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Fruit Thinning in Organic Apple Growing with Optimised Strategies including Natural Spray Products and Rope-device

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Summary

The aim of our study was to find new thinning methods for organic apple production able to fulfil the standards of Bio Suisse, the main label organisation of the organic food sector in Switzerland.

The 15 trials reported were carried out during flowering period in the years 2003, 2004 and 2005 on the cultivars 'Pinova', 'Gala', 'Maigold', 'Elstar', 'Braeburn', 'Golden Delicious' and 'Otava' at different sites. The results confirm the good efficiency of mechanical thinning with the rope thinner and the thinning potential of vinasse, a by-product of molasses. Different vinasse products were tested (K-Vinasse, light-vinasse, N-Vinasse; NK-Vinasse) and it was observed that those containing less nitrogen had a minor thinning effect. To avoid phytotoxicity on leaves, the concentration of N-Vinasse should not exceed 10 %. It seems that for 'Gala' higher concentrations are needed, 7.5–10.0 %, whereas with 'Maigold' the efficacy of N-Vinasse was the same with the 2.5 % concentration as with 5 % and 10 %. On the other hand, partly good results were obtained when N-Vinasse was over-concentrated to 12 or 15 %, applied at warm weather and rinsed with clear water 4–6 h later to avoid the phytotoxic effect ("burn and rinse" method). Corn Oil (5 %), a commercial product from New Zealand, gave encouraging results. Lime sulphur (2 %) did not effectuate a significantly better thinning effect. The best method tested with a fruit set reduction by 62 % and 3,05 times higher flower bud set next year was achieved with a combination of rope thinner and N-Vinasse: rope thinner to thin the peripheral branches and to exert a physiological stress; and N-Vinasse to thin the inner parts of the canopy that the ropes can't reach. Other tested products did not show satisfying effects. Trials also confirmed the importance of applying these thinning agents at least two times, at the appropriate phenological stage of flowering period mainly at F[2] (full bloom) and G (= F[2] of the one-year old shoots) and in case at F (king flower open). Hitting also the flowers of the one-year old shoots is important to break bi-annual bearing. Pollen tube growth was assessed by fluorescence microscopy. Almost complete inhibition of pollen tube germination was observed with lime sulphur and over-concentrated N-Vinasse (12 %) whereas with N-Vinasse at 5 % inhibition was 50 % less compared to untreated styles. Overlooking all trials, combining N-Vinasse and rope thinner was the most efficient strategy for flower thinning. However, after our trials, its efficacy seems to depend strongly on climatic conditions and phenological stages: treatments with N-Vinasse should be carried out at warm and sunny days above 16, better 18–20 °C. to maximize desiccation on the styles; whereas the rope thinner should be applied during periods of cold and clouded weather to maximize the thinning effect due to physiological stress and shortage of assimilates to the fruitlets.

Key words. pollen – germination – vinasse – molasses – rope thinner – kitchen salt – lime sulphur – corn oil

Introduction

For apple production of high fruit quality and regular yields, crop load regulation measures are of central importance in both production systems, conventional and organic. Additionally the amount of fruit load has decisive numerous effects on the trees' vegetative, reproductive, physiological and biochemical responses (Wuensche and Ferguson 2005). In certified organic apple production the use of chemical-synthetic thinning agents or plant hormones for crop regulation is not allowed. In some countries organic growers can use lime sulphur and oil products and achieve partly satisfying thinning results – but not sufficiently regularly. In Switzerland, however, none of the mentioned products is allowed, for lime sulphur especially because of its high user toxicity. As an alternative to very laborious hand thinning, Swiss growers can use the rope thinning device (Bertschinger et al. 1998). The disadvantages of the rope thinner are damages to the shoots, a too intensive physiological stress and the insufficient thinning effect in the inner parts of the canopy where the ropes cannot reach the flower buds. By increasing the travel speed of the tractor to 9–12 km h–1, damages on shoots and leaves can be avoided (Weibel and Walther 2002); however, there is still a solution lacking to thin the inner parts of the trees. In a nutrition experiment for organic apple production using N-Vinasse (a by-product of molasses) as a foliar fertilizer, we acciden-

tally discovered that N-Vinasse has a considerable thinning effect when applied during flowering period. Thus we started preliminary thinning experiments with N-Vinasse in 2001. The advantage of N-Vinasse is that it is an already approved product in organic agriculture for plant nutrition with no adverse side effects on beneficial insects (in contrast to oils, lime sulphur or soaps). It would be very complicated to get the organic registration approval for a specific new growth regulator.

In our trials of 2003, 2004 and 2005 we aimed at developing practical recommendations for the optimal use of N-Vinasse and the rope thinner device for organic crop load regulation. In particular we wanted to attain more detailed information on:

1) Thinning effect and phytotoxic side effects of different concentrations of N-Vinasse
2) Importance of different application rates of N-Vinasse
3) Importance of different phenological stages at time of application
4) Comparison of different vinasse products to lime sulphur, corn oil, rope thinner
5) Potential of the "Burn and Rinse" approach (applying a high, phytotoxic vinasse dose to "burn" the flower organs, followed 4–6 h later by a treatment with clear water to rinse away the surplus and phytotoxically acting vinasse from the foliage).
6) Sensitivity of different cultivars to the treatments, applied at different concentrations.
7) Mode of action of the different products (inhibition of pollen tube growth and germination)

Material and Methods

The trials were carried out on the commercial organic fruit farm of family E. Vogt at Remigen in Switzerland (450 m above sea level, 9.1 °C average year temp.; 900 mm average rainfall), at the fruit experimental station of Agroscope Wädenswil at Utwil (440 m above sea level, 7.7 °C average year temp.; 920 mm average rainfall), at Conthey (482 m above sea level, 9.2 °C average year temp., 598 mm average rainfall). The detailed experimental information, number of replicates and trees per plot etc. is given in Table 1, 2 and 3. In the big plots the application of the products was made with a professional orchard sprayer (Fischer 800 H) with water amounts of 1000 to 1500 l water ha^{-1} and in the small plots with a back-pack sprayer (1700 l water ha^{-1}). The rope thinner device used is manufactured by Gessler (Friedrichshafen, Germany); it has 286 ropes on its vertical, 2.0 m high axis and was operated "as soft to the trees as possible" thus with a high tractor speed of 10–12 km h^{-1} and low revs of the rope spindle (1200 rev. min^{-1} at the power shaft equal to ca. 300 revs min^{-1} of the spindle axis) that allows the ropes to just remain in a horizontal position while sliding through the canopies.

When the treatments started, all plots showed a more than medium to high flowering intensity. Three times after the last treatment we assessed i) incidence of phytotoxic effects on leaves and fruitlets, ii) fruit set, iii) russetting on fruits. The counting of the fruit and flower set was carried out after June drop and in 2005, before and after June drop. At each tree, on 8–20 representative branches per tree , all flower clusters were counted and classified by the number of fruit they carried (0, 1, 2, ≥3), thus allowing to calculate both, the number of flower buds and the number of fruit per flower bud. Fruit set was expressed as the ratio of fruits remaining per 100 initially existing flower clusters. All times, the one-year-old shoots were counted separately from those on the older wood.

In order to assess the treatment influence on bi-annual bearing, the results of thinning efficacy were completed with a counting of the flower set in the following spring. Return bloom was assessed in the year after the thinning applications where made, as percentage of flower buds on total buds (flower and leaves).

The statistical analyses were carried out with ANOVA tests including testing the residuals for normal distribution. Where ANOVA showed significant treatment influences ($p \leq 0.05$) multiple mean comparisons were carried out with a direct, post-ANOVA Tukey test at the same error probability level (JMP v. 5.1; SAS Inc.).

To assess the mode of action of the different products, we measured in 2003 the inhibition of pollen tube growth. Therefore, just before spraying the trees and for each treatment, we had tagged 10 newly opening, thus not yet pollinated, inflorescences per tree in the small plots (50 flowers per treatment) with a coloured plastic ribbon. Five days after application we sampled the tagged inflorescences and conserved them in sodium-sulphite. To colour the styles we used 0.1 % aniline blue before autoclavation. Then petals and stamens were removed with a scalpel. In the remaining organs, style and ovary, the pollen grains and tubes could be counted under the fluorescent microscope.

Results

Trials 1 and 2; big plots 2003 to test promising methods under close to practice conditions

Considering the fruit set in the practical-like plots of both cultivars 'Pinova' and 'Otava', multi-factorial analysis revealed no cultivar effect but a significant treatment effect ($p<0.0001$) as well as an interaction between treatment and cultivar ($p=0.0009$). Thus, for the following analyses cultivars were considered separately.

With 'Pinova' (trial 1), treatments had a significant statistical effect ($p<0.0001$) and shoot age was almost a significant factor ($p=0.0584$). There was no interaction between factors. We found, compared to control trees with $\bar{x}=67\pm 4$ (SE) fruit/100 flower clusters, a significantly thinning effect of minus 25 % in trees when thinned with a rope thinner ($\bar{x}=50\pm 3$ fruit/100 flower clusters; in the following text, abbreviation "fr/100 flcl" is used) and of 40 % when the rope thinner was combined with N-Vinasse ($\bar{x}=40\pm 3$ fr/100 flcl) ($p<0.05$ with Tukey-Kramer; Fig. 1). Two applications of N-Vinasse also tended to decrease the fruit set (−12 %; $\bar{x}=59\pm 4$ fr/100 flcl) but it was not significantly different from the control trees. K-Vinasse ($\bar{x}=72\pm 3$ fr/100 flcl) had a slightly fruit-keeping (fertilising?) effect with a similar fruit set than untreated control . In this treatment the leaves were particularly green and vigorous. Trees treated only one time with N-Vinasse application did not show any difference from control trees ($\bar{x}=65\pm 4$ fr/100 flcl). When analysing one-year-old branches and older branches separately, we obtained the same treatment ranking and significance of differences (data not shown).

Table 1. Description of trials and treatments carried out in 2003. All mature trees in commercial certified organic orchards; planted between 1992 and 1999; rootstocks: M9 vt, M9 T337, M27, J-TE-E, P22; tree form: free spindle; planting distances: 0.8–1 m in row to 2.7–3.5 m between rows.

Site, Plot description	Trial no.; cultivar (trees per plot)	Trial theme 2003; products, application rate, concentration	Phenological stage at application*
Trials at Remigen			
"Big plots", 2 randomised replications per treatment (1000 l water ha^{-1}). Treated with usual turbo sprayer	(1) 'Pinova' (2 x 18) (2) 'Otava' (2 x 21)	Tests with promising methods under close to practice conditions	
		Untreated control	
		Rope thinner (2x)	F^2 and F^2_{1y}
		N-Vinasse (90 g N l^{-1}) 5 % (2x)	F^2 and F^2_{1y}
		N-Vinasse (90 g N l^{-1}) 5 % (1x)	F^2
		K-Vinasse (87 g K l^{-1}) 5 % (2x)	F^2 and F^2_{1y}
		Rope thinner (1x) + N-Vinasse 5 % (1x)	F^2 and F^2_{1y}
"Small Plots" (treated by backpack sprayer; 1700 l water ha^{-1}), no block replications of the treatments	(3) 'Pinova' (2 x 5)	Preliminary tests with new products	
		untreated control	
		N-Vinasse 12 % + rinsing after 4 h with clear water ("burn and shower") (2x)	F^2 and F^2_{1y}
		N-Vinasse 5 % (2x)	F^2 and F^2_{1y}
		K-Vinasse (87 g K l^{-1}) 5 % (2x)	F^2 and F^2_{1y}
		Light-Vinasse (30 g N l^{-1}, 30 g K l^{-1}) 5 % (2x)	F^2 and F^2_{1y}
		Formulated Corn Oil (NZ) 5 % (2x)	F^2 and F^2_{1y}
		Lime sulphur (Polisenio) 2 % (2x)	F^2 and F^2_{1y}
		Salt water 10 % (2x)[6]	F^2 and F^2_{1y}
	(4) 'Maigold' (2 x 5) (5) 'Gala' (2 x 5)	Concentration series with N-Vinasse	
		Untreated control	
		N-Vinasse 2.5 % (2x)	F^2 and F^2_{1y}
		N-Vinasse 5 % (2x)	F^2 and F^2_{1y}
		N-Vinasse 10 % (2x)	F^2 and F^2_{1y}
	(6) 'Maigold' (2 x 5)	Optimal application stage of N-Vinasse	
		untreated control	
		N-Vinasse 5 % (2x)	F and F^2
		N-Vinasse 5 % (3x)	F, F^2 and F^2_{1y}
		N-Vinasse 5 % (2x)	F^2 and F^2_{1y}
		N-Vinasse 5 % (1x)	F^2
		N-Vinasse 5 % (3x)	F^2_{1y}
Trials at Wädenswil ('Golden Delicious') and Uttwil ('Gala')			
"Small Plots" (treated by backpack sprayer; 1700 l water ha^{-1})	(7) 'Golden D.' (4 x 2) (8) 'Gala' (4 x 2)	Optimal application stage of N- and K-Vinasse	
		N-Vinasse 7.5 % (1x)	F^2
		N-Vinasse 7.5 % (2x)	F^2 and F^2_{1y}
		N-Vinasse 7.5 % (3x)	F^2 and F^2_{1y} and H
		K-Vinasse 7.5 % (1x)	F^2
		K-Vinasse 7.5 % (2x)	F^2 and F^2_{1y}

* F (king flower open); F^2 (full bloom); F^2_{1y} (F^2 1-year-old shoots); H (ending bloom)

In spring 2004 the return bloom of these 'Pinova' plots reflected, with significant differences, the thinning effect of the treatments applied in 2003: significantly highest flower set with 46.7 % flower buds on the total number of buds was found in the combined treatment rope thinner plus N-Vinasse. Also treatments N-Vinasse (2x) and rope thinner (2x) revealed elevated flower sets (44.9 % and 45.6 %). Treatment K-Vinasse 5 % applied 2 times and N-Vinasse 5 % 1 time had lowest return bloom rates 39.9 % flower buds per total buds) and did not differ significantly from untreated control (34.1 %; Fig. 2).

In the parallel trial with the same treatments on cultivar 'Otava' (trail 2) the thinning effect was also significant ($p=0.05$) and followed the similar trend but was less expressed than with 'Pinova' (51± 3 to 66±6 fruit/100 flower clusters) (data not shown).

Table 2. Description of trials and treatments carried out in 2004 and 2005. All mature trees in commercial certified organic orchards; planted between 1992 and 1999; rootstocks: M9 vt, M9 T337, M27, J-TE-E, P22; tree form: free spindle; planting distances: 0.8–1 m in row to 2.7–3.5 m between rows.

Site, Plot description	Trial no.; cultivar (trees per plot)	Trial theme 2004 and 2005; products, application rate, concentration	Phenological stage at application*
Trials at Remigen			
"Big plots", 2 randomised replications per treatment (1200 l water ha^{-1}). Treated with usual turbo sprayer	(9) 'Pinova' (2 x 18) (10) 'Elstar' (2 x 18)	Tests with promising methods under close to practice conditions	
		Untreated control	
		Rope thinner (1x)	F
		Rope thinner (1x) + N-Vinasse 5 % (1x) (90 g N l^{-1}, 20 g K l^{-1})	F and $F^2{}_{1y}$
		N-Vinasse 5 % (3x)	F, F^2 and $F^2{}_{1y}$
		N-Vinasse 5 % (2x)	F^2 and $F^2{}_{1y}$
		N-Vinasse 12 % (2x)	F^2 and $F^2{}_{1y}$
		K-Vinasse (3x) (87 g K l^{-1}, 30 g N l^{-1})	F, F^2 and $F^2{}_{1y}$
		Light-Vinasse 5 % (3x) (30 g N l^{-1}, 30 g K l^{-1})	F, F^2 and $F^2{}_{1y}$
		Corn Oil 5 % (3x)	F, F^2 and $F^2{}_{1y}$
		Lime sulphur (Polisenio) 2 % (3x)	F, F^2 and $F^2{}_{1y}$
"Small Plots" (treated by backpack sprayer; 1700 l water ha^{-1}), no block replications of the treatments	(11) 'Golden D.' (2 x 9)	Risk for russeting and preliminary tests with vinegar	
		Untreated control	
		N-Vinasse 5 % (3x)	F, F^2 and $F^2{}_{1y}$
		N-Vinasse 12 % + rinsing after 4 h with clear water ("burn and shower") (2x)	F^2 and $F^2{}_{1y}$
		Corn Oil 5 % (3x)	F, F^2 and $F^2{}_{1y}$
		Vinegar 5 % (3x) organic apple vinegar, 45 g acetic acid l^{-1}	F, F^2 and $F^2{}_{1y}$
		Vinegar 10 % (3x) organic apple vinegar, 45 g acetic acid l^{-1}	F, F^2 and $F^2{}_{1y}$
Trials at Wädenswil ('Golden Delicious') and Uttwil ('Gala')			
"Small Plots" (treated by backpack sprayer; 1700 l water ha^{-1})	(12) 'Golden D.' (4 x 2)	Optimal application stage of N- and K-Vinasse	
		N-Vinasse 5 % (1x)	F
		N-Vinasse 5 % (2x)	F and F_{1y}
		N-Vinasse 5 % (3x)	F and F_{1y} and H
		K-Vinasse 5 % (1x)	F
		K-Vinasse 5 % (2x)	F and F_{1y}
		K-Vinasse 5 % (3x)	F and F_{1y} and H
	(13) 'Gala' (4 x 2)	Optimal application stage and concentration of N-Vinasse	
		1)-3) N-Vinasse 5 %, 7.5 %, 10 % (1x)	F
		4)-6) N-Vinasse 5 %, 7.5 %, 10 % (2x)	F and F_{1y}
		7)-9) N-Vinasse 5 %, 7.5 %, 10 % (3x)	F and F_{1y} and H
Trials 2005 at Conthey (Vallis)			
"Small Plots" application by usual orchard sprayer; 1500 l water ha^{-1}	(14) 'Braeburn' (4 x 10) (15) 'Gala' (4 x 10)	Verification experiments in close to practice conditions	
		Untreated control	
		Rope thinner (1x)	E
		Rope thinner (1x) + NK-Vinasse (60 g N l^{-1}; 70 g K l^{-1}) 7.5 % (2x)	F and F^2
		NK-Vinasse 7.5 % (2x)	F, F^2 or $F^2{}_{1y}$
		NK-Vinasse 15 % + rinsing after 4 h with clear water ("burn and shower") (2 x)	F^2 or $F^2{}_{1y}$
		Corn Oil 5 % (2x)	F^2 or $F^2{}_{1y}$
		Lime sulfur 2 % (2x)	F, F^2 or $F^2{}_{1y}$

* E (red bud); F (king flower open); F^2 (full bloom); $F^2{}_{1y}$ (F^2 1-year-old shoots); H (ending bloom)

Trials 3; small plots 2003 to test new products

The different new products tested in the small plots of cultivar 'Pinova' (trial 3) revealed no significant thinning effect, except for the overdosed treatment with kitchen salt, where severe leaf burning occurred and the mean fruit set per 100 flower clusters went down to almost zero ($\bar{x}$ =7±2 fr/100 flcl). The concentration recommended was much too high (10 instead of 1 %), so that the trees almost died. K-Vinasse ($\bar{x}$ =70±2 fr/100 flcl) and the

Table 3. Flowering stage, flowering time and weather conditions at the different sites (2003–2005).

Year	Site	Trial no.	Flowering stage* –time and weather conditions
2003	Remigen	(1) to (6)	F; April 22; 20.0 °C; 0 mm rain; 29 % rel. H. F^2; April 24; 24.3 °C; 0 mm rain; 63 % rel. H. $F^2{}_{1y}$; April 28; 21.7 °C; 1.1 mm; 92 % rel. H.
	Wädenswil	(7)	F^2; April 28; 13.0 °C; 0 mm rain; 64 % rel. H. $F^2{}_{1y}$; April 30; 13.0 °C; 0 mm rain; 78 % rel. H. H; May 2; 18.0 °C; 0 mm rain; 64 % rel. H.
	Uttwil	(8)	F^2; April 28; 15.8 °C; 0 mm rain; 55 % rel. H. $F^2{}_{1y}$; May 1; 15.5 °C; 0 mm rain; 55 % rel. H. H; May 5; 21.0 °C; 0 mm rain; 47 % rel. H
2004	Remigen	(9) to (11)	F; April 30; 13.6 °C; 0 mm rain; 70 % rel. H. F^2; May 3; 14.0 °C; 0 mm rain; 68.3 % rel. H. $F^2{}_{1y}$; May10; 11.0 °C; 0 mm rain; 79 % rel. H.
	Wädenswil	(12)	F; April 30; 17.0 °C; 0 mm rain; 51 % rel. H. F^2; May 3; 12.0 °C; 0 mm rain; 59 % rel. H. $F^2{}_{1y}$; May 10; 10.8 °C; 0 mm rain; 58 % rel. H.
	Uttwil	(13)	F; April 29; 19.5 °C; 0 mm rain; 51 % rel. H. F^2; May 3; 17.0 °C; 0 mm rain; 59 % rel. H. $F^2{}_{1y}$; May 11; 16.6 °C; 0 mm rain; 58 % rel. H.
2005	Conthey (Vallis)	(14)	E; April 19; 12.0 °C; 9 mm rain; 65 % rel. H. F^2; April 29; 17.0 °C; 0 mm rain; 55 % rel. H. $F^2{}_{1y}$; May 2; 22.0 °C; 0 mm rain; 59 % rel. H.
		(15)	E; April 19; 12.0 °C; 9 mm rain; 65 % rel. H. F; April 29; 17.0 °C; 0 mm rain; 55 % rel. H. F^2; May 2; 22.0 °C; 0 mm rain; 59 % rel. H. $F^2{}_{1y}$; May 4; 16.2 °C; 3 mm rain; 58 % rel. H.

*[1] F (king flower open); F^2 (full bloom); $F^2{}_{1y}$ (F^2 1-year-old shoots); H (ending bloom)

"Burn and Rinse"-method (N-Vinasse 12 % + rinsing with water) with $\bar{x}$ =70±6 fr/100 flcl a 53 % had lower fruit set than control trees ($\bar{x}$ =148±13 fr/100 flcl). However, due to a high variation between the trees these differences were not significant (Table 4). Lime sulphur did not thin better than the other products.

Trial 6; influence of phenological stage and frequency of N-Vinasse application (2003)

In experiment 6 with cultivar 'Maigold', the treatment effect was almost significant (p=0.0505) and shoot age had a high significant effect (p<0.0001). There was no interaction between both factors. The lowest fruit set was found with 3 applications of N-Vinasse (–23 %; $\bar{x}$ =53±10 fr/100 flcl) and highest on untreated control trees ($\bar{x}$ =70±9 fr/100 flcl). There was no significant interaction between the phenological stage at application and the frequency of applications. When looking only at the young shoots, there was no significant difference between treatments either, but a tendency that young branches treated lately, at full bloom on one-year-old shoots ($F^2{}_{1y}$ stage) to have a third less fruit set ($\bar{x}$ =32±6 fr/100 flcl for treatment at F, F^2, $F^2{}_{1y}$, 40±3 for $F^2{}_{1y}$ and 41±7 for F^2, $F^2{}_{1y}$) compared to control trees ($\bar{x}$ =48±8 fr/100 flcl) and trees not treated at $F^2{}_{1y}$. When considering only old shoots, there was a significant difference between trees treated at F^2 stage ($\bar{x}$ =74±0.3 fr/100 flcl) and at $F^2{}_{1y}$ stage ($\bar{x}$ =92±8 fr/100 flcl), underlining that the N-Vinasse application acts specifically on newly opened inflorescences. Furthermore, trees treated already at these early blooming stages showed a significant lower fruit set than trees treated only lately at $F^2{}_{1y}$ stage. Return bloom followed the same trend, however with no significant treatment differences (data not shown).

Trial 4 and 5; effect of different N-Vinasse concentrations (2003)

Here, the factor concentration interacted significantly with the cultivar: With 'Gala' (trial 5), treatment and branch age had a significant effect (p=0.0332 and p=0.0018, respectively): Only trees treated with 10 % N-Vinasse had a lower fruit set ($\bar{x}$ =90±1 fr/100 flcl) than the control ($\bar{x}$ =113±21 fr/100 flcl). N-Vinasse 2.5 % had

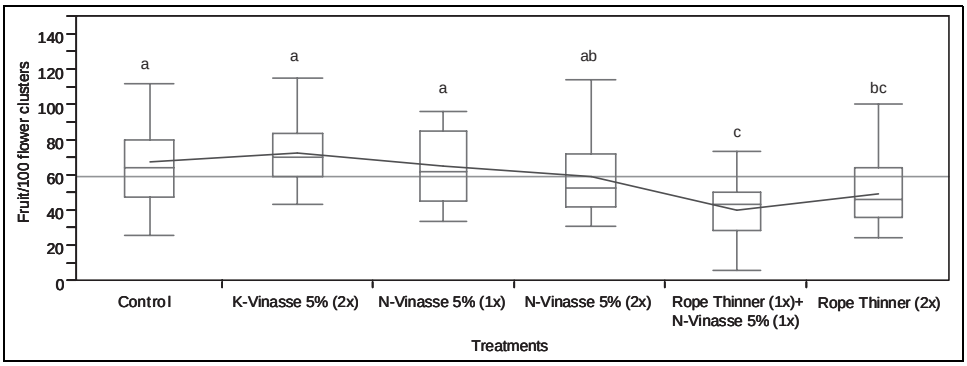


Fig. 1. Effect of 5 different thinning methods on final fruit set on cultivar 'Pinova' in the practical-like plots at Remigen 2003 (trial 1 according to Tab. 1). Box plots not marked by same letter are significantly different (post-Anova Tukey-Test; p=0.05).

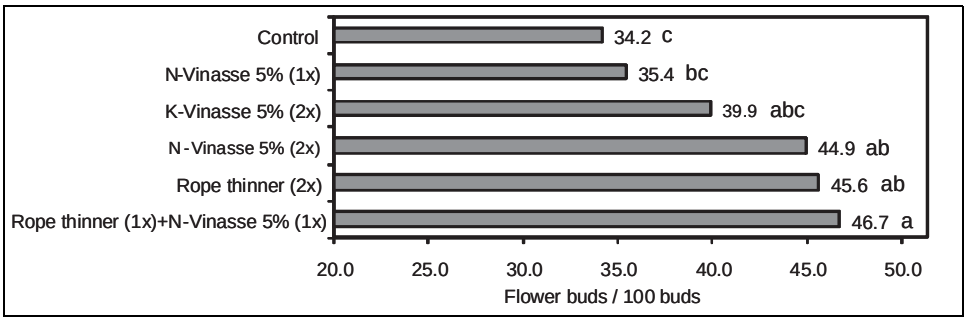


Fig. 2. Return bloom in spring 2004 with cultivar 'Pinova', practical-like plots (trial 1 according to tab. 1). Percentage of flower buds of total number of buds in 5 different thinning treatments applied in 2003. Bars not marked by same letter are significantly different (post-Anova Tukey-Test; p=0.05).

an almost fruit-keeping effect ($\bar{x}$ =155±22 fr/100 flcl), but at 5 % no difference to the control occurred (Fig. 3A). The 'Gala' trees had a higher fruit set, sometimes twice than 'Maigold' (trial 4). With 'Maigold' all three concentrations (2.5, 5 and 10 %) caused a significant but similar thinning effect with a reduction of around 23 % ($\bar{x}$ =54 fr/100 flcl) compared to untreated control (Fig. 3B). Phytotoxic reactions like burn at leaf edges increased slightly with increasing concentrations.

Trials 7 and 8; application stages with 'Golden Delicious' and 'Gala' in 2003

In the same year, parallel experiments with 'Gala' in Uttwil (trial 8) and 'Golden D.' in Wädenswil (trial 7) were carried out to test the effect of application frequency (1, 2 or 3 applications) and the difference between N- and K-Vinasse (always at 7.5 % concentration). A significant, but still insufficient thinning effect of 18 % and 24 %, respectively, could be found only on 'Gala' with treatments N-Vinasse applied 2 and 3 times. This lack of efficacy was most probably due to unfavourable low air temperatures during the applications at F and F2 (13 °C with 'Golden D.', 15 °C with 'Gala', Table 1). Also, unfavourably, the third application when it was warmer (above 18 °C) was too late in terms of the number of open inflorescences (there was rather stage H than F2 on on-year-old shoots). Consequently, only on 'Gala' and with the treatments 2 and 3 times N-Vinasse, there was a 14 % higher, thus slightly better return bloom percentage to be found compared to control (data not shown).

Table 4. PH, conductivity, thinning effect and pollen germination inhibition of the products tested on cultivar 'Pinova' at Remigen in 2003 (trial 3 according to Table 1). Means not marked by same letter are significantly different (post-Anova Tukey-Test; p=0.05).

Treatments	pH	Conductivity (mS)	Thinning effect 2003 compared to control (%)	Number of germinated pollen grains (squared)
Untreated control			0.0 a	68.3 a
N-Vinasse 5 %	4.96	14.13	21.2 a	31.2 dc
K-Vinasse 5 %	5.27	10.67	49.7 ab	56.1 ab
Light-Vinasse 5 %	4.22	9.60	9.4 a	51.7 abc
Corn Oil 5 %	7.24	1.13	17.6 a	38.8 bc
Lime sulphur 2 %	9.75	5.76	14.4 a	0.1 e
Salt 10 %	7.14	20.00	95.4 b	13.2 de
N-Vinasse 12 % + rinsing with water	4.96	14.13	49.7 ab	0.1 e

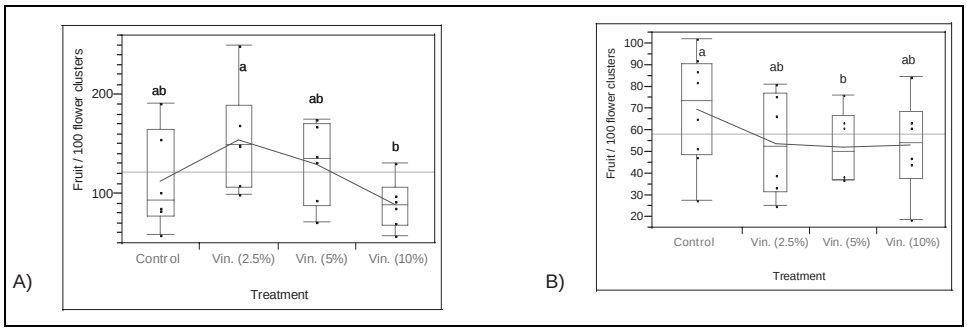


Fig. 3. Thinning effect of 3 different concentrations of N-Vinasse on A) cultivar 'Gala' and B) cultivar 'Maigold' trees (trials 4 and 5 according to Tab. 1). Box plots not marked by same letter are significantly different (post-Anova Tukey-Test; p=0.05).

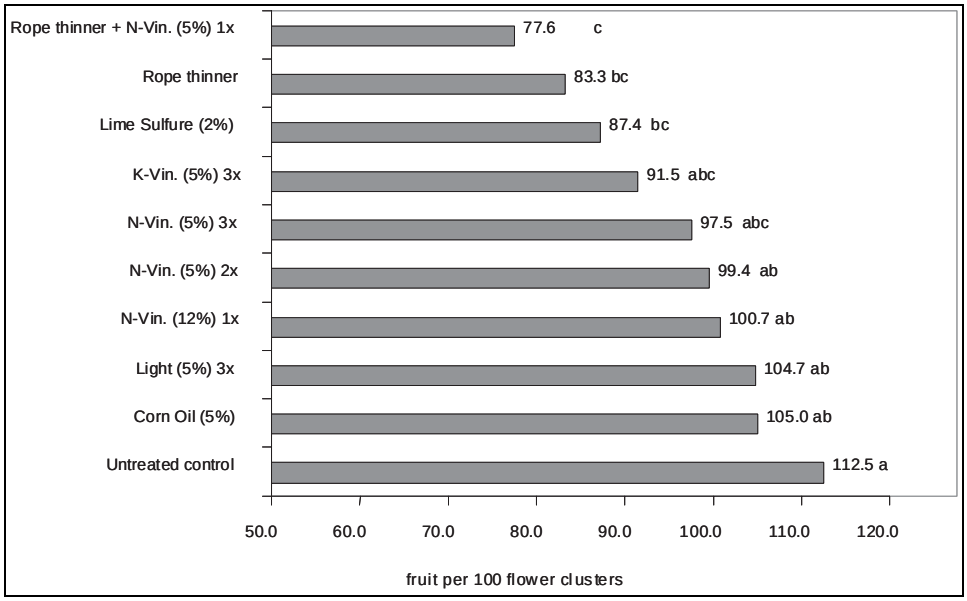


Fig. 4. Effect of 9 different thinning methods on cultivar 'Pinova' at Remigen 2004 (trial 9 according to Tab. 2). Bars not marked by same letter are significantly different (post-Anova Tukey-Test; p=0.05).

Pollen germination and pollen tube growth (2003)

The fluorescence-microscopic observations of pollen germination and pollen tube growth in the treated flower organs in trial 3 (cultivar 'Pinova') revealed significantly different modes of action of the specific thinning agents. On the stigma surface blossoms treated with lime sulphur, kitchen salt, 12 % N-Vinasse, 5 % N-Vinasse and 5 % Corn Oil all had significantly less germinated pollen grains than untreated ones, with a maximum reduction of 82 % by the ones treated with lime sulphur and 12 % N-Vinasse (Table 4). Stigma surfaces of blossoms treated with salt, lime sulphur and 12 % N-Vinasse showed a deteriorated surface.

After square root transformation of the data, the treatments with kitchen salt and lime sulphur almost completely suppressed pollen tube growth at the top third of the styles. No significant inhibition of pollen tube growth was found after one application of 5 % N-, K- and Light-Vinasse, Corn Oil and 12 % N-Vinasse+rinsing (data not shown). In contrast to that, K-Vinasse seemed to have even a positive influence with tubes being significantly more numerous than in untreated blossoms.

In the concentration experiments with 'Gala' and 'Maigold' (trials 4 and 5), we found significantly less germinated pollen on the stigma surface of 'Gala' flowers treated with 10 % N-Vinasse, but at the top third of the style, no difference was found between 10 % and the untreated control (data not shown).

The influence of the thinning agents on the pollen germination and the pollen tube growth is in good accordance with the findings on their thinning effects in the field experiments.

Trials 9 and 10; big plots with 'Pinova' and 'Elstar' in 2004 to test promising methods under practical-like conditions

In 2004 the final fruit set in the practical-like plots of both cultivars 'Pinova' (trial 9) and 'Elstar' (trial 10) was significantly influenced by factors cultivar and treatment (both $p<0.0001$). Interaction between treatment and cultivar was also significant ($p<0.0001$). Thus, the statistical data analyse was carried out separately for each cultivar.

With 'Pinova', treatments and shoot age had a highly significant effect ($p<0.0001$). We found a significantly thinning effect of 22 % in trees when thinned with a rope thinner and with lime sulphur and of 28 % when the rope thinner was combined with N-Vinasse compared with control trees ($\bar{x}$ =110.00±5.1 fr/100 flcl) (Fig. 4). The other products and methods gave similar results that were not significantly different from the control trees between 91.2 and 102.8 fr/100 flcl.

Return bloom in 2005, however, was in neither treatment different from the untreated control (53.2 % flower bud/total buds; data not shown).

With 'Elstar', the factor branch age (with $p<0.0001$) had a significant effect on fruit set but not the treatment

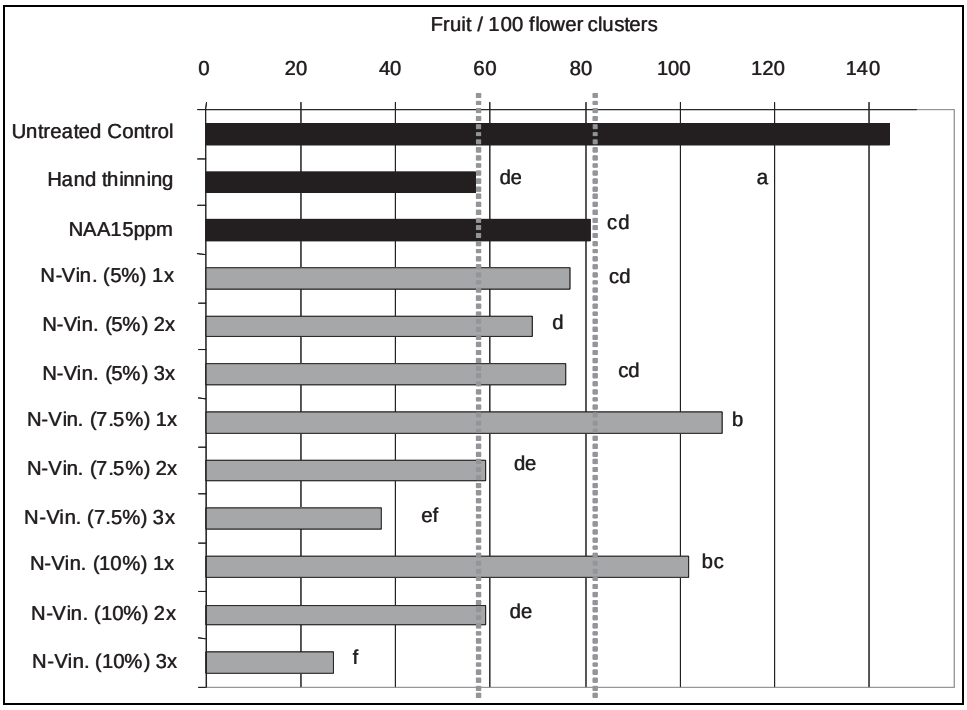


Fig. 5. Effect of different thinning treatments on final fruit set on cultivar 'Gala' at Uttwil 2004 (trial 13 according to Tab. 2). The line on the left is the reference of optimal fruit load (hand thinning), the line on the right is the fruit load achieved with the chemical standard treatment. Bars not marked by same letter are significantly different (post-Anova Tukey-Test; p=0.05).

nor the interaction between both parameters (data not shown). The treatment effect on fruit set was varying between 62.1 fruit/100 flcl for trees thinned with lime sulphur and 72.6 for trees thinned with the rope thinner. Analysing old and new branches separately did not reveal any different treatment effects, either.

Trial 11; small plots 2004 to test new products

In the trials to test new products on small plots with cultivars 'Golden D.' and 'Topaz' trees (trial 11) there were no significant treatment effects with 'Golden D.' , however with Topaz trees treated with Corn Oil carried 54 % less fruits than the control ($\bar{x}$ =197.54±12.20 fr/100 flcl). The treatments with N-Vinasse 3 times or N-Vinasse 12 % + rinsing also showed acceptable thinning effects (with around 150 fr/100 flcl). The tests with organic vinegar at 5 and 10 % concentration revealed no significant thinning effect. No phytotoxic reactions could be found in either cultivar or treatment (data not shown).

Trials 12 and 13; Confirmation experiments on concentration effect and frequency of application in 2004

Parallel trials were carried out at Uttwil (trial 13) with 'Gala' and at Wädenswil with 'Golden D.' (trial 12) to confirm the influence of frequency (1, 2, 3 times) and concentrations (5, 7.5 and 10 %) of N- and K-Vinasse. With 'Golden D.' where the applications of the second and third treatment were executed at very low temperatures below 11 °C neither the N- nor the K-Vinasse (always at 5 % concentration) induced a significant thinning effect (data not shown). With 'Gala', however, where the temperatures at and after application time were above 16.6 °C (Fig. 5) there were clear and good thinning effects with N-Vinasse, when applied at least 2 times. E.g. 2 applications at 7.5 % resulted in optimal fruit load, similar to hand thinning (50 fr/100 flcl) and were even better than the chemical standard with NAA 15 ppm (81 fr/100 flcl). In concentrations of 7.5 and 10.0 %, a 3-fold application induced overthinning (37 and 28 fr/100 flcl, respectively).

Trials 14 and 15; practical-like verification trials 2005 on 'Gala' and 'Braeburn'

Trials at Conthey carried out in 2005 served as verification trials to test the most promising methods again under close to practical conditions (big plots and commercial orchard spray equipment). At Conthey with both cultivars, best thinning effects were achieved with Corn Oil 5 % with 62.2 % less fruit set than in the untreated control (89.3 and 67.3 fr/100 flcl for 'Gala' (trial 15) and 'Braeburn' (trial 14); Table 5). Rope thinner + 2 times NK-Vinasse and Vinasse 15 % + rinsing showed effect of the same magnitude. On 'Gala' the combined treatment using the rope thinner and the Vinasse led to a significantly better thinning effect by 34.1 % in comparison to each of these methods applied alone.

The counting of return bloom in spring 2006 revealed a clear positive correlation with the thinning effect in 2005 (Table 5): On 'Gala', return bloom in 2006 with rope thinner + Vinasse was 3 times as much as untreated. On 'Braeburn', the combined treatment had, with 50 % times more flowers, a less pronounced but still significant effect. With both cultivars a similar effect on return bloom was achieved by thinning with the rope thinner alone and with Corn Oil 5 %. Neither Vinasse alone, nor – surprisingly – Vinasse + rinsing had an effect on return bloom compared to the untreated control.

Observations on side effects

In all years, field observations on negative or positive side effects of the different treatments were consistent with

Table 5. Thinning effect and return bloom of the trials at Conthey in 2005 (trials 14 and 15 according to Table 2). Means not marked by same letter are significantly different (post-Anova Tukey-Test; p=0.05).

Treatments	'Gala'		'Braeburn'	
	Fruit set 2005	Return bloom 2006	Fruit set 2005	Return bloom 2006
	(Fruit / 100 flower clusters)			
Untreated control	89.3 a	26.0 bc	67.3 a	53.3 bc
NK-Vinasse 7.5 %	72.6 ab	12.6 c	47.0 ab	41.8 c
Rope thinner	62.6 b	69.3 a	40.6 b	73.2 ab
NK-Vinasse 15 % + rinsing	56.9 bc	40.6 b	40.4 ab	52.8 bc
Rope thinner + NK-Vinasse 7.5 %	43.2 cd	78.7 a	29.6 b	80.4 a
Corn Oil 5 %	33.8 d	66.1 a	25.6 b	67.1 ab

the quantitative results. We observed small necrosis on leaf edges with N-Vinasse 12 or 15 % + rinsing and with 3 fold application of N-Vinasse. There were slight stress symptoms to observe in the lime sulphur treatments as retarded leaf and shoot growth (data not shown). With Corn Oil 5 % we discovered high phytotoxicity in the trials at Remigen on 'Pinova', to a lesser extent on 'Elstar', and no phytotox damages on 'Gala' and 'Braeburn' in the trials at Conthey. The use of the rope thinner driven at high tractor speed of 10–12 km h^{-1} and with low revs of the rope spindle caused only slight stress on leaves and shoots.

Discussion

At Remigen in 2003 and 2004, there occurred a high natural June drop which "hides" to a certain extent the thinning effect of the treatments. In this situation the counting of return to bloom is particularly important to judge the thinning treatment effect. Nevertheless, with 'Pinova' in both years the treatment effects were significant and the following methods proved a good thinning potential that has also been confirmed in the practical-like trial in 2005: i) rope device (confirming the findings of Bertschinger et al. 1998), ii) N-Vinasse when applied at least 2 times, iii) the "burn and rinse" method and iv) the combination of the rope thinner and Vinasse as presently the most efficient organic thinning method (Weibel et al. 2004). The reason for a good success of the combined method is not only the fact, that the rope thinner touches the outer and the N-Vinasse the inner part of the tree; but it also combines two complementary modes of action: i) the rope thinner triggers a physiological shock that finally leads to a shortage of assimilates in the fruitlets and their abscission (Byers et al. 1991; Byers 2003; Tromp 2005; Wertheim and Webster 2005; Wuensche and Ferguson 2005), and ii) the N-Vinasse acts phytotoxic to the sensitive flower organs and thus inhibits pollen germination or pollen tube growth. Operated at high speed (9–12 km h^{-1}) the rope thinner didn't cause relevant damages on leaves and wood as already shown by Walther (2002) and Weibel and Walther (2002).

On the other hand there were repeatedly "disappointing" results with the N-Vinasse treatments e.g. with 'Otava' and 'Golden D.' (Wädenswil) in 2003 or with 'Elstar' and 'Golden D.' at both sites in 2004. There, the sub-optimal efficacy can be partly explained by the fact that it was not always possible to apply the N-Vinasse when a maximum of inflorescences were open. However, combining the experiences of all the 15 trials described, we assume that beside application at the good moment (phenological stage), it is decisive, in line with the findings of Meland and Gjerde (1996), to apply this treatment at adequately warm temperature. It seems that day temperatures should be above 16 °C better 18–20 °C for N-Vinasse treatments to provide a good efficacy.

Matching blooming time for blossoms on old and young wood separately is critical to obtain optimum thinning results and has already been pointed out by Dennis (2000). Flowers on old wood normally open a few days before the ones on one-year-old wood. Although final fruit set on one-year-old shoots is low, flower thinning on new branches is important to control bi-annual bearing, because they carry many inflorescences that for a while will become gibberelin-dispensing fruitlets.

The concentration experiments with 'Maigold' and 'Gala' indicated that for optimal results the N-Vinasse concentration can/should be adapted to the cultivar. However the experience teaches us that the range between to weak and to strong effects lies between 5 and 10 %. These observations are in agreement with the results obtained in South Tyrol by Kelderer et al. (2004): they found a thinning effect with Vinasse products, in some cases better than with lime sulphur. On the other hand they observed more severe phytotoxic effects, like russeting and necrosis, than we did. To overcome the risk of phytotoxicity we developed the "burn and rinse" method, where we spray N-Vinasse at a high, certainly tissue "burning" dose of 12 to 15 % but "rinse" the trees with clear water 4–6 h later. The thinning effect with "burn and rinse" was satisfactory and caused less phytotoxicity compared to 10 % N-Vinasse. Thus, we consider "burn and rinse" as a feasible thinning method.

Alternative products like Light- and K-Vinasse or vinegar, in general showed too little effect. With these products we even observed a partly fertilising, fruit keeping effect. Furthermore, Vinasse products with less than 60 g N l^{-1} did not show any thinning effect.

In experiments carried out in New Zealand, a formulated Corn Oil 5 % had a good thinning effect. The best one was observed by combination with lime sulphur (Steven McArtney, personal communication), but we could not consistently confirm these results. However, the effect of Corn Oil 5 % was in the range of lime sulphur 2 % application. A similar experiment has been carried out in

France with rape oil (Ferré et al. 2003). This oil had a similar thinning effect to lime sulphur but caused serious phytotoxic damages at both concentrations tested: 2 and 1.5 l hl^{-1}.

Microscopic analyses did not reveal a clear inhibition of the pollen tube growth by the new products, except for lime sulphur and salt. However, it seems that some products deteriorate the stigma surface, preventing pollen germination there. Indeed, in some cases, we could observe a desiccation of the stigma surface. This could be due to osmotic reactions induced by the high product concentration. We also observed significantly less germinated pollen on the stigma of blossoms treated with Corn Oil 5 %, N-Vinasse 5 % and N-Vinasse 12 % followed by water rinsing. But, when the pollen tubes have already germinated and grown down the style, it is likely that the products have no influence anymore and that even a fertilisation effect can occur. In addition, these products may also act on other physiological or hormonal processes. Our complementary analyses of pH showed that pH of Vinasse products were in the optimal pH range of 4.5–6 for pollen germination (Holdaway-Clarke et al. 2003). But salt and lime sulphur, as well as Corn Oil pH (7.24; Table 4) were clearly over this range so that pollen growth could be inhibited already by a pH-induced desiccation effect.

Conclusions

To achieve a successful thinning effect with the methods presented here, it is decisive that for each method the weather conditions (air temperature) and the phenological stages are optimal at the day of application. On basis of the present results we recommend for organic apple fruit thinning:

1) to apply the rope device one or two times at stage E–F at lowest possible rotation speed of the rope spindle and at high driving speed (9–12 km h^{-1}) in order to minimize direct damages on leaves and shoots. In order to achieve a good thinning efficacy it should be used preferably at cold, cloudy days to increase the physiological shock that will induce a shortage of assimilates followed by abscission of the young fruitlets.

and / or:

2) to apply N-Vinasse or NK-Vinasse, with at least 60 g N l^{-1}, with concentrations between 5–10 % (Vol.) at least two or three times at mainly stages F2 (full bloom), at F2 of the one-year-old shoots and eventually also at stage F. Application should be done after flower opening at warm sunny days above 16 °C. The amount of water should be high, >1200 l ha^{-1}, to guarantee good product contact with flower organs. As an alternative, especially when flowering period is short or the cultivar is sensitive to phytotoxicity or russeting, the "burn and rinse method" can be applied.

On the basis of good experiences done by several organic fruits growers in commercial orchards in Switzerland and South Tyrol, we recommend to combine the two methods described above: at least one mechanical thinning with rope thinner at stage E and at least one Vinasse treatment at stage F2.

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