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Screening of eco-friendly thinning agents and adjusting mechanical thinning on 'Gala', 'Golden Delicious' and 'Fuji' apple trees

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ABSTRACT

Fruit thinning is the most important yet difficult practice that drives orchard profitability. High labor costs and difficulty to improve return bloom by hand thinning have left chemical thinning as the main method used by growers. However, unpredictability and safety/environment concerns regarding chemical thinning have set mechanical thinning as a sound alternative. Thirteen field experiments were performed during 2004–2016 in order to evaluate several agents for their use as new thinners, and adjust mechanical thinning on 'Gala', 'Golden Delicious' and 'Fuji'. Olive oil applied at bloom reduced crop load, but russetting was also increased. Therefore, while their use is not advisable for russetting prone cultivars such as 'Golden Delicious', it could be a good thinner for cultivars like 'Red Delicious'. Lime sulfur did not have a consistent thinning effect in our study when applied at bloom. Overall, no differences regarding economic value between hand, chemical, and mechanical blossom thinning were observed, suggesting mechanical thinning as a valid alternative approach. For 'Gala' strains, 6 km h^{-1} and 250 rpm with 270 strings was the best configuration to provide an ideal crop load of ~6 fruit/cm^2 of TCSA and an average fruit size of 170 g. For 'Fuji', 5 km h^{-1} and 320 rpm with 270 strings provided a crop load in accordance to the optimum range for this cultivar in our conditions. However, combination of mechanical thinning plus chemical treatments might be the ideal strategy for 'Fuji' strains when the initial number of flower clusters per tree is above 500. For 'Golden Delicious' strains, 6 km h^{-1} and 230 rpm with 270 strings was the best configuration to provide an ideal crop load within the optimum range. Mechanical thinning timing was also examined at different phenological stages (E_2, F_1, F_2, and G), with no significant differences regarding yield, fruit size or crop load between them. Two prediction models ('Gala' & 'Golden Delicious') were developed to adjust the right tractor and rotational speeds depending on the initial number of flower clusters. The method begins with first calculating the final fruit number needed per tree (crop load for each particular cultivar) in order to achieve the desired yield. Then, tractor and rotational speeds can be determined by the model once knowing the initial number of flower clusters per tree.

1. Introduction

Through management of fruit number, size, and quality, thinning is the most important yet difficult practice that drives orchard profitability (Costa et al., 2012; Dennis, 2000; Greene and Costa, 2012; Robinson et al., 2013). Chemical and hand thinning have been the main methods used by growers during the last decades to achieve a regular and consistent crop load over the seasons (Costa, 2016; Dennis, 2000).

Hand thinning is generally too expensive, and the need to wait after the period of natural drop may compromise fruit size and return bloom (Dennis, 2000; Fallahi and Greene, 2010; Mcartney et al., 1996). On the other hand, chemical thinning is highly dependent on weather conditions and cultivar, which can create inconsistent results (Greene and Costa, 2012; Robinson and Lakso, 2004). For this reason, many studies have been carried out in order to address the lack of predictability of thinner response (Greene and Lakso, 2013; Lakso and Robinson, 2015; Lakso et al., 2001).

Food safety concern and awareness of environment protection have limited the available chemical thinning agents, thus, more environmentally-friendly thinning agents and mechanical thinning implementation could become the alternatives (Bertschinger et al., 1998; Blanke and Damerow, 2008; Greene and Costa, 2012; Kon et al., 2013).

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Some authors reported a thinning effect of products such as vegetable oils, potassium bicarbonate or molasses, sprayed at bloom (Ju et al., 2001; Pfeiffer and Rueß, 2002; Stopar, 2004; Warlop, 2002; Weibel et al., 2012). However, these results are not always conclusive.

Several mechanical thinning trials have been reported abroad (Asteggiano et al., 2015; Damerow et al., 2007; Dorigoni et al., 2010; Mcclure and Cline, 2015; Mika et al., 2016; Miranda Sazo et al., 2016; Reighard and Henderson, 2012; Schupp and Kon, 2014; Seehuber et al., 2014b; Theron and De Villiers, 2014; Theron et al., 2016). However, great disparity exists regarding the machine configuration in order to get a good thinning result, and in some cases additional chemical or hand thinning treatments need to be combined to achieve satisfactory results (Basak et al., 2016; Beber et al., 2016; Hampson and Bedford, 2011; Kirstein, 2015; Kon et al., 2013).

Unlike chemical thinning agents, mechanical thinning results are not subject to cultivar, year, or weather conditions (Dorigoni et al., 2010). However, it can damage spur leaves of the flower cluster and therefore it can reduce photosynthesis, and in some cases increase fire blight (*Erwinia amylovora* Burill) (Greene and Costa, 2012; Ngugi and Schupp, 2009).

In any case, both chemical and mechanical thinning strategies save labor (Blanke and Damerow, 2008; Seehuber et al., 2014b) and must be adjusted for each cultivar (Steyn et al., 2014). The aim of this study was to evaluate several new thinning agents, and evaluate various configurations for mechanical thinning on 'Gala', 'Golden Delicious' and 'Fuji'.

2. Materials and methods

2.1. Experiment 1: kaolin, soap, vinegar, oils, and lime sulfur on 'Red Chief® Camspur^{cov}'

A field experiment was conducted in 2004–2006 in Gimenells, Lleida, Spain (lat. 41.656203°, long. 0.389703°). We compared hand thinning with applications of kaolin (Kaolin type A, Guadasequies, Valencia, Spain) at 5 kg hL^{-1} in 2004, and two consecutive sprays: 1st one at 5 kg hL^{-1} and 2nd one at 3 kg hL^{-1} in 2005–2006, potassium soap (E-Coda Oleo K, Coda, Almacelles, Lleida, Spain) at 4 L hL^{-1}, pure vinegar (Pla d'Urgell Sat. Coop. C. Ltda., Mollerussa, Lleida, Spain) at 30 L hL^{-1}, surfactant (nonylphenol polietilenglicol ether, Mojante no iónico, Químicas Oro, San Antonio de Benagéber, Valencia, Spain) at 1 L hL^{-1}, paraffin oil (Oil Oro, Químicas Oro, San Antonio de Benagéber, Valencia, Spain) at 2.5 L hL^{-1}, extra virgin olive oil (Pla d'Urgell Sat. Coop. C. Ltda., Mollerussa, Lleida, Spain) at 5 L hL^{-1} emulsified with the above mentioned surfactant at 1 L hL^{-1}, corn oil (Borgesol, Borges, Tàrrega, Lleida, Spain) at 5 L hL^{-1} emulsified with the surfactant above mentioned at 1 L hL^{-1}, and lime sulfur (LS) (Sulfocálcico Concentrado Key, Industrial Química Key, Tàrrega, Lleida, Spain) at 2, 4, and 6 L hL^{-1} on 'Red Chief®' (Table 1). Applications were done between 50 and 80% F_2 (Fleckinger, 1964) to trees of 'Red Chief® Camspur^{cov}' on 'Merton MI-793', planted in 1995 with a tree spacing of 4 m × 1.5 m. Control trees were not sprayed and not mechanically or hand thinned either. The experiment was organized in a randomized complete block design with four replications, with each experimental unit being a section of four trees. Data was taken on the two central trees of each experimental unit.

2.2. Experiment 2: kaolin, soap, oils, lime sulfur, potassium permanganate, calcium chloride, and ammonium thiosulfate on 'Golden Smoothee® CG 10 Yellow Delicious'

A field experiment was conducted in 2005–2008 in Gimenells, Lleida, Spain where we compared hand thinning with two consecutive applications of kaolin (Surround® WG Crop protectant, BASF, Barcelona, Spain) at 5 kg hL^{-1} (1st spray) and at 3 kg hL^{-1} (2nd spray) (2005), potassium soap (E-Coda Oleo K, Coda, Almacelles, Lleida, Spain) at 4 L hL^{-1} (2005–2007), extra virgin olive oil (Pla d'Urgell Sat. Coop. C. Ltda., Mollerussa, Lleida, Spain) emulsified with potassium soap (E-Coda Oleo K, Coda, Almacelles, Lleida, Spain) at 5:4 L hL^{-1} (2005–2007), paraffin oil (Oil Oro, Químicas Oro, San Antonio de Benagéber, Valencia, Spain) at 2.5 L hL^{-1} (2005), LS at 4 L hL^{-1} (2005–2008), salt (sodium chloride, Clásica, Sal Costa, Barcelona, Spain) at 2 kg hL^{-1} (2005–2006), potassium permanganate (Permanganato Potasico Pure Grade, Barcelonesa, Cornellà de Llobregat, Barcelona, Spain) at 1 (2006) or 2 (2007–2008) kg hL^{-1}, calcium chloride (Cloruro Cálcico 77% Aliment. E-509, Drogueria-Pinturas El Barco, Xativa, Valencia, Spain) at 2 kg hL^{-1} (2006–2007), ammonium thiosulfate (ATS) (Ger-ATS LG, L. Gobbi, Campo Ligure, Genova, Italy) at 1 L hL^{-1} (2008), and lime sulfur (Sulfocálcico Concentrado Key, Industrial Química Key, Tàrrega, Lleida, Spain) plus paraffin oil at 4:1 L hL^{-1} (2008) on 'Golden Smoothee®' (Table 1). Applications were done at 80% F_2 to trees of 'Golden Smoothee® CG 10 Yellow Delicious' on 'Malling M.9 Pajam® 2', planted in 1994 with a tree spacing of 4 m × 1.4 m. Control trees were not sprayed and not mechanically or hand thinned either. The experiment was organized in a randomized complete block design with four replications, with each experimental unit being a section of four trees. Data was taken on the two central trees of each experimental unit.

2.3. Experiment 3: chemical vs mechanical thinning on 'Fuji Kiku® 8 Brak' and 'Brookfield Gala® Baigent^{cov}'

A field experiment was conducted in 2010–2011 in Mollerussa, Lleida, Spain (lat. 41.618682°, long. 0.870560°) where we compared chemical and mechanical thinning, on 'Fuji Kiku® 8' and 'Brookfield Gala®', both planted in 2004 on 'Malling M.9' with a tree spacing of 3.5 m × 1.4 m. (Table 1). Chemical thinning treatments included benzyladenine (BA) (MaxCel®, Valent BioSciences Corp., Libertyville, IL) at 150 mg L^{-1}, and naphthalene acetic acid (NAA) (Etifix®, Nufarm España, S.A., Barcelona, Spain) at 10 mg L^{-1}. Thinning sprays were applied when fruit size was 10 mm. Mechanical thinning was done at 80% F_1 (Fleckinger, 1964) using a rotating string machine (Fuet; Fruttur®, Lleida, Spain) at 5 km h^{-1} of tractor speed and 320 rpm of rotational speed with 210 strings. Control trees were not sprayed and not mechanically or hand thinned either. The experiment was organized in a randomized complete block design with four replications, with each experimental unit being a section of four trees. Data was taken on the two central trees of each experimental unit.

2.4. Experiment 4: mechanical vs chemical thinning on 'Golden Reinders®'

A field experiment was conducted in 2010 in La Tallada d'Empordà, Girona, Spain (lat. 42.054349°, long. 3.061983°) where we compared chemical *vs* mechanical thinning using a Darwin® 250 machine (Darwin®; Fruit-TeL Deggenhausertal, Germany) on 'Golden Reinders®' planted in 2003 on 'M.9 NAKB 337' with a tree spacing of 3.8 m x 1.1 m. Mechanical thinning was done at 80% F_1, at 7 or 8 km h^{-1} and 270, 290, or 310 rpm with 270 strings (Table 1). Chemical thinning included BA (MaxCel®) at 100 mg L^{-1}. Thinning sprays were applied when fruit size was 10 mm. Control trees were not sprayed and not mechanically or hand thinned either. The experiment was organized in a randomized complete block design with three replications, with each experimental unit being a section of four trees. Data was taken on the two central trees of each experimental unit.

2.5. Experiment 5: mechanical vs chemical vs hand thinning on 'Gala Galaxy'

A field experiment was conducted in 2010 in La Tallada d'Empordà, Girona, Spain where we compared hand *vs* chemical *vs* mechanical thinning using a Darwin® 250 machine on 'Gala Galaxy' planted in 2000 on 'M.9 NAKB 337' with a tree spacing of 3.7 m × 1 m. Mechanical thinning was done at 80% F_1, at 5, 6, or 7 km h^{-1} and 230, 270, or