Europ.J.Hort.Sci., **68** (3). S. 101–107, 2003, ISSN 1611-4426.

Efficient Use of Prohexadione-Ca in Pome Fruits

W. Rademacher and R. Kober
(BASF Agricultural Center, Limburgerhof, Germany)

Summary

Prohexadione-Ca is a new, multi-functional plant bioregulator for use in pome fruits. In addition to regulating vegetative growth and improving fruit set, the compound reduces the incidence of shoot fire blight and other diseases. Complete absorption of the active ingredient is of great importance for the efficient use of products containing prohexadione-Ca. This can be advanced by using calcium-binding and acidifying adjuvants and by taking care that a long-lasting liquid film remains on treated shoots. Intensity of shoot growth should be under control from its beginning with dosages, which have to be adjusted according to expected shoot vigour.

Zusammenfassung

Effizienter Einsatz von Prohexadion-Ca in Kernobst. Prohexadion-Ca ist ein neuer, multifunktioneller Bioregulator für Kernobst. Mit dem Wirkstoff lässt sich das Triebwachstum regulieren und der Fruchtansatz verbessern. Zugleich wird eine Wirkung gegen Triebinfektionen durch Feuerbrand und gegen andere Pathogene erzielt. Für einen effizienten Einsatz von Prohexadion-Ca-haltigen Produkten ist eine möglichst vollständige Wirkstoffaufnahme von großer Bedeutung. Dies kann durch die Verwendung von Calcium-bindenden und säurewirksamen Adjuvantien sowie durch einen lang anhaltenden flüssigen Belag auf den behandelten Trieben gefördert werden. Die Intensität des Triebwachstums sollte von Beginn an kontrolliert werden. Die dafür benötigten Aufwandmengen sind von der erwarteten Triebkraft abhängig.

Key words. adjuvants – benefits – dosage – formulation – *Malus* – *Pyrus* – timing – uptake

Introduction

Prohexadione-Ca (ProCa) is currently being introduced in a number of countries as a plant bioregulator for pome fruits. Several contributions are available dealing primarily with its effect on vegetative growth and fruit formation (Evans et al. 1997; Byers and Yoder 1999; Greene 1999; Owens and Stover 1999; Unrath 1999; Basak and Rademacher 2000; Elfving et al. 2002; Lafer and Schröder 2003; Schröder et al. 2003). Surprisingly, shoots of trees treated with ProCa turned out to be less infected by fire blight, which opened new ways for controlling this serious bacterial disease (Winkler 1997; Fernando and Jones 1999; Momol et al. 1999; Yoder et al. 1999; Costa et al. 2001, 2002; Yoder 2001; Aldwinckle et al. 2002; Bubán et al. 2002; Deckers and Schoofs 2002; Maxson and Jones 2002). Recent reports indicate that the incidence of insect pests is also reduced (Krawczyk and Greene 2002; Leahy et al. 2002). Registration of ProCa in stone fruits, citrus and other fruit trees is presently underway or under evaluation. Further uses are in arable crops and include reduction of stem length and, hence, lessened risk of lodging in rice, small grains and grass grown for seed and control of vegetative growth in groundnuts. The toxicological and ecotoxicological features of ProCa are very favourable. The compound degrades relatively rapidly after application, and there is no risk of carry-over or bioaccumulation. Two different formulations are commercially available for use in fruit trees: REGALIS® (wettable granular with 10 % of ProCa – sold in Europe and other countries) and APOGEE® (wettable granular with 27.5 % of ProCa – sold in North America). The true active ingredient of both products is the free acid prohexadione, which, due to its lack of stability, is rather unsuitable for being contained in products. Instead, its stable calcium salt is used and prohexadione is generated only upon preparing an aqueous spray solution (details given below). In spite of this, the term ProCa will generally be used in this article.

The structure of prohexadione is closely related to 2-oxoglutaric acid and ascorbic acid (Fig. 1). This explains why the three different biochemical targets are dioxygenases, which require these compounds as co-substrates (for more details see Rademacher 2000):

- Reduction of longitudinal shoot growth is the most obvious effect caused by ProCa. This is achieved by blocking 2-oxoglutaric acid-dependent dioxygenases involved in the biosynthesis of gibberellins (GAs). Since GAs are of paramount importance for cell elongation, shoot growth is restricted at reduced levels of growth-active GAs. In most plant species, GA_{20}-3ß-hydroxylase is the most important target enzyme. This dioxygenase catalyses primarily the conversion of inactive GA_{20} into highly active GA_1. Related enzymatic steps, e.g. the one involving GA_1-2ß-hydroxylase (inactivation of GA_1 into GA_8)

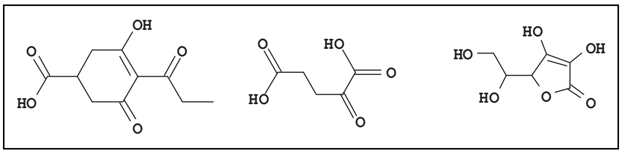

Fig. 1 Structures of prohexadione (free acid), 2-oxoglutaric acid, and ascorbic acid (from left to right).

may also be affected, although at a lesser degree of activity. One should note that inhibition of 2ß-hydroxylation might, paradoxically, lead to increases in shoot growth, since endogenous active GAs may be protected from being metabolically inactivated. Likewise, the inactivation of exogenously applied GAs (e.g. GA_1 or GA_4) by 2ß-hydroxylation can be inhibited by simultaneous treatment with ProCa, which would result in increased GA activity.

- Ethylene is generated from aminocyclopropanecarboxylic acid (ACC) in a reaction catalysed by ACC oxidase. This is a dioxygenase that requires ascorbic acid as a co-substrate and prohexadione is also inhibitory to this enzyme. Ethylene is involved in a number of developmental processes in higher plants. With regard to fruit trees, some prominent functions comprise leaf and fruit abscission, fruit ripening, but also the induction of flower buds. Reduced abortion of young fruits is often observed as a consequence of ProCa applications. Particularly in pears, overdosages of ProCa may lead to decreases in flower bud induction. Both effects appear to be at least partly resulting from lowered ethylene levels.
- 2-Oxoglutaric acid-dependent dioxygenases, in particular flavanon 3-hydroxylase, involved in the biosynthesis of flavonoids are also inhibited by ProCa. Distinct flavonoids function as phytoalexins. Reduced incidence of fire blight and other bacterial and fungal diseases in plants treated with ProCa can obviously be explained by modified flavonoid metabolism. In-depth information on this aspect is given in other contributions contained in this volume.

Because of the multiple biochemical effects, a range of benefits may result when fruit trees are treated with ProCa (Table 1). The effects on the different biochemical targets are not necessarily tied to each other. However, under practical conditions it is difficult to keep them separate. Furthermore, the overall result will be of relevance to the grower. Like other plant bioregulators, prohexadione has to enter the target cells of treated plants prior to becoming active. This process may be affected by a number of factors, which have to be regarded in order to apply REGALIS® or APOGEE® in the most efficient way. Timing and dosaging also require more attention as compared, for instance, to fungicides or insecticides. Using the multi-facetted ProCa in perennial crops, such as pome fruits, is a highly complex undertaking, which requires above-average knowledge and expertise. Summarising several years of experience, this contribution deals with distinct parameters, which may be crucial for a successful use of ProCa in pome fruits. The practical advice is addressed for using ProCa simultaneously as a plant growth regulator and for the control of shoot fire blight, since there is almost complete overlapping.

Preparing the spray solution

In order to apply ProCa in the most efficient way, some prerequisites have to be regarded when preparing the spray solution: The solubility of ProCa in water is comparatively low (at 20 °C: 174 mg L^{-1} in double-distilled water; 786 mg L^{-1} in pH 7.0 buffer; 1,602 mg L^{-1} in pH 5.0 buffer). Furthermore, prohexadione, the free acid form, is required for activity. The free acid is also much more soluble in water. In order to obtain optimal results with ProCa, a sophisticated formulation and, in certain cases, the use of appropriate adjuvants are, therefore, of great relevance. Similarities with bioregulators possessing related physicochemical properties (e.g. 1-naphthylacetic acid or GAs) are obvious (Schönherr et al. 2000).

Table 1. Potential benefits resulting from the use of ProCa in pome fruit trees

Impact on vegetative tree management
• Reduced need for dormant pruning.
• Typically no need for summer pruning.
• Possibility for tree shaping and training by directed sprays.
• Reduction of excessive shoot growth after partial or total loss of fruits (e.g. after late frost or hail).
Impact on crop protection
• Reduced tree row volume at a more open canopy enables more efficient use of fungicides and insecticides (less leaf surface; improved spray penetration). Trees dry more rapidly after rainfall, which reduces the risk of fungal infection.
• Earlier bud set makes trees less vulnerable to fungal infections and insect attacks.
• Induction of resistance against fire blight.
• Induced resistance against scab, powdery mildew and other fungal pathogens assists fungicide performance.
Impact on fruit yield and quality
• Often increased fruit set and yield.
• Typically no need for summer pruning. Therefore less risk of "sunburn" on fruits resulting from abrupt removal of shading shoots.
• A more open canopy allows higher light intensities in the inner parts of the canopy. Particularly in large trees improved fruit coloration may result.
• Often improved storage behaviour.

Binding the calcium contained in prohexadione-Ca.

In order to bind calcium from ProCa, the main component both of APOGEE® and REGALIS® is ammonium sulphate comprising 56 and 59 %, respectively. When dissolving the products in water, calcium will be bound as calcium sulphate (gypsum). The amount of ammonium sulphate contained is fully sufficient for this process in both products.

Binding or chelating the calcium contained in water.

The ratio of active ingredient to ammonium sulphate in APOGEE® and REGALIS® is approximately 1:2 and 1:6, respectively. Hence, after binding the calcium from ProCa, there is less excess of ammonium sulphate in APOGEE® than in REGALIS®. This fact is of relevance when taking into consideration that significant amounts of calcium may also be contained in the water used for preparing the spray solution. Therefore, it is generally recommended to add one to two kilograms of spray-grade ammonium sulphate to one thousand litres of water when working with APOGEE®. This may be dispensable only when soft water (e.g. rain water) is available. REGALIS® contains a significantly larger surplus of ammonium sulphate. Therefore, additional quantities are only required when hard or very hard water with more than approximately 150 mg L^{-1} of calcium is in use. The impact of very hard water on the solubility of both products is demonstrated in Fig. 2. Adding of ammonium sulphate also makes sense when relatively low amounts of REGALIS® are dissolved in large volumes of water. Under such circumstances, the relatively small amounts of ammonium sulphate present may no longer be sufficient to adequately bind calcium even from moderately soft water. Calcium can also be bound, for instance, as citrate or by chelating with EDTA. – Water hardness may be defined differently in different countries. In order to facilitate comparison, the most important units and their definitions are given in Table 2. From the foregoing it also becomes clear that neither REGALIS® nor APOGEE® must ever be co-applied with $CaCl_2$ or other calcium preparations used, for instance, against bitter pit. This could completely eliminate the activity of the products. Two to three days time distance between the treatments would solve the problem. Table 3 exemplifies the effects of ammonium sulphate, Na_2-EDTA, and calcium chloride on the bioavailability and the performance of non-formulated ProCa in seedlings of wheat and oilseed rape. These data are in line with results obtained in apple trees under orchard conditions (Byers et al. 2003).

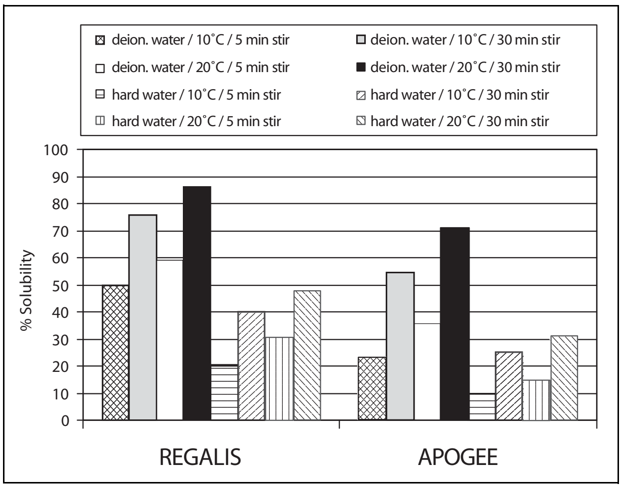

Fig. 2 Percent solubility of 250 mg L^{-1} of ProCa in water as affected by formulation, water hardness, water temperature, and stirring time. (Deionised water and WHO standard hard water with 342 mg L^{-1} calcium carbonate have been used.)

Increasing uptake velocity by acidification.

The pK_a of prohexadione in water at 20 °C is 5.15. Hence, according to the pH of its solution, prohexadione will be present primarily dissociated at slightly acidic to alkaline pH or primarily non-dissociated at a pH less than 5.15. Only the non-dissociated form may readily permeate membranes and reach its cellular target. As with other weak organic acids (e.g. GAs or naphthyl acetic acid), the velocity and intensity of prohexadione's uptake is, therefore, much facilitated by moderately acidic conditions (pH approximately 4.0 to 5.5). It is worth noting in this context that, once having entered the plant's cytoplasm, prohexadione becomes primarily dissociated since the pH here is slightly alkaline. As a result of this "ion trap mechanism", any backward flow of prohexadione is significantly impeded. Velocity and intensity of uptake of prohexadione may be of particular relevance at unfavourable weather conditions (e.g. rapid drying of liquid film after spraying or risk of rainfall). Table 3 shows the effects of citric and phosphoric acid on the biological performance and rainfastness of non-formulated ProCa as indicated by reduced shoot growth of wheat and oilseed rape seedlings, which have been used as model plants. Clear improvements are achieved if the pH of the spray solution is kept below approximately 5.0, where prohexadione is non-dissociated to a large extent. Further, calcium is bound by the acid's anions (e.g. as citrate), which would also be beneficial. Na_2-EDTA may have led to improved biological performance both by its acidifying and chelating effect. If REGALIS® or APOGEE® are applied without using acidifying adjuvants, rainfastness is achieved after approximately four to eight hours. This time span can be reduced to approximately two hours if an appropriately acidic spray solution is being used. A number of acidifying adjuvants are commercially available (e.g. LI-700® – contains propionic acid and DASH® – contains oleic acid). Where allowed, citric acid may also be used. Losses of activity have been reported if ProCa is applied tank-mixed with Solubor® (Byers et al. 2003). One may assume that this is due to the alkaline reaction caused by the boron preparation.

Other adjuvants.

Positive effects have been achieved (particularly under warm and dry application conditions) if leaf fertilisers containing nitrogen as urea, ammonium and nitrate (UAN) were co-applied with ProCa (e.g. Jordan et al. 2000). Glycerol, too, has been found to improve the

Table 2. Descriptions of water hardness and definitions of different national degrees.

Description of Water Quality	Water Hardness as [mg L^{-1} calcium carbonate]	Water Hardness as [mg L^{-1} calcium]	Water Hardness as [mol L^{-1} calcium]
Soft	0–50	0–20	0–0.5
Moderately soft	50–100	20–40	0.5–1.0
Slightly hard	100–150	40–60	1.0–1.5
Moderately hard	150–200	60–80	1.5–2.0
Hard	200–300	80–120	2.0–3.0
Very hard	>300	>120	>3.0

National degrees of water hardness:

100 mg L^{-1} (as calcium)	x	0.175	=	17.5 English (Clarke) degrees [°e]
100 mg L^{-1} (as calcium)	x	0.14	=	14.0 German degrees [°dH]
100 mg L^{-1} (as calcium)	x	0.25	=	25.0 French degrees [°f]

Table 3. Effect of non-formulated ProCa plus different adjuvants on shoot growth and rainfastness in seedlings of barley and oilseed rape*.

Adjuvant	Dosage [g L^{-1}]	Resulting pH	20 mm of Artificial Rain	Shoot Length in Barley [% of Control]	Shoot Length in Oilseed Rape [% of Control]
none	0	6.0	–	77	73
none	0	6.0	+	92	85
Citric Acid	0.25	3.6	–	58	58
Citric Acid	0.25	3.6	+	65	60
Citric Acid	1	2.8	–	57	58
Citric Acid	1	2.8	+	62	58
Citric Acid	10	2.2	–	57	55
Citric Acid	10	2.2	+	60	58
H_3PO_4 (85 %)	1	2.7	–	58	57
H_3PO_4 (85 %)	1	2.7	+	61	62
$(NH_4)_2SO_4$	1	6.1	–	61	65
$(NH_4)_2SO_4$	1	6.1	+	66	72
$(NH_4)_2SO_4$	10	5.8	–	55	65
$(NH_4)_2SO_4$	10	5.8	+	60	70
NH_4Cl	1	5.8	–	73	60
NH_4Cl	1	5.8	+	78	66
NH_4Cl	10	5.0	–	60	56
NH_4Cl	10	5.0	+	65	60
Na_2-EDTA	1	4.3	–	58	66
Na_2-EDTA	1	4.3	+	60	70
$CaCl_2$	1	5.9	–	96	100
$CaCl_2$	1	5.9	+	104	98
$CaCl_2$	10	5.7	–	99	97
$CaCl_2$	10	5.7	+	102	103

*250 mg of technical-grade ProCa + 150 mg of Citowett® + the different adjuvants were dissolved in 1 L of deionised water (pH 5.2) and sprayed until run-off to the leaves of the seedlings. 20 mm of artificial rain with fine droplets was applied 60 minutes after treatment. Final shoot length was determined 14 days later, when the untreated seedlings of barley and oilseed rape had reached shoot lengths of 32.6 and 26.7 cm, respectively.

performance of ProCa in such situations. As far as is known, part of the effect of these adjuvants consists in their functioning as "humectants": Being hygroscopic, they absorb moisture from ambient air, thereby maintaining a certain liquid film on a leaf's surface even at low levels of relative humidity. Out of the resulting "smear", uptake of dissolved prohexadione is still possible. Additionally, absorption of nitrogen seems to improve the uptake of prohexadione as well. Table 3 shows that ammonium chloride has a positive effect on the performance of ProCa, which, though, is not as strong as the one of the corresponding sulphate.

Further aspects to be considered.

Solubility of ProCa in water is in the range of only several hundred milligrams per litre (see above). Therefore, losses in efficiency may result if too high concentrations are attempted. Water temperature, agitation time and the different ratios between ProCa and ammonium sulphate in REGALIS® and APOGEE® may also have an impact on dissolving the active ingredient. Results obtained under laboratory conditions are shown in Fig. 2. In the absence of adjuvants, REGALIS® gives clearly better solubility than APOGEE®, again demonstrating the importance of sufficient ammonium sulphate in relation to ProCa. One should note that soon after spraying, the temperature of the spray solution becomes identical to ambient air or leaf temperature. This will allow further solution, should there still be dispersed and non-dissolved ProCa present. Furthermore, dissolved prohexadione will be absorbed relatively rapidly, thereby lowering the concentration left in the liquid film on a leaf and enabling further solution.

Prohexadione is an inhibitor of GA biosynthesis. In apples, mixtures of GA_4 and GA_7 are widely used to reduce fruit russetting. GA_3 is often used to induce parthenocarpic fruit formation in pears. It is highly unlikely that REGALIS® or APOGEE® will have a negative impact on the performance of the GAs when applied at the same time. However, the GAs, in particular GA_3, may counteract reduction of shoot growth. Therefore, separate treatment with a time distance of two to three days is recommended. No problems are expected if REGALIS® or APOGEE® are tank-mixed with fungicides or insecticides typically used in apple and pear production. – A summary of the main aspects to observe when preparing a spray solution is given in Table 4.

with a relatively high volume of liquid (approximately 300–400 litres per hectare and metre of crown height). A long-lasting liquid film allows efficient uptake of the active ingredient into the leaves. Applying sprays early in the evening or early in the morning, when there is less evaporation, further supports this process. Dew formation may also be employed. Favourable growth conditions at the time of and after treatment ensure the efficacy of the products as well. However, if treatments are carried out under conditions of high evaporative demand (e.g. early in the afternoon at comparatively high temperatures and low relative humidity) significant losses in activity may result. Table 5 gives a summary of the main aspects to be observed for efficient application.

Rates and timing

Reducing shoot growth by 40 to 60 % is the target. Dosages must be adjusted to the expected growth intensity of the trees, which is a function of many parameters, such as species, variety, rootstock, age, fruit load, availability of water and nutrients, and climatic conditions. Therefore it is virtually impossible to give general recommendations and the following refers primarily to using REGALIS® in Central Europe in a standard apple orchard (M.9 used as a rootstock, adult trees with a crown height of 200–250 cm, 2,500 to 3,500 trees per hectare, adequate supply of water and nutrients). The maximum dosage of REGALIS® in apples is 2.5 kg of product (=250 g a.i.) per hectare and season. A splitting with two dosages of each 75 to 150 g ha^{-1} a.i. has turned out to give the best results in the majority of cases. Young trees with a high fruit load are not necessarily candidates for REGALIS® treatments (unless there is a risk of shoot fire blight).

Table 4. Recommendations for preparing spray solutions with REGALIS® or APOGEE®

- Do not exceed 250 ppm of active ingredient.
- Avoid using hard water (>100 mg L^{-1} of calcium for REGALIS®/40 mg L^{-1} of calcium for APOGEE®), add water conditioner (e.g. 0.5–2 kg of spray-grade ammonium sulphate/1000 L) if needed.
- Avoid alkaline water (pH>7.0), add acidifying agent to improve uptake (suitable pH range: 4.0–5.5).
- Try to avoid cold water (<10 °C) for making a spray solution.
- Allow sufficient time for agitation.
- Do not mix with Ca- or gibberellin-containing products (separate treatments by 2–3 days).

Table 5. Best conditions for treating trees.

- A water volume of 300–400 L ha^{-1} per metre of crown height is recommended.
- After spraying, a long-lasting liquid film on the leaves is important for complete uptake of prohexadione.
- Best weather conditions at or following treatment: cloudy skies, 17–22 °C day temperature, and high relative humidity. Make use of dew formation!
- Do not apply when there is high evaporation (warm, low relative humidity, windy).
- Best results are obtained, when weather conditions at and after treatment support intense shoot growth.

Spraying the trees

Prohexadione can enter a plant cell only in dissolved form. Therefore, as is practised with other bioregulators, REGALIS® or APOGEE® should be applied

The highest efficacy for the regulation of vegetative growth and for the control of shoot fire blight is achieved when growth is under control from the very beginning. On the other hand, a minimum of leaf surface is required for good uptake of the active ingredient when the first application is being made. The optimal time for the initial treatment is reached when two to five leaves per shoot are fully developed. At this stadium, the new shoot axis has a length of approximately 2–5 cm. Often, this growth stage corresponds with the end of flowering. – A shoot length of 10 cm should not be exceeded for the first treatment. If the first treatment is too late (e.g. at 20 cm of shoot length), elongation growth may even be stimulated. At this stage of development, relatively high levels of growth-active GAs will be endogenously present, the metabolic inactivation of which may be inhibited by ProCa.

A lower dosage (e.g. 75–100 g ha^{-1} a.i.) is recommended for the first treatment when a regular to high fruit load is expected. This will avoid increasing fruit set even further, and there will be no increased need for thinning. In contrast, a higher initial dosage (e.g. 100–150 g ha^{-1} a.i.) should be chosen if fruit set is expected to be too low (for instance after late frost flower damage or with alternating trees in the "off" year). If possible, open flowers should still be present at the time of application. Under such circumstances, fruit set and final yield may be significantly increased (LAFER and SCHRÖDER 2003). A second and, perhaps, even a third application is recommended after an interval of three to five weeks, each. Due to the relatively rapid degradation of prohexadione, such repeat treatments are of special importance to reduce the risk of re-growth at the end of the season. In most European countries a period of delay of 55 days must be observed between the final application of REGALIS® and harvest. – Table 6 summarises the recommendations for timing and dosaging in apples.

Pears lack dwarfing rootstocks comparable, for instance, with M.9 in apples. Therefore the required dosages are generally higher by some 25 to 50 %. Accordingly, higher annual dosages are registered for pears in several countries as compared to apples. As with apples, the first treatment should be applied at a few centimetres of shoot growth. Repeated applications at a time interval of three to five weeks are recommended (e.g. 4x 75 or 3x 100 g ha^{-1} of active ingredient). After treatment with REGALIS® or APOGEE®, pear trees may produce slightly less flowers in the following spring, which, though, is without negative effect on yield. However, return bloom may be reduced more severely if significant overdoses of the products had been applied.

Special hints

In pears, but also in highly vigorous apple orchards, good experience has been obtained with combining ProCa treatments and moderate root pruning (SCHRÖDER et al. 2003). This type of treatment keeps the dosage of ProCa within limits and does not run the risk of losing the crop and inducing alternate bearing if intense root pruning is followed by a period of drought.

Translocation of prohexadione in a fruit tree is almost exclusively acropetally from the lower parts of a shoot to its upper, growing parts. This enables the use of ProCa for forming the crown of a tree by treating only selected shoots. Since most of a tree's vigour is present in the upper part of the crown, it may make sense to treat this part with higher dosages of ProCa. This can be done by adjusting the nozzles of a blast sprayer accordingly or by selectively treating the upper part with a spray gun. However, at least the first treatment should cover the whole tree in order to induce sufficient resistance against fire blight.

Hail damage facilitates fire blight infection. A severe hailstorm may even cause losses of leaves and fruits, which typically leads to an intense flush of growth at the expense of inducing flower buds for the next season. Therefore, treating hail-damaged trees with ProCa will not only reduce the risk of fire blight: It will also reduce the vegetative growth reaction and the concomitant loss of flower buds on the two year old wood in apple as well as in pear trees. As a result, fruit yield in the following year can be kept in a much more normal range (T. Deckers, Royal Research Station of Gorsem, B-3800 Sint-Truiden, personal communication).

Conclusions

Products containing prohexadione-Ca offer more than "just" regulation of shoot growth and are, therefore, of considerable interest among fruit growers. Like other plant bioregulators used in fruit trees, efficient application of REGALIS® and APOGEE® is not easy. So far, no major problems have emerged in countries, in which commercialisation has already begun. However, the process of optimising usage is still ongoing and continued efforts to support and advise growers are indicated.

Table 6. Recommendations for timing and selecting rates in apples*.

- Maximum registered dosage: 250 g of a. i. per hectare and season (in most countries).
- Pre-harvest interval: 55 days (in most countries).
- The actual seasonal dose depends on the vigour of the trees. Vigour is determined by a number of parameters, e.g. rootstock, age of tree, variety, fruit load, supply of water and nutrients, climatic conditions including light intensity and day length
- In most cases, split applications should be preferred. The rate per single treatment should be between 75 and 150 g ha^{-1} a.i..
- The first is a "must" treatment and should be carried out at a shoot length of 2–5 cm (or 2–5 fully developed leaves per shoot – approximately growth stage 30–31 BBCH) (MEIER et al. 1994). Often, this timing coincides with the end of flowering (growth stage 67–69 BBCH).
- A lower dosage (75–100 g ha^{-1} a.i.) is recommended for the first treatment when a high fruit set is expected.
- A higher dosage (100–150 g ha^{-1} a.i.) is recommended for the first treatment when a low fruit set is expected. If possible, trees should still be flowering at treatment.
- A second treatment should be made 3–5 weeks after the first or when new shoot growth is expected. In some cases even a third treatment may make sense.

* dosages refer to using REGALIS® under standard conditions (see text for details)

Acknowledgements

The European Commission supported part of these investigations (QLK5-CT-1999-01583). For details see: http://www.weihenstephan.de/ob/fireblight/

References

ALDWINCKLE, H. S., M. V. BHASKARA REDDY and J. L. NORELLI 2002: Evaluation of control of fire blight infection of apple blossoms and shoots with SAR inducers, biological agents, a growth regulator, copper compounds, and other materials. Acta Horticulturae **590**, 325–331.

BASAK, A. and W. RADEMACHER 2000: Growth regulation of pome and stone fruit trees by use of prohexadione-Ca. Acta Horticulturae **514**, 41–50.

BUBÁN, T., P. SALLAI, E. OBZSUT-TRUSKOVSZKY and L. HERTELENDY 2002: Trials with applying chemical agents other than bactericides to control fire blight in pear orchards. Acta Horticulturae **590**, 263–267.

BYERS, R. E. and K. S. YODER 1999: Prohexadione-calcium inhibits apple, but not peach, tree growth, but has little influence on apple fruit thinning or quality. HortScience **34**, 1205–1209.

BYERS, R. E., D. H. CARBAUGH and L. D. COMBS 2003: Prohexadione-calcium suppression of apple tree shoot growth as affected by spray additives. HortScience (in press).

COSTA, G., C. ANDREOTTI, F. BUCCHI, E. SABATINI, C. BAZZI, S. MALAGUTI and W. RADEMACHER 2001: Prohexadione-Ca (Apogee®): Growth regulation and reduced fire blight incidence in pear. HortScience. **36**, 931–933.

COSTA, G., C. ANDREOTTI, E. SABATINI, A. M. BREGOLI, F. BUCCHI, G. SPADA and F. MAZZINI 2002: The effect of prohexadione-Ca on vegetative and cropping performance and fire blight control of pear trees. Acta Horticulturae **596**, 531–534.

DECKERS, T. and H. SCHOOFS 2002: Host susceptibility as a factor in control strategies of fire blight in European pear growing. Acta Horticulturae **590**, 127–138.

ELFVING, D. C., D. SUGAR and D. FAUBION 2002: Pear tree shoot growth patterns in relation to chemical control of vegetative growth with prohexadione-calcium (APOGEE®). Acta Horticulturae **596**, 711–716.

EVANS, R. R., J. R. EVANS and W. RADEMACHER 1997: Prohexadione calcium for suppression of vegetative growth in eastern apples. Acta Horticulturae **451**, 663–666.

FERNANDO, W. G. D. and A. L. JONES 1999: Prohexadione calcium – a tool for reducing secondary fire blight infection. Acta Horticulturae **489**, 597–600.

GREENE, D. W. 1999: Tree growth management and fruit quality of apple trees treated with prohexadione-calcium (BAS 125). HortScience **34**, 1209–1212.

JORDAN, D. L., C. W. SWANN, A. S. CULPEPPER and A. C. YORK 2000: Influence of adjuvants on peanut (*Arachis hypogaea* L.) response to prohexadione calcium. Peanut Science **27**, 30–34.

KRAWCZYK, G. and G. M. GREENE 2002: The impact of plant growth regulator Apogee on insect pest populations and fruit quality. Pennsylvania Fruit News **82**, 18–24.

LAFER, G. and M. SCHRÖDER 2003: Was kann Regalis, der neue Bioregulator im Apfelanbau. Besseres Obst **5**, 6–11.

LEAHY, K., D. GREENE and W. AUTIO 2002: Effects of gibberellin synthesis inhibition on feeding injury by potato leafhopper on apple. Fruit Notes of New England **67**, 9–12.

MAXSON, K. L. and A. L. JONES 2002: Management of fire blight with gibberellin inhibitors and SAR inducers. Acta Horticulturae **590**, 217–223.

MEIER, U., H. GRAF, H. HACK, M. HESS, W. KENNEL, R. KLOSE, D. MAPPES, D. SEIPP, R. STAUSS, J. STREIF and T. Van Den BOOM 1994: Phänologische Entwicklungsstadien des Kernobstes (*Malus domestica* Borkh. und *Pyrus communis* L.) des Steinobstes (*Prunus*-Arten), der Johannisbeere (*Ribes*-Arten) und der Erdbeere (*Fragaria* x *ananassa* Duch.): Nachrichtenblatt des Deutschen Pflanzenschutzdienstes **46**, 141–153.

MOMOL, M. T., J. D. UGINE, J. L. NORELLI and H. S. ALDWINCKLE 1999: The effect of prohexadione calcium, SAR inducers and calcium on the control of shoot blight caused by *Erwinia amylovora* on apple. Acta Horticulturae **489**, 601–605.

OWENS, C. L. and E. STOVER 1999: Vegetative growth and flowering of young apple trees in response to prohexadione-calcium. HortScience **34**, 1194–1196.

RADEMACHER, W. 2000: Growth retardants: Effects on gibberellin biosynthesis and other metabolic pathways. Annual Review of Plant Physiology and Plant Molecular Biology **51**, 501–531.

SCHOENHERR, J., P. BAUR and B. A. UHLIG 2000: Rates of cuticular penetration of 1-naphthylacetic acid (NAA) as affected by adjuvants, temperature, humidity and water quality. Plant Growth Regulation **31**, 61–74.

SCHRÖDER, M., G. BAAB and J. ZIMMER 2003: Wuchsregulierung bei Apfel – Bioregulatoren Teil 2. Obstbau **5**, 250–254.

UNRATH, C. R. 1999: Prohexadione-Ca: A promising chemical for controlling vegetative growth of apples. HortScience **34**, 1197–1200.

WINKLER, V. W. 1997: Reduced risk concept for prohexadione calcium, a vegetative growth control plant growth regulator in apples. Acta Horticulturae **451**, 667–671.

YODER, K. S., S. S. MILLER and R. E. BYERS 1999: Suppression of fireblight in apple shoots by prohexadione-calcium following experimental and natural inoculation. HortScience **34**, 1202–1204.

YODER, K. S. 2001: Suppression of fire blight of apple shoots by Apogee. The Compact Fruit Tree **34**, 50–53.

Received May 28, 2003 / Accepted June 20, 2003

Addresses of authors: Wilhelm Rademacher and Reiner Kober, BASF Agricultural Center, 67114 Limburgerhof, Germany, e-mail: wilhelm.rademacher@basf-ag.de.