Invited lecture

REGULATION OF FRUITING IN PLUM PRODUCTION

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Abstract. This short overview article describes different strategies to adjust crop loads in plums in order to get regular cropping, improve fruit size and fruit quality. There are three principal methods of regulating the crop loads of plum, which can be combined: numbers of flowers on the tree can be reduced, flowers can be prevented from fruit setting and the amount of fruitlets can be reduced by thinning methods. The methods of achieving these strategies, by manual, mechanical and chemical means are described and discussed.

Keywords: ACC, ATS, ethephon, fruit quality, GAs, mechanical thinning, *Prunus domestica*, *Prunus salicina*, sulfur, thinning, yield.

Introduction

Most European and Japanese plum cultivars produce few flowers and even fewer fruits in the two or three years following planting of young trees. Thereafter they frequently initiate and form too many flowers and set too many fruits to obtain regular and marketable crops from year to year. If consistent cropping is to be sustained and fruit quality maximized, the fruit set remained by the tree must be balanced with the tree size and the leaf area (Måge, 1994, Webster and Spencer, 2000). In addition, adjustment of the crop load will protect branches from breakage due to the heavy weights of the fruits.

The abundance of flowers produced is often far in excess of the grower's target for fruit set and to retain an optimum number of marketable fruits. For example a fruit set of only 5% flowers on the plum cultivar Victoria are required to provide a full crop (Webster and Holland, 1993) and for apple a fruit set of 10% flowers is sufficient (Meland, 1998). At this crop load level, most of the fruits will be in the sizes preferred by the fresh fruit market (Byers, 1997).

When too many fruits are set, other problems in addition to fruit size and quality, like branch breakage can occur. Excessive fruit numbers often reduce the numbers and quality of flowers in the following season and may lead to the establishment of a biennial pattern of cropping. Pollination, pollen-tube growth and especially fertilization and seed growth lead to a burst in hormone activity in the ovary (Luckwill, 1953). Large seed numbers of the fruits within the tree produce gibberellins (Chan and Cain, 1967; Hoad, 1984). These gibberellins move from fruits into the adjacent spurs and leaf axils where they inhibit the initiation or stimulation of the abscission of new floral primordial. Other hormones like auxin likely may play a role in biennial bearing and the effect of crop load on floral initiation has yet to be fully explained (Bangerth, 1977).

The crop load effect is little investigated in plums. The optimum goal is to produce maximum and annual crop of high fruit quality under the climatic conditions for a region. The crop levels have an impact on the growth of the tree. Leaf and whole canopy photosynthesis increased curvilinear with higher crop in apples (Palmer, 1992). The reduction in photosynthesis in trees with lower fruit number frequently occurs after shoots have terminated vegetative growth. Increasing fruit load in apples led to increases in dry matter production, per unit leaf area and partitioning to fruit and to decreases in fruit size (Palmer, 1992). Leaf photosynthesis was increased in cropping trees in July and August at the time of maximum fruit load. Similar approaches are expected to take place in plums, but have so far not been investigated.

Fruits compete with each other for water, nutrients, assimilate, and with other vegetative sinks in the tree such as vegetative shoots and roots. The leaf areas of the trees, the amount of available light (light interception) and the ambient temperature are important for the total carbon production and influence the optimal crop load (Palmer, 1992). Management factors like the choice of rootstocks used, the tree spacing and the tree pruning and management are factors which have a strong impact on the crop loads as well. The within tree competition can be altered by other management techniques like manipulation of the vegetative growth (shoot pruning/ training) and root growth (root pruning/restriction).

Optimum crop levels are expressed as number of fruits per 100 flowers, number per unit branch length or numbers per trunk cross sectional area and differ for each cultivar and change for the same cultivar when grown on different sites. It is difficult to estimate and establish general guidelines for optimal crop loads for different plum cultivars. They have to be defined for each species/cultivar in the different climatic environments.

Strategies for optimizing crop load

Regulation of crop load is a prerequisite to obtain the optimum fruit load and yield of marketable fruit size and fruit quality. In years with few flowers fruit set needs to be promoted, but in most years flowering is abundant and fruit set needs to be limited to avoid oversetting and too high yields of poor quality fruits (Fig. 1). Thinning can be done at various times; pre-bloom, at full bloom and post-bloom. Pruning is as well one method of thinning (Njoroge and Reighard, 2008). However, even when stone fruit trees are properly pruned, they still often set too many fruit (DeJong and Grossman, 1994). The severity of thinning, as well as the timing, is closely linked to the reproductive and vegetative performance of the tree (Costa and Vizzotto, 2000). Thinning must therefore be done annually, to achieve the advantages it has on flower number, fruit size, fruit quality, fruit-to-shoot ratio and in preventing alternate bearing (Costa et al., 1983).

There are three principal methods of regulating the crop loads of plum. Numbers of flowers on the tree can be reduced; flowers can be prevented from fruit setting and the amount of fruitlets reduced by thinning methods (Dennis, 2000). One or more of these methods can be combined.

Figure 1. Oversetting of ‘Opal’ plums (left) and ‘Jubileum ‘(right). (Photo’s: Mekjell Meland).

Reduction of flowering intensity

It is difficult to control the numbers and quality of the flowers developed and distributed around in the tree and their fruit set. The reduction can be conducted by management techniques like pruning prior to flowering. It is important to leave branches with sufficient fruit bearing capacity and at the same time stimulate to renewed extension growth for floral buds and fruiting for coming years.

Hormones like gibberellins used in one season can depress flowering the next spring (Gonzáles-Rossia et al., 2006; Southwick and Glozer, 2010). One of the chemical thinning approaches for plums is to use gibberellins, e.g. gibberellic acid (GA_3), but results are often inconsistent. GA3 applied during flower induction will reduce flowering the next season and indirectly reduce the number of fruits, which will lead to a reduction in hand thinning costs (Gonzáles-Rossia et al., 2006). Therefore, to be effective, GA_3 must be applied when flowerbuds differentiation can be affected (Costa and Vizzotto, 2000). The main reason why GA_3 sprays are not used as a chemical thinner is because “thinning” is performed long before bloom and climatic conditions, i.e. frost during bloom, might still negatively influence fruit set of the fewer blossoms (Costa and Vizzotto, 2000).

The effects of Gibberellic Acid (GA_3) on regulating crop load of several *Prunus* species are well known (Byers et al., 2003; Conveva and Cline, 2006).

However, for the most of these studies, timing of application coincided with pit hardening (Stage III of fruit growth) and, which mostly improves fruit firmness and delays fruit maturity in the year of application. In a recent study on sweet cherries, Lenahan et al. (2006) found that GA_3 applied at the end of Stage I of fruit growth in an “off-year”, resulted in floral bud inhibition that year, and reduced return bloom and yield the following year while improving fruit quality.

Gibberellic acid (GA_3) was tested as a novel approach to regulate the crop load of the plum cultivar ‛Opal’ at Ullensvang, western Norway (Meland and Kaiser, 2014). The objective was to reduce flower bud induction in the “off-year” thus adjusting crop load the subsequent year. In 2008, an “off-year”, GA_3 was applied to 9 year-old ‘Opal’ trees as a high volume spray to the point of run-off at 50 ppm or 100 ppm at either 5 weeks after full bloom or 10 weeks after full bloom or on both dates and compared with untreated control trees. Trees were unthinned the first year but then thinned to commercial standard the following year. In the year of application, total yield was recorded and fruit quality evaluated. Return bloom, fruit set, yield and fruit quality were assessed the subsequent year. In general, there were no significant differences in crop load of all treated trees compared to untreated trees in the year of application (non-target crop).

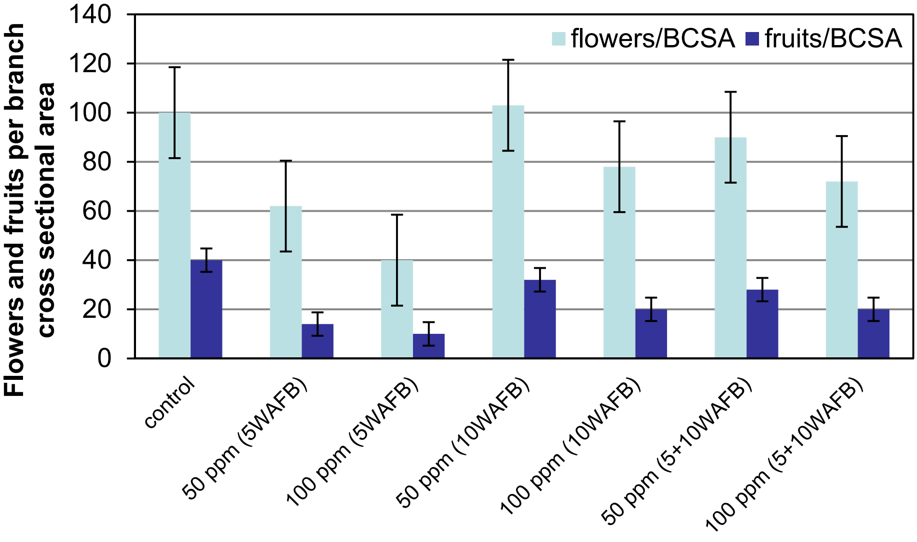

Figure 2. Effects of GA_3 applications to ‘Opal’ plum trees 5 and 10 weeks after full bloom in 2008 on return bloom and fruit set in 2009. (Source: Meland and Kaiser, 2014).

However, fruit weight increased slightly on those trees when GA_3 was applied 5 weeks after full bloom compared to all other treatments and untreated trees. The following year (target crop) fruit set was significantly reduced for all GA_3

treatments (Fig. 2). The most effective application time was 5 weeks after full bloom. Before thinning, initial fruit set was greatest on untreated trees as well as on those trees treated with GA_3 10 weeks after full bloom. Fruit weight and fruit color were significantly better on trees with the least fruit set. GA_3 applications had no effect on fruit firmness. It is concluded that GA_3 is an effective tool for inhibiting flower bud induction in an "off-year" thus enabling crop load management the subsequent "on-year".

Other fruitlets thinners inhibit the gibberellin biosynthesis or auxin transport, other thinners are inhibiting the photosynthesis. Reducing photosynthesis by shading trees is very effective in promoting fruitlet abscission (Byers et al., 1985; Stopar, 1998).

Flower thinning

The fruit size at harvest can be improved by reducing the competition between fruits for water and assimilates in the early stage of fruitlet development. Early reduction in the season by flower thinning, improves the amount of floral primordia the next year (Goffinet et al., 1995; Hansen, 1971; Meland, 1998). This is particular important for cultivars with abundant fruit set and for cultivars situated in areas with favourable conditions for fruit set. However, growers consider flower thinning as a high risk and like to be sure to have adequate fruit set before conducting any reduction of the crop load. Flower thinning can be conducted by hand, mechanically and by chemical methods.

Figure 3. The plums trees have abundant of flowers (left). Handthinning is labouring intensive (right). (Photo's: Mekjell Meland).

Hand and mechanical thinning of flowers

Flowers can be removed by mechanical means. Flowers number can be reduced by dormancy pruning, physical removal by hand (Fig. 3) or specialized brushes from machines. Cultivars with very high floral abundance usually require much hand labour and costs can be far too much to be economically achievable.

There are different mechanical thinning devices available on the market, both handheld and devices mounted on the front of a tractor. The use of a mechanical thinning device is independent of the production-scheme, being suitable for both integrated, as well as organic fruit cultivation. Mechanical thinning is best suitable for vertical, tall, slender spindle type trees and fruit-wall-trained trees, with mostly thinner, flexible branches, which provide access to the trunk without solid/thick vertical structural branches. Two main concepts are developed for mechanical blossom thinning of fruit trees. The ‘Baum’ was developed at the University of Bonn, Germany (Damerow et al., 2007). This thinning device comprises a 3 m tall, vertical square beam mast with three horizontal arms and variable angle rotors arranged vertically up the mast (Fig. 4). Each of the arms can be adjusted vertically from a height of 0.50 m to 2.30 above the ground allowing for adaptation to the type of fruit tree and for a vertical coverage of the tree canopy ranging from 0.25 m to 3.25 m. Radiating from four sides of each rotor at right angles are 0.35 m long, stiff plastic tines that act as whips when rotating and passing through the trees. The rotors are actuated by the tractor’s hydraulic system and optimum rotor speeds range from 320 to 420 rpm, while optimum tractor speeds range between 5 and 7.5 km/h. Increases in rotor speed and increases in tractor speed have opposing effects; while an increase in rotor speed enhances the thinning efficacy, increases in tractor speed reduces this effect .

The second machine is as well a rotating string thinner (Darwin 300; Fruit-Tec, Deggenhausertal, Germany) designed by H. Gessler, a German grower, to remove apple blossoms in organic orchards. A description of the string thinner and details of its application can be found in Bertschinger et al., (1998). The string thinner consisted of a tractor-mounted frame with a 3.0-m-tall vertical spindle in the center of the frame. Attached to the spindle there are 36 steel plates securing a total of 648 plastic cords each measuring 50 cm long. The speed of the clockwise rotating spindle is adjusted with a hydraulic motor. The height and angle of the frame is adjustable to conform to the vertical inclination of the tree canopy, and the intensity of thinning is adjustable by changing the number of strings and the rotation speed.

The third machine is a hand-held device developed in France with rotating plastic strings at the end of a stick that can be used to partially remove flowers and young fruitlets at specific areas within a tree (Martin et al., 2010) (Fig. 5).

Mechanical thinning of the plum cultivar ‘Ortenauer’ using the three rotors device ‘Baum’ was successfully employed at 400-500 rpm at a tractor speed of 5 km/h and reduced hand thinning by 180 hours up to 310 hours per ha when used alone. A combination of mechanical thinning followed by ATS application further reduced labor by about 20 or more hours per ha (Weber, 2013). Mechanical thinning of peaches during bloom by the Darwin machine reduced the crop load by an average of 36%, decreased the follow up hand thinning time and increased fruit in higher market value size categories by 35%. It was concluded that the mechanical thinning appears to be a promising technique for supplementing hand thinning in apple and peach trees (Schupp et al., 2008).

Figure 4. The Baum machine (left) and the Darwin machine (right) both originating from Germany. (Photo’s: Frank Maas, left; Michael Blanke, right).

Figure 5. The Electroflor hand-held mechanical thinning device developed in France (Photo’s: Frank Maas).

Chemical thinning of flowers

Chemical methods of flower thinning have been used on *Prunus spp*. for many years (Grauslund, 1980; Jakob, 1998, Kvåle, 1978). The chemicals spayed at bloom in some way will prevent their pollination and/or fertilization (Byers et al., 2003). All these chemicals reduce the competition between fruits at an earlier stage in the season than is achieved using fruitlet thinners later. Blossom thinners used alone or in combination with fruitlet thinning will lead to increased fruit size and return bloom. For alternate bearing cultivars with small fruits, only fruitlets thinning are often not sufficient to achieve these goals.

Two approaches are available for blossom thinning. One method is to reduce the number of healthy flowers by spraying with caustic compounds that burn stigmas and styles and inhibit pollination. A second method involves chemicals that enhance ethylene formation of the flowers. During flowering the chances of stimulating ethylene-induced fruit drop is relatively high. By applying extra ethylene through spraying with etephon reduces the auxin level in the plant tissue and enhancing the flower abscission. Ethephon applied at anthesis increases the whole senescence and contribute to the increased abscission (Sanzol and Herrero, 2001).

Flower thinning compounds

The fertilizer ammonium thiosulphate (ATS) has been extensively tested as a flower thinner for many fruit crops in the last decades (Wertheim, 1998). ATS is thought to thin by the desiccation of flowers and damage to the base of the flower peduncle. Its efficacy is therefore influenced greatly by the proportions of flowers at vulnerable stages in relation to the time of spraying (Byers et al., 1985; Byers et al*.,* 2003). In experiments conducted in 1998 and 1999 the final fruit set was reduced to about half of the unthinned trees when 1.5% ATS were applied at full bloom to the cultivar ‘Victoria’. The yields were significantly reduced and the pack out percentage increased (Meland, 2004). Webster and Holland (1993) reported that two or three sprays at intervals during the blossom period were much more effective than a single spray. Blossoms sprayed at or soon after anthesis were more sensitive to ATS than those sprayed earlier. The stigma is the most sensitive tissue part of the flower; disruption of pollination and fertilization appears to be the main effect of blossom thinning treatments. Multiple applications in these trials would likely have increased the thinning effect because of the low temperatures and extended flowering period in 1998 and 1999. Some minor leaf damage was recorded when treating the trees with ATS. These leaf symptoms disappeared during the season and seemed to have no effect on the growth of the trees

In apple the efficacy of inhibition of fruit set by ATS was shown to be very dependent on the concentration and timing of ATS application after flower bud opening (Maas, 2016). The time window for ATS to affect fruit set was shorter at higher temperatures and corresponded to the calculated pollen tube growth rate. At 50% growth of the pollen tube of the distance between the stigma and ovary of the flower, the efficacy of inhibition of fertilization and subsequent fruit set decreased by about 50%. At 80% pollen tube growth or more, ATS application no longer inhibited fruit set in ‘Elstar’apple (Maas, 2016). The time for the pollen tube to reach the ovary according to the pollen tube growth model used and the local temperature conditions during the trial varied between 95 and 49 hours at average daily temperatures of 13.5 and 21.2 °C, respectively. These results clearly indicate that the time window for an ATS thinning application is narrow and becomes even more narrow at higher temperature during bloom.

Table 1. The effects of different thinning agents on yield efficiency, total yield, fruit size, fruit quality and return bloom of ’Opal’ plums in 2000 (Source: Meland, 2007).

Treatment	Flower clusters per tree[1]	Yield kg per tree	Yield, % >36 mm fruit size	Fruit weight, g	Soluble solids, %	Return bloom[2]
Untreated	7.3	42.5	41	28	12.8	7.3
Handthinned	7.7	16.6	93	41	16.8	9.0
1,0% ATS	8.0	28.2	88	38	16.2	8.3
5% lime sulphur	7.0	20.9	92	41	16.7	8.3
LSD, P=0.05%	NS	11.6	22	5	2.0	NS

[1] Flower clusters scores 1-9 where 0= no flowering and 9= very abundant flowering
[2] Return bloom scores 1-9 where 0= no flowering and 9= very abundant flowering.

A single dilute application at full bloom of with 1% ATS or 5% lime sulphur at full bloom to the cultivar ‘Opal’ reduced fruit set and crop load and increased the fruit quality and return bloom (Meland, 2007) (Table 1).

Sulphur-containing chemicals are blossom thinners and have been mainly used in Northern Europe. Lime sulphur sprays up to 5% are most effectively applied at full bloom. (Kvåle and Ystaas 1969). However, sometimes these chemicals give inconsistent results on a commercial scale. Recently, limitations for the use of chemicals in the orchards have come forward. The traditionally used compound lime sulphur is withdrawn in some countries by manufacturers because of the cost of registration.

In Norway, trials were conducted on mature ‘Jubileum’/’St. Julien’ A’ trees treated with different concentrations of sulfur (0.4%, 0.8%, 2% and 4%); a mixture 0.4% sulphur plus 2% soya oil; and 2% soya oil plus 1.5% ammoniumthiosulphate, ATS (powder and liquid formulation) at full bloom and compared to untreated control and handthinned check in 2008. Treatments were applied to single whole tree plots in a randomized complete block design with six replications. Experimental trees were sprayed to the point of run-off with a hand sprayer and spraying dates were

May 6 (2008). Flower thinners were efficient at relatively low temperatures. In 2008 all thinning treatments reduced fruit set significantly compared to unthinned controls. Sulfur, soya oil both alone and in combination was less effective than ATS. Sulfur at different rates had a moderate thinning effect but it is not recommended for use in plum thinning under these conditions. Instead, 1.5% ATS application at full bloom resulted in adequate thinning of ‘Jubileum’ plums under cool mesic northern climatic conditions (Meland and Kaiser, 2012).

Reduction of amounts of fruitlets

Hand thinning of fruitlets

This method is widely practiced and is still the most reliable method of achieving optimum crop loads and fruit distribution. However, hand thinning is very laboured intensive and expensive. Guidelines for hand-thinning vary within the cultivars and the growing conditions. To space the fruits about 5- 7 cm apart on the branches is a rule of thumb. It has not been investigated which crop load potential is the optimum for different plum cultivars in order to produce maximum crop load and still achieve the fruit quality wanted.

The European plum cultivar ‘Opal’, widely grown in Scandinavia, frequently initiates too many flowers and set too many fruits. If excess fruitlets remain on the trees until harvest, the crop consists of small, unmarketable fruits of low fruit quality and return bloom will be reduced. For two seasons starting in 2008 on mature ‘Opal’/‘St. Julien A’ trees, two crop loads 50% and 25% flowers reduced were established at full bloom and at 10-12 mm fruitlet size and compared with an un-thinned control treatment (Table 2). Final fruit set varied from 63% on the control trees to 18% when thinned at bloom. Yield was negatively correlated with the fruit set response. Thinning at the fruitlet stage resulted in smaller fruits at the same crop level compared to flower thinning. Fruit quality parameters characterized by bright yellow skin background colour, red surface colour and the concentrations of soluble solids increased significantly as the crop load was reduced. Other fruit quality parameters like percentage acidity were not significantly different and did not show a clear response to the degree of thinning. Return bloom was promoted most when trees were thinned at bloom the year before.

Hand thinning 10-12 mm fruitlets to 25% fruit set resulted in the largest fruit on average (42 g/fruit) with acceptable yields (37 kg/tree) when compared to unthinned control trees (31 g/fruit and 54 kg/tree respectively). Flower-thinning to 25% of full bloom resulted in unacceptably low fruit set (18%) and the lowest yields (23 kg/tree) and is to be avoided. Return bloom was not fully acceptable for all treatments except on those trees on which flowers were thinned to 25%. Fruit quality parameters: bright yellow background skin colour, red surface skin colour and soluble solids content increased significantly with reduced crop load. Fruit acidity was not significantly affected by any treatment. Flower thinning to 50% of full bloom or fruitlet thinning up to 50% had the greatest positive effect on fruit size; yield, fruit quality and return bloom compared to the unthinned control and future investigations should examine the impact of these over a longer time period (Meland et al. 2016).

Table 2. Effects of different crop loads on fruit set, yield and fruit quality of 'Opal 'plums in 2008 and return bloom in 2009. (Source: Meland et al., 2016).

Crop level	Fruit set[y] (%)	Yield per tree (kg)	Fruit weight (g)	Soluble solids (%)	Firmness (Durofel)	Back ground colour (1-9)	Acid (%)	Return bloom 2009
Unthinned	63.1 c[z]	53.4 c	30.9 a	12.6 a	75.1 b	6.9 a	1.3 a	97.7 a
50% flowers	40.5 b	38.0 ab	38.7 b	13.0 a	72.4 ab	7.5 ab	1.3 a	162.2 b
25% flowers	17.5 a	23.2 a	40.0 b	14.6 b	72.6 ab	8.2 b	1.3 a	261.5 c
50% fruitlets	39.6 b	42.8 bc	38.4 ab	13.2 ab	69.9 a	8.0 b	1.2 a	159.5 b
25% fruitlets	31.4 b	36.5 ab	41.8 b	14.0 ab	72.1 ab	7.8 ab	1.3 a	162.7 b
SE	10.67	10.59	5.76	0.97	3.40	0.79	0.09	32.74

[y] Expressed as % of initial number of flowers per tree.
[z] Means followed by the same letter are not significantly different at $P < 0.05$ according to Tukey's test.

Chemical thinning of fruitlets

Chemical thinners are used to stimulate increased fruitlet abscission. The ideal chemical fruitlet thinner would be one that can be applied once the degree of natural fruit set is established and the abscission is complete. Growth of the pericarp of plums follows a double sigmoid curve. A rapid initial growth (Stage I) is followed by a shorter and slower phase when the seeds are developing (Stage II) followed by another phase with rapid pericarp growth which last until harvest (Stage III). Most trials have shown that sprays applied for fruitlet thinning are the most effective when applied during Stage II and is referred to early pit hardening (Webster and Spencer, 2000). Optimum fruitlets size for applying chemical thinning varies depending on the cultivar.

Ethephon

Exogenously applied ethephon stimulates ethylene production, which in turn causes fruit abscission (Wertheim, 2000). Previous evaluations of ethephon on stone fruit at full bloom or two weeks after full bloom with warm weather conditions demonstrated that ethephon is a successful thinning agent (Meland, 2004). However, ethephon thinning 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. 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; Meland and Birken, 2010). 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. However, most common is that growers prefer to first see fruit set and then determine the need for 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. 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.

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 (Meland and Kaiser, 2017). In general, flower-thinning treatments reduced fruit set significantly (Table 3). 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 (Table 3). Up to 375 mg/L of ethephon was required at full bloom whereas only 125 mg/L of ethephon was required post bloom to get a noticeable 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. 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.

Table 3. Effects of different ethephon concentrations applied in 2007 at full bloom or post bloom on trunk cross sectional area (TCSA), fruit set, yield, fruit weight and return bloom of ‘Jubileum’ plum in Ullensvang, Norway. (Source: Meland and Kaiser, 2017)

Ethephon concentration (mg/L)	TCSA (cm^2)	Harvested fruit /100 flowers	Yield (kg/tree)	Fruit weight (g)	Flowers/ branch in 2008
0 control	29.0	21.4	21.5	40.0	149
250 full bloom	27.0	19.8	20.8	43.5	141
375 full bloom	27.9	14.2	14.2	50.9	147
500 full bloom	29.5	6.8	7.4	54.2	153
125 post bloom	28.2	16.3	13.0	40.1	130
250 post bloom	30.2	14.6	12.3	42.1	145
375 post bloom	30.9	2.4	1.5	46.6	123
Significance	NS	***	***	***	NS
LSD (P = 0.05)	4.06	6.9	5.0	7.3	-

ACC

A new chemical thinner currently being evaluated in pome fruit is 1-aminocyclopropane-1-carboxylic acid (ACC) (Schupp et al., 2012). According to Adams and Yang (1979), ACC is effectively converting to ethylene in apple tissue. Further studies on mung beans confirmed that ACC, a precursor of ethylene, increased the corresponding rate of ethylene production (Yoshii and Imaseki, 1981).

A study was conducted to evaluate this new chemical thinning strategy on ‘African Rose™’. The chemicals evaluated were 1-aminocyclopropane-1-carboxylic acid (ACC) at 150, 300 and 500 µL/L in the 1st season and 400, 600 and 800 µL/L in the 2nd season, and 6-benzyladenine (6-BA) at 100 or 300 µL/L in the 1st season and 100 µL/L in the 2nd season. 6-BA was included to prevent ACC-induced leaf drop. ACC was also combined with mechanical thinning utilizing the Darwin 300™ and hand thinning during bloom included as treatment. All the foliar applications were made when the average fruitlet size was 8 - 10 mm. ACC consistently reduced the commercial hand thinning requirement in both seasons. In the second season, there was a linear decrease in yield efficiency as the ACC rate increased, while a quadratic response was seen in fruit size with the two higher rates inducing larger but similar fruit size.

Brevis®

Inhibition of photosynthesis by the new fruit thinning agent Brevis® containing metamitron as active ingredient has been shown to be a very effective thinning agent in apple (Brunner, 2014) and pear (Maas and Steeg, 2011; Stern, 2014, 2015) with good thinning efficacy in the both cooler Norwegian (Maas and Meland, 2016) and warmer Israelian growing conditions (Stern, 2014, 2015). Unfortunately Brevis® cannot be used for thinning plum as it causes strong phytotoxicity symptoms in the leaves without any significant fruit thinning (Fig. 6, Maas, personal observation).

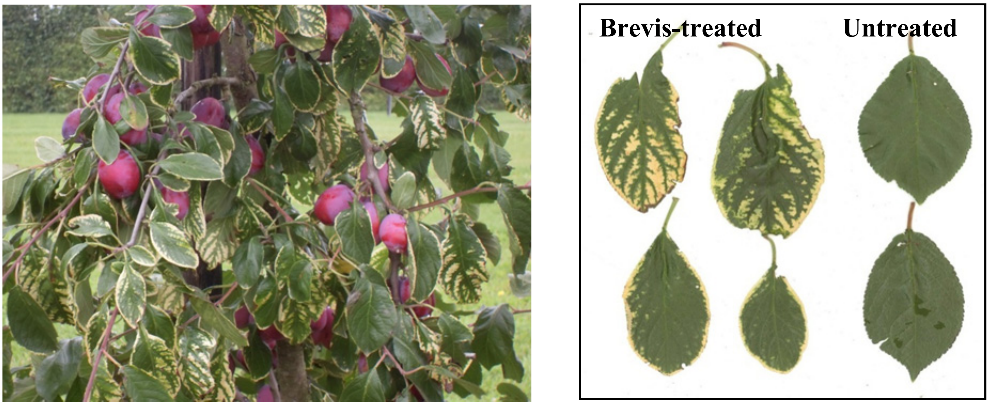

Figure 6. Leaf phytotoxicity symptoms ‘Victoria’ plum treated with 2.3 kg/ha Brevis® on May 20, 2010. (Photo’s: Frank Maas, September 8, 2010).

Factors affecting the results of chemical thinning

The results of chemical thinning are greatly influenced by climatic conditions around the time of spraying, the efficiency of spaying application, spray additives and water pH. In general high temperature and pH favour the effect of thinning. Other factors are floral abundance and other tree factors like tree vigour. The health status of the tree including the nutritional levels has to be considered before applying a thinning agent. Alternate bearing trees in their ‘on year’ are more difficult to thin than in the ‘off year’.

Conclusion

There is an increasing market demand for large plums with good flavour and colour and high sugar content in the market. Except breeding new cultivars which produce optimum numbers of fruit without need for thinning, there is a strong need for methods of regulating the crop load of the traditional cultivars. Manual thinning is too costly to be economically achievable and can be used only as a supplement to chemical thinning. Different thinning concepts are available from mechanical thinning to chemical thinning during bloom or at fruitlet stages. A common approach is to use mechanical thinning and chemical thinning first followed by fine adjusting by hand. Many factors affect the final results of thinning practices and chemical thinning is one of the most demanding cultural practices a grower is conducting in order to get the fruit set level and fruit quality to its target values.

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