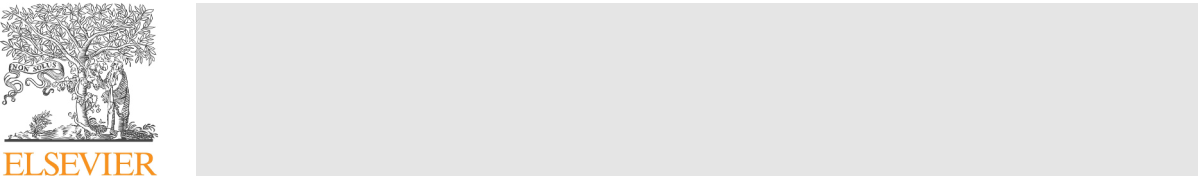
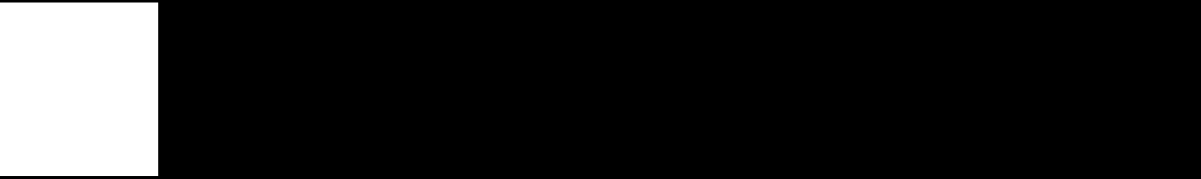
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Thinning efficacy of metamitron on young 'RoHo 3615' (Evelina®) apple T



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ABSTRACT

To achieve a high quantity of premium class fruit, chemical thinning is an important component of crop load management in apples. For this purpose, the triazine-type photosynthetic inhibitor metamitron was registered for fruit thinning in Germany. Frequent studies demonstrated consistent thinning effects of metamitron on trees of different apple and pear cultivars. In the present study, the efficacy of metamitron applied at a low con-centration (165 g ha−1) was investigated in 2016 and 2017 on young 'RoHo3615' apple trees, planted in 2014. The highest fruit set reduction was achieved when metamitron was applied twice. Single application, in contrast, led to variable results and pointed out the strong dependence of the thinning efficacy of metamitron on fa-vourable weather conditions. Adding citric acid or the growth regulator prohexadione-Ca in combination with ammonium sulphate did not affect the thinning efficacy of metamitron. The fruit quality was high in any treatment and no effects of thinning treatment on fruit colouration or percentage of skin russeting were ob-served. Consequently, metamitron is an effective fruit thinning agent for young apple trees, which can be ad-ditionally used in combination with the mentioned substances, while maintaining a high fruit quality

**1. Introduction**

Important quality attributes of apples, determining the market value, are fruit size and colouration. These parameters are positively correlated with the tree-specific leaf area to fruit ratio (Hansen, 1980; Palmer, 1992) and, consequently, with the fruit carbohydrate supply. Low carbon supply reduces fruit growth (Zibordi et al., 2009; Lakso and Goffinet, 2017) and potentially delays fruit development. The reduction of crop load increases the leaf area per fruit ratio within individual trees and thus improves the carbon supply per fruit. This, in turn, enhances fruit size and quality and is, therefore, an essential tool in fruit pro-duction. Crop load reduction can be achieved by reducing the number of flower buds per tree via pruning (Breen et al., 2015), mechanical removal of flowers (Kon et al., 2013) or by triggering fruit abscission (Bangerth, 2000), e.g. as reaction of trees to carbohydrate deficit, or by increasing the competition for carbohydrates between fruit and other sink organs ([Byers et al., 1990](#page6); [Zibordi et al., 2009](#page6)).

The triazine-type herbicide metamitron acts as photosynthesis in-hibitor and restricts the photosynthetic electron transport, affecting the photochemical efficiency and consequently the carbon assimilation of the leaves. Metamitron can be active for up to 29 d after application, depending on cultivar, applied concentration and fruit development stage (Köpcke, 2004; McArtney et al., 2012; Gonzalez et al., 2019). This



substance affects the carbon supply to demand-balance within trees, which potentially leads to a carbon supply deficit for the individual fruit. Therefore, metamitron is an effective thinning agent for apples when applied once or twice in the period from petal fall to 20 mm fruit diameter at concentrations of 150−700 g ha−1 (Köpcke, 2004; [Stern,](#page6) [2014](#page6); Gonzalez et al., 2019). However, the temperature before, during and after the application is crucial for the thinning efficacy of meta-mitron (Clever, 2018). When the carbon demand of all fruit exceeds the supply for more than 3 d, abscission of surplus fruit potentially adapts the sink demand for carbon to the actual conditions (Lakso, 2011). High temperatures, especially at night, promote fruit abscission (Kondo and Takahashi, 1987) due to increased growth rates of fruit and terminal shoots. Furthermore, high temperatures generally enhance the mi-tochondrial respiration of tree organs and, thus, the sink strength for carbohydrates. Additionally, low photon flux rates during the rapid foliage development in the early season (i.e. two to three weeks after full bloom) intensify this effect ([Lakso,](#page6) 2011).

Therefore, the susceptibility of fruit to thinning agents is highest during the initial three weeks after full bloom on warm days with low solar radiation (S) (Lakso et al., 2006). Recent reports specified the required weather conditions for effective thinning with metamitron in the period from 5 d prior to 5 d subsequent to the application as night temperatures > 10 °C and S > 16 MJ m−2 d−1 for at least 2–3 d

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(Clever, 2018). To optimally schedule the application of metamitron, warm days with low solar radiation should be forecasted. However, the prediction of the efficacy of fruit abscission as a response to the thin-ning treatment from measured temperature and solar radiation is cur-rently not possible, because it has not yet been related to accumulated heat units or photothermal units. So far, to quantify fruit abscission, manual measurements of the growth of individual fruit are necessary to predict thinning response, because those fruit going to abscise will terminate their growth ([Greene et al., 2013](#page6)).

In 2016, metamitron was registered as fruit thinning agent for ap-ples and pears in Germany at concentrations between 165 g ha−1 – 330 g ha−1. The application recommendations of the product advise not to apply metamitron for thinning of apples and pears in orchards younger than 4–5 years and 7–8 years, respectively. However, both young and mature trees require crop load management to balance the generative and vegetative growth and to ensure flower bud develop-ment for the subsequent year. To avoid disproportionate or un-predictable effects, the lowest concentrations of metamitron re-commended by the manufacturer for mature trees should be used on young trees, also, due to economic considerations. The compatibility of metamitron with other compounds in one tank-mix has not been suf-ficiently investigated or the findings have not been published, and, therefore, results are limited to studies with metamitron in combination with surfactants (Köpcke, 2004). No agent, so far, has been identified to increase or reduce the thinning efficacy of metamitron. In practice, knowledge on compatibility of metamitron with other compounds, applied to apple trees in the same period, would be beneficial in order to reduce the frequency of single applications in orchards, to potentially increase thinning efficacy of metamitron, to reduce the risk of over-thinning and to avoid adverse effects.

The aim of the present study was to evaluate (i) the optimal timing for the application of a low concentration of metamitron on young trees of the apple cultivar 'RoHo3615', and, (ii), whether additives can in-fluence the thinning efficacy of metamitron.

**2. Materials and methods**

Two field trials were carried out in 2016 and 2017 on trees of*Malus* x *domestica* BORKH. 'RoHo 3615'/M.9 (a red mutant of 'Pinova'; Evelina®) planted in 2014 in a sandy loam soil at the Saxon State Office for Environment, Agriculture and Geology research orchard (51.003919 N, 13.887303 E) in Dresden, Germany. Trees were trained as a slender spindle with a spacing of 3.2 m × 1.0 m. The orchard was managed according to the federal regulations of integrated production. The trial was arranged in randomised blocks with four replications of five-tree plots per treatment. To minimise the variance between the trees, those with a similar numbers of flower clusters (FC) were pre-selected (2016: 165 ± 29 FC; 2017: 149 ± 18 FC). Flower clusters per tree were counted manually and the variance analysed at confidence level = 5 %. Full bloom was on 03.05.2016 and 27.04.2017. Metamitron at 165 g ha−1 (Brevis, Adama Deutschland GmbH, Köln, Germany) was applied with a tunnel sprayer (TSG NO1, Lipco, Sasbach, Germany), using a water volume of 500 L ha−1, twice, at D = 8 mm and 12 mm; once at D = 8 mm; once at D = 12 mm; once in tank-mix with 106 g ha−1 prohexadione-Ca and 563 g ha−1 ammonium sulphate (Regalis®Plus, BASF SE, Ludwigshafen, Germany); once at D = 8 mm in tank-mix with 500 g ha−1 citric acid. Furthermore, 150 g ha−1 6-ben-zyladenine (6-BA; Exilis®, Fine Agrochemicals Ltd., Worcester, UK) was applied at D = 8 mm for comparison while the controls remained un-treated. The applications were carried out 16 d after full bloom (DAFB), 24 DAFB in 2016 (D = 8 mm: 19.05.; D =12 mm: 27.05.) and 23 DAFB, 31 DAFB in 2017 (D =8 mm: 17.05.; D =12 mm: 25.05.). The tem-perature at 2 m height and solar radiation, S, were recorded in 1 h in-tervals in the periods from 5 d prior to 5 d subsequent to the applica-tions with a PT100 temperature sensor and a pyranometer, in the spectral range from 350 nm to 1100 nm, attached to a weather station

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(TOSS GmbH, Potsdam, Germany) located in the same orchard. From the hourly temperature (TH), the accumulated growing degree hours (GDHTB) in the periods 5 d prior, 5 d after and ± 5 d from each ap-plication, were calculated (Eqn. 1); TU is the optimum temperature for growth and TB the base temperature, which were set to 25 °C and 10 °C, respectively (Anderson et al., 1986). The average temperatures at night (Tnight) and day (Tday) were calculated, considering the hours when S was = 0 and > 0, respectively. The average daily integral of S, Sdaily, in the same periods was expressed in [MJ m−2 d−1].

|  |  |  |  |
| --- | --- | --- | --- |
| GDHTB *=* | hn | (TU - TB) - 2 · (1 *+* cos ( *+* · (TH - TB ) · (TU - TB) - 1)) (1) |  |
| i*=*h1 |  |



In 2016 at 20 DAFB, 24 DAFB, 30 DAFB, the actual quantum yield of linear electron transport through PSII (ϕPSII; ((Fm' – Ft) ⋅ Fm'−1) was measured around noon on 5 exposed spur leaves per treatment in 1.2 m height under ambient daylight conditions, using a portable chlorophyll fluorometer (JUNIOR-PAM, H. Walz GmbH, Effeltrich, Germany). Fm' is the maximum fluorescence signal, obtained after a saturating light pulse, while Ft denotes the terminal steady state fluorescence signal at the ambient light conditions (Matyssek and Herppich, 2019). Rates of photosynthetic electron transport through PSII, JF [μmol m−2 s−1], were estimated (Eqn. [2](#page2); c.f. Herppich et al., 1998) as

|  |  |
| --- | --- |
| JF = ϕPSII · PPFR · La · f | (2) |

The photosynthetic photon flux rates, PPFR [μmol m−2 s−1], were estimated by multiplying ambient S, Sa [W m−2], with the conversion factor 4.57 (McCree, 1972). The fraction of photons absorbed by leaves, La, and the light distribution factor, f, between PS I and PS II were set to 0.85 (Palmer, 1977) and 0.5, respectively. The average reduction in JF in comparison to the control, JF; RD [%], was calculated as (Eqn. 3)

|  |  |
| --- | --- |
| JF; RD = 100 - (meanJF, treatment · meanJF, control−1 · 100) | (3) |

After physiological fruit drop, all trees were hand thinned to one or two fruit per cluster and the number of removed fruit per tree, HTF [fruit tree−1], recorded (20.06.2016; 30.06.2017). The fruit set after physiological fruit drop, FS [fruit cluster−1], and the thinning efficacy of the different treatments in comparison to the control, Eff [%], were determined for every tree (Eqs. 4, 5).

|  |  |
| --- | --- |
| FS = (F + HTF) · FC−1 | (4) |
| Eff = 100 – (FStreatment · meanFScontrol−1 · 100) | (5) |

All fruit were harvested when a starch index [1–10] of 5 (Zude-Sasse et al., 2000) was achieved (29.09.2016, 27.09.2017). The harvested fruit of each individual tree, F [fruit tree−1], were size and colour graded and the fresh mass, FM [g], of the individual fruit determined with a commercial grading machine (Vision, Aweta, Pijnacker, The Netherlands). In 2016, subsamples of 100 randomly selected fruit per treatment were manually assessed for the percentage of skin russeting on the fruit surface. To assess the effect of the thinning treatments on the flower clusters per tree in the subsequent year, FCyr+1, FCyr+1 was counted before flowering (2017: -13 DAFB; 2018: -10 DAFB).

The variances of F, FC, FCyr+1, FM, FS, JF, percentage of yield with > 60 % red skin, percentage of russeting on fruit surface and yield between the different treatments (confidence level = 5 %) were ana-lysed with the software R (Version 3.4.1; R Core Team, 2018) using the package userfriendlyscience (Peters, 2018).

**3. Results and discussion**

*3.1. Weather conditions in the period 5 d prior to 5 d subsequent to the application*

In 2016, the minimum requirements for successful thinning with metamitron (Clever, 2018) were exceeded in the periods ± 5 d of both applications (Table 1). Both, the night temperatures and the

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**Table 1**

Time of application of thinning treatments and average temperatures at night and day (Tnight, Tday,), average daily integral of solar radiation (Sdaily) and accumulated growing degree hours on base of 10 °C (GDH10°C) in the period from 5 d prior to 5d after thinning applications.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Time of application | Period | Tnight [°C] | Tday [°C] | Sdaily [MJ m-2 d-1] | GDH10°C |  |
| 2016 | 8 mm, | 5 d prior application | 7.9 | 11.7 | 13.4 | 285 |  |
|  | 16 DAFB | 5 d after application | 14.0 | 19.8 | 16.3 | 997 |  |
|  | 12 mm, | application ± 5 d | 11.1 | 15.6 | 14.6 | 1282 |  |
|  | 5 d prior application | 14.4 | 18.7 | 14.4 | 909 |  |
|  | 24 DAFB | 5 d after application | 15.4 | 20.7 | 15.1 | 1132 |  |
| 2017 | 8 mm, | application ± 5 d | 14.9 | 19.7 | 14.6 | 2040 |  |
| 5 d prior application | 12.3 | 20.2 | 19.7 | 872 |  |
|  | 23 DAFB | 5 d after application | 14.3 | 18.0 | 20.4 | 1011 |  |
|  | 12 mm, | application ± 5 d | 13.3 | 19.5 | 19.9 | 1884 |  |
|  | 5 d prior application | 10.7 | 16.6 | 18.2 | 703 |  |
|  | 31 DAFB | 5 d after application | 15.4 | 21.3 | 23 | 1232 |  |
|  |  | application ± 5 d | 13.5 | 19.9 | 20.6 | 1935 |  |
|  |  |  |  |  |  |  |  |

accumulated GDH10°C were considerably higher before the application at D = 12 mm than before that at D = 8 mm. Therefore, the weather conditions before the treatment at D = 12 mm were more beneficial for fruit thinning, which was also visible in the thinning efficacy. In 2017, the night temperatures during both thinning treatments were perma-nently above 10 °C, but solar radiation dose did not drop below 16 MJ m-2 d−1.

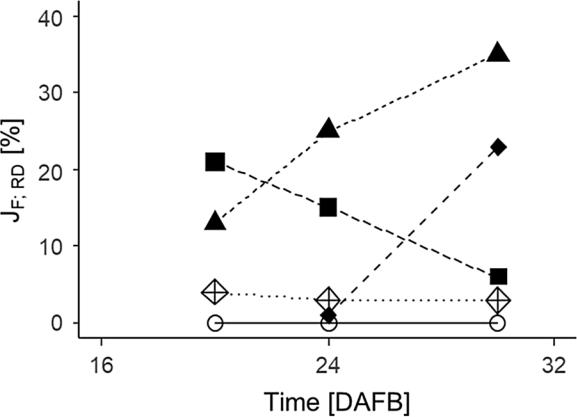
In 2017, in the period 5 d after application at D = 12 mm, GDH10°C were slightly elevated in comparison to 5 d after application at D = 8 mm. However, no difference in thinning efficacy of single application of metamitron occurred between the two application dates. Thinning efficacy of metamitron applied at D = 12 mm in 2017 was lower than thinning efficacy of the same treatment in 2016, despite GDH10°C after the application exceeded that of 2016. However, night temperature prior application at 12 mm D was elevated, and solar radiation 5 d prior and subsequent to the application was reduced in 2016 in comparison to 2017, possibly explaining the differences in thinning efficacy.

The required temperatures for effective fruit thinning with 6-BA, > 20 °C after the application (Yuan and Greene, 2000), were not achieved in both years.

*3.2. Photosynthetic performance of leaves subsequent to the metamitron application*

In 2016, photosynthetic electron transport rates, JF, were highest in control leaves at any measurement day (Table 2, Fig. 1), but were not significantly different from leaves treated with 6-BA. Four days after the first application, JF was reduced in leaves treated with metamitron if compared to the controls and leaves treated with 6-BA. The same was valid 8 d after metamitron application. On these days, chlorophyll fluorescence was measured prior to the 2nd application of metamitron. Compared to the measurements at 8 d after the 1st application, JF; RD of leaves treated once with metamitron at D = 8 mm was lower than 14 d after application. However, 14 d after application, differences in

**Fig. 1.** Relative reduction in the actual photosynthetic electron transportthrough PS II (JF; RD) of leaves (n = 5) of 'RoHo 3615′/M.9 apple trees in re-sponse to chemical thinning treatment at different dates in 2016. (Open circle = control; closed triangle = metamitron\* applied at 16 DAFB and 24 DAFB; closed square = metamitron\* applied at 16 DAFB, closed dia-mond = metamitron\* applied at 24 DAFB, open diamond =150 g ha−1 6-benzyladenine applied at 16 DAFB with 500 L ha−1 water. \*) 165 g ha−1 with 500 L ha−1 water).



comparison to untreated leaves still persisted (Table 2). Also, the standard deviation (SD) in JF was higher for leaves treated with me-tamitron in comparison to untreated leaves (Table 2). A minor decrease in SD of JF with time was observed. On leaves treated twice with me-tamitron, SD of JF was highest 14 d after the first application, likewise JF; RD , as a consequence of the additional photosynthetic inhibition, when JF was already reduced.

The results indicated that metamitron was presumably metabolised within the third week after the applications. In leaves of 'Cameo' apple trees treated with 300 g ha−1 metamitron, JF recovered to the initial

**Table 2**

Means ( ± SD; n = 5) of the actual photosynthetic electron transport rates through PS II (JF) of leaves of 'RoHo 3615'/M.9 apple trees in response to chemical thinning treatments at 18 d after full bloom (DAFB), 22 DAFB and 28 DAFB in 2016. The respective average ambient photon flux rates (PPFR) were 1800 μmol m−2 s−1, 1600 μmol m2- s−1 and 1200 μmol m−2 s−1. All treatments were applied with 500 L ha−1 water. Superscript letters indicate significant differences between means.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Treatment | Time of application | | 20 DAFB | 24 DAFB | | 30 DAFB | |  |
|  |  |  |  |  |  |  |  |  |
| Control | – | DAFB, 24 DAFB | 594 ± 10b | 479 | ± 16b | 372 | ± 16d |  |
| Metamitron1 | 16 | 519 ± 66a | 361 | ± 102a | 244 | ± 89a |  |
| Metamitron1 | 16 | DAFB | 471 ± 20a | 406 | ± 75a | 349 | ± 27bc |  |
| Metamitron1 | 24 | DAFB | – | 475 | ± 13b | 284 | ± 63a |  |
| 6-BA2 | 16 | DAFB | 572 ± 51b | 468 | ± 19b | 360 | ± 18bcd |  |
| Metamitron1, prohexadione-Ca3, (NH₄)₂SO₄ 4 | 16 | DAFB | 474 ± 37a | 402 | ± 83a | 322 | ± 19ab |  |
| Metamitron1, citric acid5 | 16 | DAFB | 509 ± 56a | 405 | ± 87a | 341 | ± 31bc |  |

1) 165 g ha−1; 2) 150 g ha−1; 3) 106 g ha−1; 4) 563 g ha−1; 5) 500 g ha−1.

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value before treatment within 5 d subsequent to the application (McArtney et al., 2012), whereas in 'Fuji' and 'Gala' apples, the period of photosynthetic inhibition, as a consequence of the treatment with me-tamitron, persisted longer than 20 d after the application ([Gonzalez](#page6) et al., 2019). Fitted curves of the relative photosynthesis inhibition demonstrated differences among cultivars (Gonzalez et al., 2019). Ad-ditionally, the phenological stage strongly affected the duration of the inhibition of photosynthesis (Köpcke, 2004). Photosynthesis remained inhibited for up to 29 d when metamitron was applied at petal fall. However, on 'Elstar' and 'Golden Delicious' trees treated with 200 g ha−1 metamitron, actual photosynthetic efficiency of the leaves fully recovered within 16 d after treatment when the agent was applied at D = 6-8 mm, similar to the findings in the presented trial.

The addition of prohexadione-Ca and ammonium sulphate or citric acid did not affect the photosynthetic electron transport in comparison to the sole application of metamitron at D = 8 mm (Table 1). This confirms earlier findings that the addition of the surfactant Polysorbate 20 did not further reduce the photosynthetic activity of treated leaves in comparison to the exclusive use of metamitron (Köpcke, 2004). The surficial absorption of metamitron by apple leaves generally enables the transport to the PS II, because 2 h after its local application the sub-stance can be located evenly distributed among the vessels of the entire leaf (Köpcke, 2004). At 6 d after the 2nd application, JF was 34 % lower than that of the controls, whereas that of leaves treated once at D = 12 mm was reduced by 23 % and, thus, similar to the results obtained by one application of metamitron at D = 8 mm (Fig. 1). An additional temperature effect on JF could not be observed, since TH at each mea-surement ranged between 22 °C and 23 °C.

*3.3. Thinning efficacy of metamitron treatments*

In both years, the reduction of fruit per tree was highest on trees treated twice with metamitron (Table 3), probably due to the length of JF reduction in comparison to that after a single application (Fig. 1). In 2016, however, differences in the thinning efficacy between the dif-ferent single applications of metamitron occurred. When applied at D = 12 mm, fruit set was reduced by 26 % in comparison to the control, which was not significantly different from the thinning efficacy at the double-application of metamitron. In contrast, fruit set was not reduced in any metamitron treatment at D = 8 mm. The stronger reduction at D

* 12 mm can be explained by the higher Tday and Tnight in the periods before and after application and slightly reduced solar radiation 5 d after application (Table 1). The phenological stage in the range from D

**TabPlease let Tab 3 appear after Tab 2le 3**

* 8 mm to D = 12 mm had no effect on the thinning efficacy of me-tamitron because no differences between both treatments occurred in the following year. In general, application of metamitron alone can be used for effective thinning of apple trees until D = 20 mm ([McArtney](#page6) [and Obermiller, 2012](#page6)). In contrast to 2016, thinning efficacy after single application of metamitron at D = 8 mm, was, indeed, higher in 2017. The results further highlighted the pronounced effect of the weather conditions on the thinning efficacy of low concentrations of metamitron. The data tendentially supposed a slight increase in the thinning efficacy when accumulated GDH10°C was increased in the days before and after the metamitron treatments ( ± 5 d).

The presented results confirm earlier finding on young 'Summerred'/M.9 apples that 165 g ha−1 metamitron given once at D = 15 mm or twice at D = 15 mm and 19 mm significantly reduced fruit set ([Maas and Meland, 2016](#page6)). However, the number of flower clusters in the subsequent year was only enhanced in comparison to the controls at double application. At 330 g ha−1 metamitron, applied once or twice, over-thinning appeared on the young trees in the above study. Double application of a low concentration (150 g ha−1) reduced fruit set of mature 'Gala' trees in a warm climate, where Tnight after application rose above 20 °C ([Stern, 2014](#page6)). In general, on mature apple trees, no or only low reduction in fruit set subsequent to the application of low concentrations (≤ 165 g ha−1) of metamitron was expected, especially when applied once (cf. [Gonzalez et al., 2019](#page6)). Despite of the young age of the trees, the canopies nearly filled out the allotted space within the rows from the third year (2016). Hence, a dosage larger than 165 g ha−1 metamitron may have been helpful to improve thinning during a single application, particular when applied at 8 mm in both years and at 12 mm in 2017. However, since the manufacturer advised not to thin young trees with metamitron, only low concentrations were applied, to avoid unpredictable thinning effects.

The addition of prohexadione-Ca and ammonium sulphate, which is often applied in commercial production to control vegetative growth of the trees, did not affect the thinning efficacy of a single application of metamitron ([Table 3](#page4)). Thus, it can potentially be added when meta-mitron is applied for fruit thinning without negative consequences. The same is valid for citric acid, which was added to metamitron to po-tentially facilitate the dissolving of the water-soluble granulate and the absorption of the substance by the leaves. As described before, the absorption of metamitron by the leaves was already sufficient. There-fore, the thinning efficacy could not be enhanced by the addition of citric acid in both years. Furthermore, application of 6-BA did not re-duce the number of fruit per tree in treated trees compared to controls,

Effect of chemical thinning treatments on fruit tree−1, fruit set (FS, fruit flower clusters−1), thinning efficacy (FS of the treatments relative tomeanFS of the controls), number of hand-thinned fruit tree−1 (HTF) and HTF per flower clusters on 'RoHo 3615'/M.9 trees in two consecutive years. Superscript letters indicate significant differences between means.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Treatment | Fruit diameter at application (mm) | Fruit tree-1 | FS | Thinning efficacy | HTF | HTF clusters−1 |  |
|  |  | after fruit drop | after fruit drop | [%] |  |  |  |
|  |  |  |  |  |  |  |  |
| 2016 |  | 173c | 1.06b | 0b | 82d | 0.51d |  |
| Control | 8, 12 |  |
| Metamitron1 | 104a | 0.74a | 30a | 34a | 0.24a |  |
| Metamitron1 | 8 | 158bc | 0.98b | 6b | 71cd | 0.44cd |  |
| Metamitron1 | 12 | 139b | 0.79a | 26a | 51b | 0.30ab |  |
| 6-BA2 | 8 | 164bc | 0.99b | 7b | 72cd | 0.43cd |  |
| Metamitron1, Prohexadione-Ca3, (NH₄)₂SO₄ 4 | 8 | 143b | 0.92b | 14b | 60bc | 0.39bc |  |
| Metamitron1, Citric acid5 | 8 | 164bc | 0.95b | 11b | 70cd | 0.41cd |  |
| 2017 |  | 204b | 1.43c | 0c | 93c | 0.64c |  |
| Control | 8, 12 |  |
| Metamitron1 | 129a | 0.83a | 40a | 36a | 0.24a |  |
| Metamitron1 | 8 | 181b | 1.19b | 14b | 73b | 0.48b |  |
| Metamitron1 | 12 | 182b | 1.23bc | 12b | 78bc | 0.53bc |  |
| 6-BA2 | 8 | 177b | 1.15b | 14bc | 73b | 0.49b |  |
| Metamitron1, Prohexadione-Ca3, (NH₄)₂SO₄ 4 | 8 | 176b | 1.28bc | 8bc | 75bc | 0.55bc |  |
| Metamitron1, Citric acid5 | 8 | 180b | 1.24bc | 11bc | 77b | 0.53bc |  |

1) 165 g ha−1; 2) 150 g ha−1; 3) 106 g ha−1; 4) 563 g ha−1; 5) 500 g ha−1.

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which was due to the unfavourable weather conditions. The thinning efficacy of 6-BA-treated trees did not differ from thinning efficacy on trees after a single application of metamitron at D = 8 mm in both years. The capacity of the trees to bear high quality fruit, named fruit bearing capacity (FBC), was estimated from the number of leaves of two randomly selected trees per year divided by 30 (2016: FBC = 90; 2017: FBC = 105). Previously, 30 leaves were reported to be necessary to achieve maximum fruit growth rates (Haller and Magness, 1933). In both years, only the double application of metamitron reduced the number of fruit per tree to nearly the FBC, whereas the natural fruit drop in the controls reduced the fruit per tree to almost double of the FBC. Knowledge of the FBC is important to define a target fruit number per tree for crop load management (CLM) and to evaluate the actual crop load at any time during the season to plan further CLM practices (Robinson et al., 2017). In practice, if the first application of metami-tron or any other chemical thinning compound did not sufficiently re-duce the crop load, a second application may be necessary. This deci-sion should be well-considered because a second application, especially after a short interval of 5 d, can also cause over-tinning of the trees as a consequence of the prolonged period of photosynthetic inhibition. Köpcke (2004) suggests the application of metamitron for thinning when the target fruit number per tree exceeds actual fruit per tree by minimum 30 %. For the estimation of fruit abscission after chemical thinning treatments, Greene et al. (2013) developed a model where the number of fruit which will abscise can be quantified from measure-ments of the diameter of random fruit 3–4 d and 7–8 d after each treatment. The model assumes that fruit, with growth rates in D ≤ 50 % of growth rates from fruit with the highest growth rates, will abscise. This model can be helpful for decision making.

*3.4. Effect of thinning treatments on the number of hand thinned fruit, fruit quality and return bloom*

After fruit drop has ended, hand thinning of surplus fruit is still an important component of crop load management. In the present trials, the number of hand-thinned fruit per tree to FBC was opposite to the thinning efficacy and, therefore, lowest when metamitron was applied twice. The crop loads in these treatments were hand-thinned below the FBC, because after the thinning treatments at some clusters more than two fruit remained, potentially leading to low fruit size. Therefore, in both years, the yield was reduced when metamitron was applied twice

compared to the controls and the other treatments (Table 4). In 2016, the number of hand-thinned fruit after a single application of meta-mitron at D = 12 mm was lower compared to a single application at D

* 8 mm and that of 6-BA. The results of the latter treatments were not different from the control. In 2017, the number of hand-thinned fruit was reduced compared to controls and similar to the 6-BA treatment, when metamitron was applied once at D = 8 mm. No differences to control was recorded for trees, treated with metamitron at D = 12 mm or with metamitron combined with prohexadione-Ca and ammonium sulphate or citric acid. The time necessary to thin one apple per hand is assumable 1.5 s. Based on this assumption, the required time to hand thin one hectare of orchard, tHT [h ha−1], can be estimated (tHT = HTF·1.5 s · tress · ha−1 · 3600−1). In 2016 and 2017, hand thinning of 1 ha in the present orchard with 3125 trees ha−1 would have required 108 h and 121 h, respectively, in the controls. The differences between both years were expected, because of differences in flower clusters per tree, magnitude of natural fruit abscission and FBC, which was slightly enhanced in 2017 in comparison to 2016, due to the progressed growth of the young trees. Nevertheless, when metamitron was applied twice, the time to hand-thin 1 ha would have been reduced to 44 h and 48 h, in 2016 and 2017 respectively. In comparison, in 2016, when metamitron was applied once at D = 12 mm, tHT would have been reduced to 67 h ha−1, which is a reduction in comparison to the controls by 62 %.

From an economical perspective, the optimum timing for a single application of metamitron at a low concentration would be generally preferred. It was demonstrated that a single application of a low con-centration can reduce fruit per tree almost as effective as a double application, with slightly enhanced tHT. In 2017, however, thinning efficacy at the single applications of metamitron was considerably lower than for the double application, because the mutual effect of high temperature and low solar radiation were not as beneficial for thinning as in 2016. Therefore, the appearance of beneficial weather conditions and a precise weather forecast are crucial for apple fruit thinning with a single application of metamitron at a low concentration.

The fruit quality was high in all treatments ([Table 4](#page5)) because of the additional hand-thinning after fruit drop. The highest percentage of fruit with diameters below 70 mm was 3.8 % on trees thinned with 6-BA in 2016. The red skin colour, which is one important quality attri-bute of 'RoHo 3615', was high in the fruit of any treatment. Metamitron did not cause skin russeting, which naturally appears in a low percen-tage around the pedicle of 'RoHo 3615'. Return bloom, expressed as

**Table 4**

Effect of chemical thinning on yield parameters and flower clusters per tree in the subsequent year, FCyr+1, of ‘RoHo 3615′/M.9 trees in two consecutive years.

Superscript letters indicate significant differences between means.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Treatment | Time of application | Fruit tree−1 at | Yield [kg] | Fresh mass | Yield > 60 % | Fruit with skin russeting | FCyr+1 |  |
|  |  | harvest |  | [g] | red skin | > 10 % of fruit surface |  |  |
|  |  |  |  |  | [%] | [%] |  |  |
|  |  |  |  |  |  |  |  |  |
| Control | 2016 | 91b | 18.3b | 203.4a | 77ab | 44a | 147a |  |
| 8 mm, 12 mm |  |
| Metamitron1 | 70a | 14.5a | 208.4a | 84ab | 49a | 161b |  |
| Metamitron1 | 8 mm | 87b | 17.5b | 200.6a | 75a | 36a | 150a |  |
| Metamitron1 | 12 mm | 86b | 17.5b | 203.0a | 78ab | 48a | 148a |  |
| 6-BA2 | 8 mm | 92b | 18.2b | 198.3a | 76a | 48a | 146a |  |
| Metamitron1, Prohexadione-Ca3, | 8 mm | 83b | 16.3ab | 198.6a | 88b | 43a | 142a |  |
| (NH₄)₂SO₄ 4 | 8 mm | 92b | 18.1b | 195.5a | 76ab | 44a | 146a |  |
| Metamitron1, Citric acid4 |  |
| Control | 2017 | 111b | 19.8b | 177.7a | 96a | – | 142bc |  |
| 8 mm, 12 mm |  |
| Metamitron1 | 91a | 17.2a | 189.6b | 96a | – | 159c |  |
| Metamitron1 | 8 mm | 108b | 19.2ab | 177.7a | 94a | – | 133ab |  |
| Metamitron1 | 12 mm | 104b | 18.6ab | 180.7ab | 97a | – | 127a |  |
| 6-BA2 | 8 mm | 104b | 18.5ab | 176.8a | 94a | – | 155c |  |
| Metamitron1, Prohexadione-Ca3, (NH₄)₂SO₄ 4 | 8 mm | 101ab | 17.9ab | 175.5a | 95a | – | 123a |  |
| Metamitron1, Citric acid5 | 8 mm | 103ab | 18.7ab | 179.6ab | 94a | – | 129ab |  |

1) 165 g ha−1; 2) 150 g ha−1; 3) 106 g ha−1; 4) 563 g ha−1; 5) 500 g ha−1.

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flower clusters per tree in the year after thinning treatment (FCyr+1), was enhanced in 2017, when in 2016 metamitron was applied twice (Table 4). In 2018, return bloom was reduced, when in 2017 metami-tron was applied once at D = 12 mm and at D = 8 mm in tank-mix with prohexadione-Ca and ammonium sulphate. Because, 'RoHo 3615' has a general low susceptibility to alternate bearing, FCyr+1 in the year after the metamitron application was, nevertheless, sufficient to achieve the FBC of the trees, assuming that each flower cluster can generate minimum one fruit at harvest (Breen et al., 2016).

**4. Conclusion**

Metamitron effectively reduced the actual photosynthetic perfor-mance (JF) of the leaves of young apple trees of the cultivar 'RoHo 3615′ at a low concentration, when applied once, for at least two weeks. However, fruit set reduction was only achieved when warm weather conditions promoted the fruit abscission in the days prior and sub-sequent to the application. The results pointed out that metamitron applied once can be used for successful fruit thinning of young 'RoHo 3615' apple trees at a low rate (165 g ha−1 ), under conditions of high night temperatures and low solar radiation during the day.

When metamitron was applied twice, JF was further reduced and the period of photosynthetic inhibition extended, leading to consistent thinning results. The combination with citric acid or prohexadione-Ca and ammonium sulphate caused similar reductions in JF as metamitron alone, without any additional effect on fruit thinning or fruit quality.

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**CRediT authorship contribution statement**

**Martin Penzel:** Software, Data curation, Validation, Writing - re-view & editing. **Christian Kröling:** Conceptualization, Project admin-istration, Resources, Supervision, Writing - review & editing.

**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influ-ence the work reported in this paper.

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