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Effects of Ethephon as a Blossom and Fruitlet Thinner on Yield and Fruit Quality of 'Jubileum' European Plum in a Nordic Climate

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Abstract

European plum cultivar Jubileum (*Prunus domestica* L.) blooms abundantly most years and too many fruit can be set if flowers and/or fruitlets are not properly thinned. In 2007, 2008 and 2009, mature 'Jubileum/St. Julien A' trees were treated with ethephon either at full bloom, at concentrations of 250, 375 and 500 mg/l or when fruitlets averaged ~12 mm in diameter at concentrations of 125, 250 and 375 mg/l. In general, flower-thinning treatments reduced fruit set significantly. Fruit set decreased with increasing ethephon concentrations, and the highest rate of ethephon applied either at full bloom (500 mg/l) or post bloom (375 mg/l) resulted in excessive over-thinning. Up to 375 mg/l of ethephon was required at full bloom whereas only 125 mg/l of ethephon was required post bloom for marked fruitlet thinning. Yields confirmed the fruit set response and yield reductions were significant. In most years, all thinning treatments resulted in fruit larger than 38 mm in diameter compared to fruit from unthinned control trees. Fruit quality, characterized by blue surface color and soluble solids content was generally higher and increased significantly with the reduction in crop load. Fruit firmness of fruit from all ethephon applications was lower than that of the fruit from unthinned control trees. In contrast, titratable acidity did not show a clear response to ethephon thinning. Return bloom the following year was mostly unaffected by all ethephon applications compared to the control. In conclusion, an ethephon application at a rate of up to 375 mg/l applied at full bloom will result in adequate thinning of 'Jubileum' plums and achieved a target of about 10-15 % reduction in fruit set. When weather conditions are not conducive during flowering, a post bloom ethephon application at 125 mg/l may be applied however, this should only be considered in years of excessive flowering and as a last resort.

The European plum cultivar 'Jubileum', which is widely grown in Norway, frequently produces too many flowers and sets too many fruit. Consequently, unless flowers and/or fruitlets are thinned, regular yields of marketable fruit of acceptable quality and size cannot be achieved. Unlike other European countries, the Norwegian market requires European plums of at least 36-38 mm in diameter. In addition, branches may break under the heavy crop load and flowering may be reduced in the subsequent season. Hand thinning of flowers and/or fruitlets is both tedious and costly. Consistent annual yields of high quality fruit may be achieved in commercial orchards when this cultivar is thinned at full bloom using mechanical thinning (Seehuber et al., 2011; Weber, 2013) or a chemical agent such as ammonium thiosulfate (ATS) (Seehuber et al., 2011; Meland, 2004). Further crop load adjustments are usually made by hand following "June drop". Should it be possible to avoid hand thinning, this will reduce labor costs and improve fruit quality, thereby significantly increasing the value of the crop.

Exogenously applied ethephon stimulates ethylene production, which in turn causes fruit abscission (Wertheim, 2000). Previous evaluations of ethephon on stone fruit at

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full bloom or two weeks after full bloom with warm weather conditions demonstrated that ethephon is a successful thinning agent (Meland, 2004) however, results were not always predictable nor consistent (Webster and Spencer, 2000). Usually ethephon performs better as a fruitlet thinner. This may be attributable to the higher temperatures later in the season and/or increased sensitivity of the fruit to ethephon at the later 'pit hardening' stage (Webster and Spencer, 2000). Chemical thinning of blossoms permits reduction of the potential overset at the earliest possible stage, thus reducing the impact on photoassimilate reserves, but fruit can abscise under Nordic conditions due to a post bloom late frost. In Scandinavia, fruit thinning with ethephon at the early bloom stage or lime sulphur at full bloom have been recommended (Kvåle, 1978). A single dilute application of 250 mg/l ethephon at full bloom reduced fruit set and crop load, and increased fruit quality and return bloom of the cultivar 'Victoria' (Meland 2007). However, these chemicals occasionally produce inconsistent results on a commercial scale. Fruit thinning following bloom permits a more exact evaluation of fruit set before any application of a thinning agent. Jakob (1998) found that the mixture ethephon-NAA applied to plums 30–40 days after bloom had a significant thinning effect. Using ethephon alone at post bloom was too unpredictable and caused over-thinning.

Martin et al. (1975) found that 'French Prune' could be effectively thinned using ethephon spays if applied when the seeds were approximately 8-9 mm long. However, the main problem with these sprays was the inconsistent response from site to site and from season to season. Consequently, warm weather (>15 ºC) at the time of spraying and ethephon concentrations of between 200-250 mg/l appear most appropriate for thinning European plum cultivars and in general this coincides with the fruitlet stage reported by Webster and Spencer (2000). Basak et al. (1993) found that 'Opal' and 'Common Prune' were thinned effectively using 200 mg/l ethephon applied two weeks after flowering and Seehuber et al. (2011) and Weber (2013) using ATS and/or ethephon four weeks after flowering.

The aim of the present investigation was to evaluate the effect of ethephon at different concentrations as a thinning agent for 'Jubileum' plum when applied at full bloom or post bloom.

Materials and Methods

In 2007, a field trial was initiated on six-year-old European plum 'Jubileum', grafted on 'St. Julien A' rootstock in a commercial orchard near the shore of the Hardangerfjord near Nibio, Ullensvang (60.2 ºN). Productive, uniform slender spindle trees, spaced at 2 x 4 m and pruned to a maximum height of 2.5 m with an optimum yield of 15-18 kg/tree. Trees were grown in a loamy sand with ~4% organic matter and sprayed in 2007, 2008 and 2009 either at full bloom at concentrations of 250, 375 or 500 mg/l ethephon or post bloom at concentrations of 125, 250 or 375 mg/l ethephon when fruitlets averaged ~12 mm in diameter. Optimum yield was set at ≥10 kg/tree. The experiment was a two by three factorial (2 timings and 3 ethephon concentrations) plus an untreated control. Before budbreak each year, trunk circumference (cm) was measured at 0.25 m above the soil level. Experimental trees were blocked using cm^2 trunk cross sectional area (TCSA) measured before bloom the first year. Subsequently, each tree received the same treatment each year. Orchard floor management consisted of frequent mowing of the interrows and a 1 m wide herbicide strip was maintained in the intrarow. Trees were irrigated by drip irrigation when water deficits occurred. All trees received the same amount of fertilizers based on soil and leaf analysis.

The ethephon source was 'Cerone' (48 % a.i. ethephon w/v) (Bayer Crop Science, Monheim am Rhein, Germany). In all three years, treatments were applied to whole trees as dilute sprays with a handgun to the point of run-off with approximately 2 l/tree. To prevent spray drift during application a portable plastic shield was placed between each tree. No surfactants or other additives were included with the sprays. The date of application for each year, maximum daily temperature on the day of application and the highest maximum daily temperature on the 3 days following application; maximum solar radiation on the day of application and the highest solar radiation on the 3 days following application, and relative humidity on the day of application are presented in Table 1.

Fruit set was calculated each year by counting the number of flowers on three branches per tree prior to ethephon application. Subsequently, fruit counts were measured each year shortly before harvest on the same branches. At harvest, fruit were selectively picked on two occasions one week apart. Fruit were harvested according to commercial fruit standards and the first selective picked dates were 08/31/2007, 09/4/2008 and 09/08/2009.

Total yields were recorded for each tree at harvest and graded according to current standards (Standardization Organization of Norway, 1999). A sample of 10 randomly selected fruit from each experimental tree was used to determine fruit quality. Fruit firmness was measured on two sides of each fruit, using a fruit texture digital table penetrometer (Durofel®, Copa-Technology CTIFL, Vandoeuvre-lès-Nancy, France). Surface color was rated on a scale from 0 to 100%, where 0 % = no blue color and 100% blue color, covering the entire fruit surface area. From each sample total soluble solids concentration was evaluated using a handheld digital refractometer (Atago® ,Tokyo, Japan). Titratable acidity (TA) was measured using an auto-titrator (model TIM865 Titration Manager, Radiometer Analytical SAS, Lyon, France) with 0.1 mol/l NaOH to endpoint pH 8.2 and expressed as percentage of malic acid (%). The following spring, return bloom was recorded as the total number of flowers per branch from the same three sample branches. Data were evaluated using Genstat® 17 statistical software (VSN International, Rothamsted, UK) testing for differences between all crop load parameters and effects on fruit quality. Unless noted otherwise, only results significant at $P \leq 0.05$ are discussed.

Results and Discussion

2007. Both TCSA and the number of flowers per branch were uniform at the start of the experiment (Table 2). All thinning treatments reduced crop load compared to the unthinned control. Fruit set was reduced curvilinearly with increasing concentration of ethephon. The two highest rates of ethephon, 500 mg/l at full bloom and 375 mg/l post bloom, resulted in insufficient yields for commercial

Table. 1: Climate data in Ullensvang, Norway on the day of application of ethephon at full bloom or post bloom and the 3 days following application between 2007 and 2009.

Year	Application time	Date	Max. temp. (°C)	Highest max. temp subsequent 3 days (°C)	Daily solar radiation (W/m^2)	Max daily solar radiation subsequent 3 days (W/m^2)	Relative humidity (%)
2007	Full bloom	13 May	13.7	10	498	513	40
	Post bloom	17 June	17.2	23.5	402	825	50
2008	Full bloom	5 June	17.9	20.3	642	758	40
	Post bloom	16 June	18.4	16.6	888	512	46
2009	Full bloom	1 May	19.8	14.4	658	706	65
	Post bloom	15 June	17.7	18.9	725	834	29.5

Table 2: Effects of different ethephon concentrations applied in 2007 at full bloom or post bloom on trunk cross sectional area (TCSA), fruit set, yield, yield efficiency (YE) and return bloom of 'Jubileum' plum in Ullensvang, Norway.

Ethephon concentration (mg/1)	TCSA (cm^2)	Harvested fruit/100 flowers	Yield (kg/tree)	YE (kg/cm^2)	flowers/branch in 2008
0 control	29.0	21.4	21.5	0.105	149
250 full bloom	27.0	19.8	20.8	0.130	141
375 full bloom	27.9	14.2	14.2	0.148	147
500 full bloom	29.5	6.8	7.4	0.086	153
125 post bloom	28.2	16.3	13.0	0.224	130
250 post bloom	30.2	14.6	12.3	0.215	145
375 post bloom	30.9	2.4	1.5	0.054	123
Significance	NS	***	***	**	NS
LSD (P = 0.05)	4.06	6.9	5.0	0.109	-

production (7.4 and 1.5 kg/tree respectively). Furthermore, fruit were more sensitive to ethephon at the later treatment date. All ethephon treatments resulted in a significantly higher percentage of fruit larger than 38 mm in diameter at harvest (data not shown). Fruit weight increased when ethephon was applied at 375 or 500 $mg \cdot L^{-1}$ (Table 3) and as expected, the largest fruit were on trees with the lowest fruit set. However, linear regression of fruit size versus yield combined for all treatments was poorly correlated (R^2=0.124). At harvest, only those fruit from trees sprayed with 375 mg/l ethephon post bloom had significantly higher average soluble solids (17.6%) but the lowest concentration of ethephon at bloom reduced soluble solids (9.8%) relative to the untreated control trees (11.7%). None of the ethephon treatments had a marked effect on fruit firmness compared to fruit from the untreated control trees. Fruit surface color was improved for all treatments applied after bloom. Fruit acidity and return bloom were similar for all treatments.

Table 3: Effects of different ethephon concentrations applied in 2007 at full bloom or post bloom on fruit weight and fruit quality at harvest of 'Jubileum' plum in Ullensvang, Norway.

Ethephon concentration (mg/1)	Fruit weight (g)	Fruit firmness[z] (units)	Fruit surface color[y] (%)	Soluble solids (%)	Acidity (%)
0 control	40.0	75	73.3	11.7	3.1
250 full bloom	43.5	72	60.0	9.8	3.2
375 full bloom	50.9	75	72.5	10.8	3.2
500 full bloom	54.2	77	78.7	11.9	3.1
125 post bloom	40.1	75	81.7	12.1	3.1
250 post bloom	42.1	75	80.8	12.6	3.0
375 post bloom	46.6	78	95.0	17.6	2.9
Significance	***	*	***	***	**
LSD (P = 0.05)	7.3	3.2	8.5	1.6	0.2

[z] Fruit firmness measured with Durofel, Copa-Technology, CTIFL, Vandoeuvre-lès-Nancy, France
[y] Fruit surface color rated 0-100%, where 0 = no blue color and 100% = blue color covering entire fruit surface

Table 4: Effects of different ethephon concentrations applied in 2008 at full bloom or post bloom on trunk cross sectional area (TCSA), fruit set, yield, yield efficiency (YE) and return bloom of 'Jubileum' plum in Ullensvang, Norway.

Ethephon concentration (mg^1)	TCSA (cm2)	Harvested fruit/100 flowers	Yield (kg/tree)	YE (kg/cm^2 TCSA)	flowers/branch in 2008
0 control	35.0	17.6	11.1	0.316	65
250 full bloom	34.4	12.9	6.2	0.184	70
375 full bloom	32.3	11.6	8.0	0.263	73
500 full bloom	33.9	4.5	4.4	0.136	42
125 post bloom	32.4	9.6	9.1	0.280	74
250 post bloom	34.6	6.3	5.2	0.155	47
375 post bloom	37.4	3.9	2.5	0.074	37
Significance	NS	**	**	**	*
LSD (P = 0.05)	4.06	7	5.0	0.109	2.97

2008. Flowers per branch was less than half the previous year for all treatments (Table 4) and it is likely that this was due to inclement weather earlier that spring. Effects of ethephon thinning with respect to fruit set and yield were similar to those in 2007 and both were significantly lower than the untreated control. The highest concentration of ethephon applied at full bloom or post bloom resulted in over-thinning with 4.5 and 3.9 fruit at harvest/100 flowers, respectively. This was reflected in the unacceptably low yields for these same treatments of 4.4 and 2.5 kg per tree at harvest, respectively when compared to the untreated control trees (11.1 $kg.tree^{-1}$). However, linear regression of fruit size versus yield pooled over all treatments was again poorly correlated (R^2=0.031). As in 2008, there were no significant effects of these high ethephon concentrations on return bloom in 2009 (Table 4). Both the lowest and the intermediate concentrations of ethephon applied at bloom (250 and 375 mg/l) as well as the lowest concentration applied post bloom (125 mg/l) resulted in satisfactory fruit set (12.9, 11.6 and 9.6 fruit/100 flowers at harvest), respectively (Table 4). These thinning effects were also resulted in acceptable yields (6.2, 8.0 and 9.1 kg/tree at harvest respectively) when compared to the control (11.1 kg/tree). All other treatments resulted in significantly reduced yields (≤5.2 kg/tree).

In 2008 ethephon applied at bloom did not affect fruit weight, fruit firmness, soluble solids concentration or acidity, but the lowest concentration enhanced surface color (Table 5). Post bloom applications of 250 mg/l reduced fruit weight, and 375 mg/l reduced flesh firmness. Yields and fruit acidity in 2008 were in general almost half that of the previous year, but soluble solids were almost double, which infers that fruit maturity is markedly affected by crop load.

2009. TCSA and return bloom in 2010 were unaffected by any of the ethephon treatments (Table 6). Ethephon applications of 250 mg/l at full bloom or at concentrations of 250 or 375 mg/l post bloom did not affect fruit set (69.1, 85.6 and 78.7 fruit/100 flowers) compared to the untreated control (57.7 fruit/100 flowers) (Table 6). In addition, only the 250 mg/l ethephon application at full bloom resulted in fruit that was numerically greater than fruit on control trees (92.7 g vs. 88.5g, respectively). In contrast, all post bloom ethephon treatments resulted in significantly smaller fruit than the untreated control (all ≤ 78.7 g) (Table 7). Furthermore, all post bloom applications at 250 or 375

Table 5: Effects of different ethephon concentrations applied in 2008 at full bloom or post bloom on fruit weight and fruit quality at harvest of 'Jubileum' plum in Ullensvang, Norway.

Ethephon concentration (mg/1)	Fruit weight (g)	Fruit firmness (z) (units)	Fruit surface color (y) (%)	Soluble solids (%)	Acidity (%)
0 control	76.0	73.2	70	21.3	1.4
250 full bloom	80.0	73.8	78	20.3	1.4
375 full bloom	76.7	73.5	67	17.1	1.2
500 full bloom	72.0	70.7	72	21.7	1.7
125 post bloom	68.7	68.7	73	19.4	1.3
250 post bloom	62.1	70.3	73	21.2	1.2
375 post bloom	71.6	65.1	82	22.0	0.9
Significance	**	**	**	NS	NS
LSD (P = 0.05)	8.4	4.4	7.2	-	-

(z) Fruit firmness measured with Durofel, Copa-Technology, CTIFL, Vandoeuvre-lès-Nancy, France
(y) Fruit surface color rated 0-100%, where 0 = no blue color and 100% = blue color covering entire fruit surface

mg/l ethephon resulted in significantly lower yields (12.8 and 7.8 kg/tree respectively) than the untreated control trees (16.8 kg/tree) (Table 6). The relationship of fruit size versus yield pooled over all treatments was once again very poorly correlated (R^2=0.145). All ethephon treatments in 2009 had little effect on fruit quality (Table 6). Compared to control fruit, the lowest concentration of ethephon significantly reduced surface color, but color was acceptable for the market. The highest post bloom ethephon concentration increased soluble solids concentration from 16.0 to 17.8%.

Many factors must be taken into account for consistent thinning with ethephon, including site, cultivar, spray volume, timing of application and temperature (Marini, 2004). However, in the present study many of these factors were constant. We believe spray volume was adequate in the present study, since all treatments were applied to run-off with a

Table 6: Effects of different ethephon concentrations applied in 2009 at full bloom or post bloom on trunk cross sectional area (TCSA), fruit set, yield, yield effiiciency (YE) and return bloom of 'Jubileum' plum in Ullensvang, Norway.

Ethephon concentration (mg/1)	TCSA (cm^2)	Harvested fruit/100 flowers	Yield (kg/tree)	YE (kg/cm^2 TCSA)	flowers/branch in 2008
0 control	41.5	57.7	16.8	0.406	141
250 full bloom	40.7	69.1	16.1	0.407	151
375 full bloom	41.1	55.3	17.5	0.435	150
500 full bloom	41.3	63.8	19.5	0.488	123
125 post bloom	40.5	53.3	17.1	0.425	110
250 post bloom	41.7	85.6	12.8	0.318	98
375 post bloom	43.4	78.7	7.8	0.185	91
Significance	NS	**	***	**	NS
LSD (P = 0.05)	4.06	8.93	5.0	0.109	-

Table 7: Effects of different ethephon concentrations applied in 2009 at full bloom or post bloom on fruit weight and fruit quality at harvest of 'Jubileum' plum in Ullensvang, Norway.

Ethephon concentration (mg/1)	Fruit weight (g)	Fruit firmness[z] (units)	Fruit surface color[y]	Soluble solids (%)
0 control	88.5	66.8	77	16
250 full bloom	92.7	67.1	68	15.2
375 full bloom	86.4	65.1	73	15.1
500 full bloom	85.8	63.5	74	15.3
125 post bloom	77.3	65.7	79	16
250 post bloom	78.7	67.7	80	16.8
375 post bloom	70.7	66.2	78	17.8
Significance	***	n.s.	**	**
LSD (P = 0.05)	8.13	-	6.09	1.40

[z] Fruit firmness measured with Durofel, Copa-Technology, CTIFL, Vandoeuvre-lès-Nancy, France

[y] Fruit surface color rated 0-100%, where 0 = no blue color and 100% = blue color covering entire fruit surface

handgun. In our experiment the nearest day to the indicated phenological stage with temperature above 15 °C was selected in order to achieve optimum thinning (Table 1). In a cooler climate like in Norway, optimum weather conditions may not be adequate during bloom to thin plum trees successfully. For this reason it is important for the growers to have a second thinning window at fruitlet stage. Under the conditions reported, ethephon proved to be an effective fruit thinner at different concentrations and could be applied at either bloom or post bloom.

Ethephon reduced fruit set significantly with increasing rate of the thinner. A higher dosage of ethephon at bloom is needed compared to the fruitlet stage in order to achieve the same fruit set. These results are contrary to those with apple. 'Golden Delicious' apple trees were most sensitive to thinning at pink bud stage. After bloom higher rates were necessary in order to get the same reduction in fruit set (Koen and Jones, 1985). In both 2007 and 2008, concentrations of up to 375 mg/l ethephon applied at bloom and 125 mg/l post bloom reduced crop load to the target of about 10-15 fruit/100 flowers, which is required in order to fulfill the market requirements for fruit quality. This is in accordance with previous reports (Kvåle, 1978; Meland, 2007; Webster & Spencer, 2000).

Reducing plum crop load usually increases fruit weight due to less competition for carbohydrates among the remaining fruit on the tree during fruit growth. In this study yield was high and fruit were smaller on average in 2007, but fruit weight was higher following bloom thinning than post bloom thinning. Soluble solid concentration is usually negatively related to crop load but in our study, timing of thinning had little if any effect on soluble solid concentration. Embree et al. (2001) found that ethephon applied to small fruitlets resulted in advanced fruit maturity at harvest, increasing fruit color and blossom density the following year. Similarly, Seehuber et al (2011) and Weber (2013) found that post bloom applications of ethephon resulted in advanced maturity with cv. 'Ortenauer' plums and softer fruit postharvest. In the current study, in fruit firmness was little affected by ethephon treatment.

A general response to heavy thinning is increased return bloom the following season. Kvåle (1978) found that return bloom was positively affected for 'Opal' and 'Victoria' plums when thinned with ethephon at bloom the subsequent year. Treating apple trees with ethephon at or shortly after bloom in a biennial bearing “on year”, promoted return bloom (Bukovac et al., 2006; Meland and Gjerde, 1993; McArtney et al., 2007). This observation was not confirmed in the present study and there were no improvements in the amount of bloom the year after ethephon application either at full bloom or post bloom.

Conclusions

Ethephon applications at either 250 or 375 mg/l applied at full bloom resulted in adequate thinning of ‘Jubileum’ plums and successfully resulted in a target of about 10 -15 % fruit set in most years. Furthermore, these concentrations had negligible impact on fruit size, internal fruit quality or external fruit color and in some years they were actually improved. Post bloom ethephon applications to ‘Jubileum’ did not result in optimal fruit set, yield or fruit size and should not be considered as an alternative to blossom thinning. Indeed, high concentrations of post bloom ethephon (250 and 375 mg/l) applied to ‘Jubileum’ plum trees often resulted in unacceptably low yields and small fruit. The higher concentrations should be avoided because the negative effects appeared cumulative over three years. However, it is not always possible to apply foliar sprays during flowering in Norway, due to inclement weather and under these circumstances a 125 mg·L^{-1} ethephon applied post bloom to the fruitlets is recommended. In conclusion, if weather conditions during bloom are not conducive to applying ethephon at concentrations of 250 or 375 mg·L^{-1}, a window of opportunity still exists for spraying ‘Jubileum’ plum trees with 125 mg·L^{-1} when average fruitlet diameter is ~12 mm, but this should only be considered an option in years of excessive bloom or consider mechanical blossom thinning.

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