year-old trees (Fig. 2). Potassium iodide sometimes induced faster defoliation of one-year-old than of two-year-old trees (Fig. 2 — observations after 2 weeks). Copper sulphate at the lower concentration was more effective on two-year-old than on one-year-old trees. Magnesium chlorate had a similar influence on one- and two-year-old McIntosh trees.

Shoot injury observed in the fall on the trees
of all three cultivars

Bark injuries were sometimes noticed as a result of treatment with defoliant. They occurred most often in the upper part of shoots, mainly at bud bases, where the solution usually accumulates, and at the bases of secondary, late season growth (lammas shoots). The first symptom of injury was light coloration of the bark, but later the cracks appeared in the epidermis leaving the parenchyma of the bark bare. Sometimes the bark cracks were also visible (Fig. 3).

Fig. 3. Bark injury resulting from chemical defoliation. Control shoot on right

The most severe bark injury was caused by potassium iodide (Table 4). Its harmful effect was observed in both years and on all three varieties tested. The least bark damage was caused to McIntosh trees. One-year-old trees were usually more severely injured than 2-year-old ones. It was found that KJ was more harmful when used on the first

Table 4

Shoot injury of chemically defoliated trees expressed as χ^2 in relation to untreated control trees which had no injury. Observations 3 weeks after treatment

Variety	Tree age	Year of observa- tion	Potassium iodide				Copper sulphate				Magnesium chlorate			
			0.3%		0.5%		1.0%		2.0%		0.4%		0.5%	
			Date of treatment ^a											
			1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Jonathan	one-year-old	1969	38.40**	23.14**	53.61**	38.40**	0	0	0	0	—	—	—	0
		1970	11.08**	12.64**	48.00**	21.82**	0	0	4.36*	1.02	5.58*	0	4.36*	0
	two-year-old	1969	38.40**	17.92**	65.24**	27.02**	0	0	0	0	—	—	—	0
		1970	2.08	0	5.58*	3.20	0	0	0	0	1.02	0	0	0
McIntosh	one-year-old	1969	14.76**	10.68**	17.92**	10.68**	0	0	0	0	—	—	—	0
		1970	0	0	3.42	1.04	0	0	0	8.00**	2.20	0	0	1.40
	two-year-old	1969	0	0	0	0	0	0	0	0	—	—	—	0
		1970	0	0	3.42	2.18	0	0	0	4.80*	0	0	0	0
Yellow Transparent	two-year-old	1969	61.18**	13.28**	72.38**	27.33**	0	0	0	0	—	—	—	0
		1970	6.13*	1.02	24.00**	28.50**	2.18	0	4.36*	17.67**	—	0	1.02	0

^a 1st date treatment — Sept. 15 in 1969 and Sept. 18 in 1970; 2nd date treatment — Sept. 25 in 1969 and Sept. 28 in 1970.

* Differences significant at $P = 0.05$. ** Differences significant at $P = 0.01$. Separate statistical analysis was done for each variety in a given year.

Degree of frost resistance of shoots determined by the method of electrolyte

Method of defoliation	Concentration %	Date of treatment ^a	One-year-old trees		
			Jonathan		
			1969/70	1970/71	
			F	uf	f
Untreated controls	—	—	44.5 a	41.8 b	57.9 cd
Hand defoliated	—	1st	53.1 c	—	—
	—	2nd	51.1 abc	61.7 cd	77.6 ef
	—	3rd ^b	—	—	—
Potassium iodide	0.3	1st	52.2 bc	—	—
	0.3	2nd	44.1 a	62.0 cd	63.1 d
	0.5	1st	62.0 d	—	—
	0.5	2nd	45.5 ab	77.2 ef	79.7 ef
Copper sulphate	2.0	1st	47.1 abc	—	—
	2.0	2nd	45.6 ab	50.4 bc	81.9 f
Magnesium chlorate	0.5	1st	—	78.0 ef	84.9 fg
	0.5	2nd	45.9 ab	43.0 b	69.5 de
Mean % of diffusion of electrolytes on shoots	Unfrozen		35.3		
	Frozen		63.0		

^a Explanation in Table 4. ^b Additional, third date of hand defoliation October 7.

F — Mean % of diffusion of electrolytes in unfrozen and frozen shoots used when interaction unfrozen shoots; f — % of diffusion of electrolytes in frozen shoots; uf and f are used when

In 1969/1970 there were no significant differences in frost resistance among 2-year-old trees at $P = 0.05$. Separate statistical analysis was done for each variety in a given year.

date than on the second, and more at 0.5% concentration than at 0.3%. Potassium iodide applied on the first date in 1969 caused the dessication of the apical part of one-year-old Jonathan trees and to a lesser degree of McIntosh trees.

On the trees treated with CuSO_4 , shoot injury was observed in 1970 only. The cold and wet fall of 1970 seemed to favour tree defoliation by CuSO_4 but also increased bark damage. In contrast to KJ, the bark injury caused by CuSO_4 occurred mostly on trees treated on the second date. The higher concentration of CuSO_4 was more toxic than the lower one. This compound injured mostly one-year-old trees of Yellow Transparent and McIntosh. Respectively, 50% and 33% of trees were injured but the injuries were classified as mild ones (1 - 5 nodes and internodes injured). Slight injury also occurred on one-year-old Jonathan trees: 16.7% of trees treated on the first date and 4.2% of those treated on the second date showed the harmful effect of the defoliant. Copper sulphate caused no injury to two-year-old Jonathan trees and only occasionally injured 2-year-old McIntosh trees.

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diffusion. The lower the per cent of diffusion, the higher the frost resistance

One-year-old tress					Two-year-old trees		
Yellow Transparent			McIntosh		Jonathan	McIntosh	
1969/70	1970/71		1970/71		1970/71	1970/71	
F	uf	f	uf	f	F	uf	f
36.0 ab	25.3 ab	38.3 c	32.6 ab	56.5 cd	43.8 a	22.8 ab	50.6 d
40.5 d	24.4 ab	56.3 e	51.1 c	65.7 fg	67.6 c	29.4 bc	70.8 g
37.1 bc	23.1 ab	48.1 de	32.7 ab	63.1 defg	52.7 ab	21.3 a	59.8 f
—	25.0 ab	38.3 c	28.3 a	58.5 def	45.9 a	23.5 ab	51.5 de
39.4 cd	24.5 ab	49.3 de	31.1 ab	61.0 defg	65.6 c	25.5 ab	58.4 ef
36.5 abc	24.2 ab	46.7 de	31.8 ab	60.6 defg	48.0 ab	24.1 ab	55.7 def
41.4 d	23.8 ab	51.0 e	32.6 ab	64.2 efg	70.3 c	34.5 c	55.0 def
39.7 cd	23.5 ab	42.4 cd	30.4 ab	57.8 cde	59.3 bc	24.9 ab	55.0 def
39.5 ab	26.8 b	48.5 de	32.1 ab	62.9 defg	52.6 ab	23.5 ab	66.8 g
36.0 ab	20.9 a	44.9 de	39.4 b	62.1 defg	47.5 a	23.3 ab	54.0 def
—	22.4 ab	45.3 de	36.5 ab	74.4 h	53.4 ab	23.9 ab	60.4 f
33.6 a	23.6 ab	46.3 de	39.6 b	67.6 gh	49.7 ab	25.5 ab	55.1 def
26.5					44.9		
47.8					64.5		

"defoliation" × frozen or unfrozen is not significant; uf — % of diffusion of electrolytes in interaction "defoliation" × frozen or unfrozen is significant.
under the various treatments. Means designated by the same letter do not differ significantly

Magnesium chlorate appeared less phytotoxic than other defoliant. Sporadic shoot injuries appeared on one-year-old trees treated on the first date. The damage caused by magnesium chlorate was sometimes not apparent until replanting. Some of the one-year-old Jonathan trees defoliated on the first date showed dessication of a 3 - 4 cm long apical part of the shoot. Similar symptoms were observed on single trees of other varieties.

Frost resistance

The frost resistance of chemically defoliated trees was determined by laboratory methods (Table 5) and from field observations (Table 6). One and two-year-old trees of all 3 varieties were investigated. Chemically defoliated trees were compared with untreated and hand defoliated controls.

In the Table 5 the results for unfrozen shoots are also presented since they were taken from the field in January and already showed differences in diffusion of electrolytes. If the interaction "defoliation"

Table 6

Degree of injury after overwintering in field conditions for defoliated trees as compared with untreated control values, expressed as χ^2

Treatment	Concen- tration %	Date of treat- ment ^a	One-year-old trees				Two-year-old trees			
			Jonathan		Yellow Transparent		McIntosh		Jonathan	
			1969/70	1970/71	1969/70	1970/71	1969/70	1970/71	1969/70	1970/71
Hand defoliated		1st	12.0**	—	27.4**	13.5**	38.9**	14.3**	0	4.8*
		2nd	3.3	8.0*	17.5**	1.5	30.6**	3.4	0	1.0
		3rd ^b	—	—	—	1.5	—	1.0	—	0
Potassium iodide	0.3	1st	20.3**	—	6.8*	1.0	3.9	0	0	1.0
	0.3	2nd	12.0**	9.9**	9.3**	1.0	6.7*	1.0	0	1.0
	0.5	1st	24.0**	—	12.1**	0.4	6.3*	1.0	0	9.9**
	0.5	2nd	24.0**	24.0**	5.7*	1.1	5.4	0	0	3.4
Copper sulphate	1.0	1st	—	—	5.8*	1.0	4.0	3.4	—	—
	1.0	2nd	—	—	3.6	1.0	12.8**	0	—	—
	2.0	1st	2.2	—	3.6	5.5	2.5	3.4	0	3.4
	2.0	2nd	1.1	24.0**	5.8*	4.3	6.9*	12.0**	0	1.0
Magnesium chlo- rate	0.4	1st	—	—	—	—	—	14.3**	—	—
	0.4	2nd	—	—	—	1.0	—	17.1**	—	—
	0.5	1st	—	17.1**	—	0.4	—	14.3**	—	2.2
	0.5	2nd	0	2.1	0	0.4	29.6**	14.3**	0	1.0

Separate statistical analysis was done for each variety in each year. a Explanation in Table 4. b Explanation in Table 5.

* Differences significant at $P = 0.01$. ** Differences significant at $P = 0.05$.

x "frozen or unfrozen" was not significant the average values "F" for both frozen and unfrozen shoots were given.

Warm and sunny weather in the end of the growing season of 1969 favoured accomplishment of tree growth and shoot maturity. In contrast, the cold and wet end of the growing season of 1970 caused prolonged vegetation thus decreasing the frost resistance of defoliated trees.

From the experiments on the influence of defoliation on frost resistance it was evident that one-year-old trees suffered more from frost than two-year-old trees (Table 5, 6).

Hand defoliation of trees of all three varieties done on the first date (September 15 - 18) caused a drastic decrease in frost resistance. It should be mentioned, however, that such an early defoliation of nursery trees is not practiced. Hand defoliation carried out on the second date (September 25 - 28) influenced the resistance of trees to low temperatures less adversely.

The most marked decrease in the frost resistance of defoliated trees was caused by KJ. The trees of three varieties showed more frost injury from first date treatment with KJ than from second date treatment. In most cases the higher concentration of KJ was more dangerous than the lower one. Jonathan trees appeared the most susceptible and McIntosh the most resistant.

Copper sulphate decreased the frost resistance of trees of all varieties to a much smaller degree than did KJ. Of the trees defoliated with CuSO_4 one-year-old Jonathan and McIntosh trees appeared most susceptible to frost injury. Very little frost injury occurred on Yellow Transparent trees. In most cases copper sulphate applied on the second date caused more injuries after overwintering in the field than when used on the first date (Tab. 6). This might be correlated with the higher activity of this compound during second date treatment.

Magnesium chlorate, the most effective defoliant for McIntosh, distinctly reduced the frost resistance of treated trees when sprayed on both dates and both concentrations. This compound induced a much lower frost injury in Jonathan and Yellow Transparent trees. One-year-old Jonathan trees suffered more when sprayed on the first date.

Growth of treated trees

Spring observations of chemically defoliated trees have shown that in certain cases defoliation had a negative influence on bud development (Tab. 7). Most of the injured buds were found in the upper part of the shoots. This part is usually cut back during spring pruning.

There were more dead buds on hand defoliated trees than on those chemically defoliated on the same date. Heavy injury of buds appeared on trees hand defoliated on the first date and very few bud injuries

Table 7

Average number of damaged buds per shoot in defoliated trees

Treatment	Concentration %	Date of treatment ^a	One-year-old trees						Two-year-old trees					
			Jonathan		Yellow Transparent		McIntosh		Jonathan		McIntosh		Jonathan	
			1970	1971	1970	1971	1970	1971	1970	1971	1970	1971	1970	1971
Untreated control	—	—	0.4	0.5	0.0	0.0	0.9	0.0	0.2	0.6	0.1	1.2	0.1	1.2
Hand defoliated		1st	6.3	—	8.2	2.9	23.7	8.7	1.6	5.3	0.7	7.5	0.7	7.5
		2nd	5.3	8.8	5.6	0.0	2.8	7.9	0.3	5.2	0.2	2.3	0.2	2.3
		3rd ^b	—	—	—	0.0	—	3.3	—	1.7	—	0.8	—	0.8
Potassium iodide	0.3	1st	4.0	—	2.8	0.9	2.1	1.4	2.7	9.9	0.1	1.6	0.1	1.6
	0.3	2nd	2.2	11.0	0.5	0.9	1.4	1.1	1.3	5.0	0.4	0.9	0.4	0.9
	0.5	1st	11.8	—	4.4	4.6	5.1	2.5	4.1	10.8	0.4	3.5	0.4	3.5
	0.5	2nd	4.0	11.2	1.5	2.6	1.9	1.2	3.5	9.4	0.1	1.9	0.1	1.9
Copper sulphate	1.0	1st	—	—	0.1	1.6	1.5	2.6	—	—	—	—	—	—
	1.0	2nd	—	—	0.0	0.5	2.0	3.2	—	—	—	—	—	—
	2.0	1st	3.3	—	0.1	1.4	2.0	0.8	0.7	4.4	0.0	3.6	0.0	3.6
	2.0	2nd	1.3	22.0	0.1	3.9	1.2	11.5	1.3	6.5	0.3	8.0	0.3	8.0
Magnesium chlorate	0.4	1st	—	—	—	—	—	13.6	—	—	—	—	—	—
	0.4	2nd	—	—	—	1.2	—	12.1	—	—	—	—	—	—
	0.5	1st	—	18.2	—	0.1	—	9.0	—	2.6	—	6.0	—	6.0
	0.5	2nd	0.8	9.6	0.1	1.6	—	6.3	0.6	6.2	1.0	7.3	1.0	7.3

^a Explanation in Table 4. ^b Explanation in Table 5.

could be found on those defoliated on the third date (October 7). Injured buds occurred rarely on untreated control trees. Then it was usually only an apical bud.

In general, the number of buds killed was greater on one-year-old trees than on two-year-old trees.

On Jonathan and Yellow Transparent trees KJ often injured more buds than other defoliant. More dead buds could be found on the trees treated with the higher concentration of KJ than on those treated with a lower concentration. Also more severe bud injury appeared on trees sprayed on the first date than on the second. Very little bud injury occurred on McIntosh trees defoliated with KJ.

Copper sulphate injured buds to a smaller extent than KJ. In 1970 when trees were defoliated during cold weather, CuSO_4 applied on the second date injured the buds to the same extent as KJ. The greatest number of buds killed was found on McIntosh trees and the smallest on Yellow Transparent.

Magnesium chlorate caused more severe bud injury to McIntosh trees than CuSO_4 . Jonathan and Yellow Transparent trees treated with $\text{Mg}(\text{ClO}_3)_2$ had fewer buds killed than with other defoliant. Magnesium chlorate injured sometimes more buds at a 0.4% concentration than at 0.5%. This phenomenon is difficult to explain. One-year-old plants showed greater bud injury when sprayed on the first date, while on two-year-old trees greater injury resulted from second date treatment.

Measurements of shoot growth and trunk diameter (Tab. 8) carried out at the end of the growing season have shown that in most cases chemically defoliated trees did not differ significantly from untreated controls or from those defoliated by hand. In a few cases chemically defoliated trees showed better growth than hand defoliated but not as good as untreated controls. For instance, two-year-old Jonathan trees defoliated on the second date of 1971 with 2% CuSO_4 or 0.5% $\text{Mg}(\text{ClO}_3)_2$ grew better than trees hand defoliated on the first date. Similarly, McIntosh trees treated with 2% CuSO_4 on the second date in 1969 showed significantly better growth than trees hand defoliated on the first date.

In most cases Yellow Transparent trees treated with KJ or CuSO_4 in 1969 showed weaker growth than untreated controls. Potassium iodide in concentration 0.5% applied on the first date had an obviously harmful influence on Jonathan trees. These trees showed significantly weaker growth than any other trees observed in the experiments of 1970.

DISCUSSION AND CONCLUSIONS

The results presented indicate a high effectiveness of all chemicals investigated (KJ, CuSO_4 , $\text{Mg}(\text{ClO}_3)_2$) as defoliant for nursery apple

Table 8

Influence of defoliants on tree growth

Treatment	Concen- tration %	Date of treat- ment ^a	One-year-old trees observed in 2nd year of growth						Two-year-old trees observed in 3rd year of growth											
			Yellow Transparent						Jonathan						McIntosh					
			1970		1971				1970		1971				1970		1971			
			L	D	L	D	L	D	L	D	L	D	L	D	L	D	L	D	L	D
Untreated control		—	413.7	b	231.1	507.9	228.0	317.5	24.2	214.4	bcd	25.0	270.5	ab	34.2	188.8	24.6			
Hand defoliated		1st	337.6	—	148.2	446.1	180.7	279.5	24.6	170.1	b	16.0	147.6	a	21.4	113.0	9.1			
		2nd	355.5	ab	209.3	441.7	176.8	335.2	29.3	215.7	bcd	22.8	283.2	ab	25.7	101.4	11.4			
		3rd ^b	—	—	478.3	186.1	—	—	—	245.5	bcd	28.4	—	—	—	142.2	16.9			
	0.3	1st	258.4	a	180.1	483.2	175.2	260.9	30.2	209.9	bc	19.5	194.5	ab	26.1	117.5	18.9			
Potassium	0.3	2nd	237.1	a	181.5	483.8	180.3	331.5	18.2	239.0	bcd	35.4	237.0	ab	34.6	133.5	16.6			
iodide	0.5	1st	270.1	—	228.9	437.8	159.7	189.6	28.6	157.8	a	24.8	214.7	ab	29.4	181.2	22.2			
	0.5	2nd	299.3	—	194.8	479.7	220.1	306.0	24.6	250.1	bcd	20.7	243.8	ab	29.3	150.4	22.4			
Copper	2.0	1st	273.5	a	199.4	482.8	200.0	271.7	26.6	202.9	bc	17.2	250.7	ab	31.3	92.8	9.5			
sulphate	2.0	2nd	267.0	a	191.7	490.2	209.4	273.8	21.5	314.6	d	22.9	302.5	b	36.0	94.5	12.4			
	0.5	1st	—	—	459.4	210.0	—	—	—	182.0	bc	23.4	—	—	—	130.5	14.4			
Magnesium chlorate	0.5	2nd	356.2	ab	280.6	457.2	222.4	319.5	32.5	257.3	cd	26.0	181.7	ab	28.2	139.8	13.4			

^a Explanation in Table 4. ^b Explanation in Table 5.

L — total length of one-year-old shoots in cm; D — increase of stem diameter in %.

Values designated by the same letter do not differ significantly at P = 0.55; Values in columns having no letter designation do not differ significantly. Separate statistical analysis was done for each variety in each year.

trees. They appeared to be more effective when applied on variety Yellow Transparent, which in Poland ceases growth early, than on Jonathan or McIntosh, which end their growth late in the season. The reaction of different varieties to the defoliants investigated was also different. McIntosh trees were best defoliated by $\text{Mg}(\text{ClO}_3)_2$, Jonathan by KJ. Different reaction of apple varieties to various defoliants was observed by Daukaeva (1964), Sergeev and Daukaeva (1967), Levin (1969), Sabirov and Razzakov (1969). This fact can be explained by differences in the anatomical structure of the leaves of different varieties and possibly by differences in the biochemical action of the defoliants on particular apple varieties.

In general, two-year-old trees were better defoliated than one-year-old trees. A higher efficiency of defoliants on older trees than on one-year-old ones was often observed at the beginning of their action, and when they were applied on earlier dates. A higher efficiency of defoliants on older trees has also been noted by Sergeev and Daukaeva (1967). In a few cases, under high temperatures and solar radiation during and after spraying, KJ was more effective on younger trees than on older ones.

It seems that tree vigour, soil conditions and weather during and after spraying are of great importance. Heavier defoliation was always observed on trees growing under poor soil conditions. High temperature and light intensity favoured the defoliating action of KJ. Copper sulphate, on the other hand, seemed to be more effective during cold and wet weather. The effectiveness of defoliants in connection with climatic conditions was discussed by Imamaliyev (1960) and Daukaeva (1964).

The optimal date for defoliating apple nursery trees under our climatic conditions seems to be the end of September. Early treatment, on September 15 - 18 was usually less effective in our experiments, and more often caused bark injury. Early application of chemicals often reduced frost resistance markedly and caused retardation of tree growth the following season.

Depending on the defoliant and its concentration, the beginning of leaf fall was observed 7 - 10 days after treatment. Heavy defoliation was observed 13 - 18 days after treatment. In the experiments of Sergeev and Daukaeva (1967), 70 - 100% defoliation was obtained 9 - 20 days after spraying.

Of the 3 defoliants investigated, the best results were obtained with $\text{Mg}(\text{ClO}_3)_2$ at 0.4 - 0.5%. This compound acted quickly, was efficient and, in general, did not cause bark injury. Magnesium chlorate cannot be recommended for defoliating McIntosh trees because it reduces frost resistance of this cultivar. It is also possible that $\text{Mg}(\text{ClO}_3)_2$ reduces the

frost resistance of one-year-old trees of other varieties, which end their growth late in the season.

Potassium iodide was also highly effective as a defoliant. Its efficiency was, however, accompanied by severe bark injury, reduction in frost resistance and retardation of tree growth the following season. This defoliant (at 0.3%) may possibly be used for defoliating two-year-old trees at the end of September.

Copper sulphate sometimes defoliated trees less effectively than other defoliants. It can be used for defoliating two-year-old trees of all varieties and for one-year-old trees of those varieties which end their growth early in the season. Because of the possibility of injuring bark and reducing frost resistance this chemical cannot be recommended for one-year-old trees of those varieties which grow until late season. The low price of the chemical, and its property of protecting trees against fungi and bacteria invading shoots through leaf scars suggests further investigation of this compound.

The results of the experiments presented clearly indicate that defoliants can reduce the frost resistance of defoliated trees under the climatic conditions of Poland. This is particularly true when defoliants are applied on one-year-old trees ceasing their growth late or if they are applied early in the autumn (middle of September). Observations of nursery trees have shown that frost injury occurred in both years of the experiment and particularly during the winter of 1970/71. The field observations were supported by the laboratory tests which showed that most frost injury occurred on chemically defoliated one-year-old trees of Jonathan and McIntosh. Two-year-old trees appeared more resistant to frost injury.

Hand defoliation carried out in September on the first date reduced the frost resistance of trees in all cases. Hand defoliation carried out on the second date (September 25 - 28) sometimes reduced the frost resistance of defoliated trees. If it was done on October 7, there was no difference in frost resistance between these trees and untreated controls. Since mass leaf fall from chemically defoliated trees begins 13 - 16 days after treatment, the frost resistance of trees defoliated chemically on the first date should be compared with the resistance of trees defoliated by hand on the second date.

Little data can be found in the literature on the influence of defoliants on the frost resistance of trees. There is, however, some disagreement in opinions on this matter. The results obtained in our experiments support the opinion presented by Kuzniecov (1961). On the other hand, Rakitin and Imamaliyev (1959 b), Sabirov and Razzakov (1969) and Sergeev and Daukaeva (1967) report increasing frost resistance in trees defoliated with $Mg(ClO_3)_2$. The experi-

ments of Sergeev and Daukaeva were carried out under severe climatic conditions where green leaves on trees are often killed by frost. In such cases, the application of defoliant may favour increased frost resistance.

The influence of defoliant on growth depended on the degree of bud and stem injuries which took place in the autumn and also on frost injury. The injuries mainly appeared in the upper parts of shoots which are usually removed by pruning after replanting. Practically, they are not very important. Buds which were not killed by defoliant in the fall or later by frosts grew as in control trees. Certain buds which had injured bark at their bases grew normally. Many investigators report bud and apical shoot tip injuries by defoliant (Larsen, 1966; Sabinov and Razzakov 1969).

It was shown in our experiments that too high a concentration of defoliant was sometimes less effective than a lower one. Concentrations of defoliant as high as 0.5% KJ applied in 1970 caused leaf drying and dried leaves stayed attached to the tree. The results obtained by Daukaeva (1964) agree with our findings that the early application of defoliant may be dangerous. Sergeev and Daukaeva (1967) observed better growth of defoliated trees after replanting. In our experiments some defoliated trees also grew better than controls, for instance Jonathan treated in 1970 with CuSO_4 .

The results of these experiments suggest that the search for a new and better defoliant should be continued. The defoliant should be effective, not injuring trees and not decreasing the frost resistance of defoliated trees. In other papers, experiments with Ethrel and its combinations with inorganic defoliant will be presented.

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Wpływ KJ , $CuSO_4$ i $Mg(ClO_3)_2$ na opadanie liści, odporność na mróz i późniejszy wzrost jabłoni w szkółce

Streszczenie

Badano wpływ defoliantów nieorganicznych (jodek potasu, siarczan miedzi i chloran magnezu) na opadanie liści odmiany jabłoni wcześniej kończącej wzrost (Oliwka Żółta) i dwóch odmian późno kończących wzrost (McIntosh i Jonatan).

Doświadczenie założono na drzewkach jednorocznych i dwuletnich. Defoliację chemiczną i ręczną przeprowadzono w dwóch terminach: 1-szy 15 - 18 IX i 2-gi 25 - 28 IX. Dodatkowo w roku 1970 zastosowano 3-ci termin defoliacji ręcznej 7 X — tj. na początku okresu wykopywania drzewek w szkółkach. Zastosowano następujące środki i stężenia: KJ 0.3% i 0.5%, $\text{CuSO}_4 \cdot 5 \text{H}_2\text{O}$ 1% i 2% oraz $\text{Mg}(\text{ClO}_3)_2 \cdot 6 \text{H}_2\text{O}$ 0.4% i 0.5%

Stwierdzono wyższą skuteczność defoliantów dla odmiany wcześniej kończącej wzrost (Oliwka Żółta) niż dla odmian pozostałych.

Dwuletnie drzewka zrzucały liście na ogół łatwiej niż jednoroczne.

Drugi termin defoliacji był lepszy niż pierwszy, ponieważ liście były zrzucone pod wpływem defoliantów w większym procencie, a uszkodzenia kory i uszkodzenia mrozowe występowały rzadziej i były słabsze.

Wszystkie zastosowane związki działały bardzo skutecznie jako defolianty. Dla Oliwki Żółtej i Jonatana najlepszym defoliantem był chloran magnezu, gdyż powodował szybkie zrzucenie liści, najslabiej uszkadzał drzewka i u dwuletnich drzewek nie obniżał odporności na mróz. U odmiany McIntosh związek ten wywołał jednak silne uszkodzenia mrozowe. Możliwe, że zastosowane stężenie było zbyt wysokie dla tej odmiany.

Jodek potasu był dobrym defoliantem, ale często wywoływał uszkodzenia kory, pąków i wyraźnie obniżał mrozoodporność jednorocznych drzewek. Związek ten prawdopodobnie będzie można stosować w niższym stężeniu 0.3%, nie wcześniej niż w trzeciej dekadzie września, do defoliacji drzewek dwuletnich.

Siarczan miedzi w stężeniu 2% dobrze defoliował drzewka dwuletnie wszystkich odmian oraz jednoroczne drzewka Oliwki Żółtej. Mało wpływał na mrozoodporność z wyjątkiem jednorocznych drzewek odmiany McIntosh i Jonatan.

Defoliacja ręczna stosowana w drugiej i trzeciej dekadzie września często obniżała odporność na mróz, ale zastosowana 7 października nie wpłynęła istotnie na mrozoodporność. Wszystkie trzy wymienione defolianty można stosować w praktyce jednak w bardzo ograniczonym zakresie i tylko dla drzewek dwuletnich. Sprawa defoliacji drzewek jednorocznych jest jeszcze nie rozwiązana ze względu na to, że badane defolianty często obniżały ich mrozoodporność.

Stosowane defolianty w większości przypadków nie osłabiały w sposób istotny wzrostu drzewek. W kilku przypadkach obserwowano jednak słabszy wzrost drzewek defoliowanych jodkiem potasu w połowie września.