Mechanical thinning of Pome Fruit

by

Deon Louw Kirstein

Thesis presented in partial fulfilment of the requirements for the Degree of Masters in Science in Agriculture (Horticultural Science) at the Faculty of AgriSciences, at Stellenbosch University

Supervisor: Professor Karen. I. Theron
Department of Horticultural Science
Stellenbosch University

Co-supervisor: Professor Wiehann. J. Steyn
Department of Horticultural Science
Stellenbosch University

December 2015

DECLARATION

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December 2015

ACKNOWLEDGEMENTS

The Department of Horticultural Sciences for the overall support and services given to make this master's study possible.

Prof Theron to whom I owe the greatest thanks. Securing and implementing the project whilst I was still an undergrad in 2013, patience in the trial and writing process, as well as the invaluable advice and input to write a sensible thesis. Thank you also for giving me the space to grow as an individual.

Prof Steyn for being a second set of eyes to everything and giving valued recommendations and input.

SAAPPA for funding the project.

Wetlab and field assistance for the early morning starts and long days in the orchards and laboratory: Gustav Lötze, Tikkie Groenewald, Andrew Swartz, Revouna Poole, Shantel Arendse and Michiela Arendse.

Producers for their plant material and assistance: Oak Valley Estate; Coenie Groenewald. Eikenhof; Charl Nortier and Lushof; Danie Viljoen and Chris Hands. Maredal; Phil Kilpen.

Thank you to my family and friends whose constant encouragement and belief I valued very much.

SUMMARY

Thinning is an important practice in pome fruit production which aims to ensure an optimal yield of high quality, large sized fruit as well as an adequate return bloom. In South Africa, pome fruit thinning is generally done by means of chemicals, with follow-up hand thinning. When thinning is effective, set and thus the hand thinning requirement should be reduced. This is important as labor cost associated with hand thinning is high and continually rising. Chemical thinning is weather dependent and can be environmentally harmful, which has led to a shift towards environmentally acceptable methods of thinning such as mechanical thinning. From 2013 until 2015 the mechanical string thinners, viz. Darwin 300™, BAUM, and Bloom Bandit™, were evaluated. These machines are used to thin trees during full bloom and reduce the number of flowers before fruit set. The aim of the trials was to reduce fruit set and therefore hand thinning requirement, while increasing fruit size and quality, maintaining yield and return bloom. A range of tractor speeds and rotational rates were evaluated with the Darwin 300™ on 'Forelle' pears and 'Cripps' Pink' apples, while the BAUM was evaluated only on 'Cripps' Pink' apples. The hand-held Bloom Bandit™ was evaluated on 'Forelle', 'Cripps' Pink', 'Fuji' and 'Cripps' Red'. The tractor-driven mechanical thinning devices gave erratic results. The most consistent results on 'Forelle' were obtained using the Darwin 300™ at 5.2 $km \cdot h^{-1}$ and 300 rpm, while the BAUM gave no consistent results. The unreliability of results were due to South African pome fruit orchards currently being unsuitable for tractor-driven mechanical thinning machines. The 'Forelle' orchard trained to a Palmette system was the most suited for thinning, which is reflected in the more positive results obtained, but further improvements are possible. The Bloom Bandit™ effectively thinned pear and apple trees and increased fruit size without a decrease in yield or return bloom. More time is spent on thinning with the device compared to tractor-driven machines and this should be taken into account when considering using the Bloom Bandit™. Thinning intensities of 25%, 50% and 75% of clusters or flowers was applied to mature 'Forelle' and 'Cripps' Red' trees during full bloom. Variable effects were seen on fruit set, yield was reduced to acceptable levels, while fruit size was improved in 'Forelle' but not 'Cripps' Red'. Results showed that when thinning mechanically, the aim should be to remove between 25% and 50% of flowers clusters in 'Forelle' and 50% of flowers clusters in 'Cripps' Red'. These levels of thinning gave the best results in terms of the remaining hand thinning requirements and improved return bloom in 'Forelle'. We, however, only evaluated full cluster thinning and not within cluster thinning, which might also occur during mechanical thinning.

OPSOMMING

Vruguitdunning is 'n belangrike praktyk in kernvrugproduksie en het ten doel om voldoende opbrengs van hoë kwaliteit, groot vrugte en voldoende opvolgblom te lewer. In Suid-Afrika, word kernvrugte gewoonlik chemies uitgedun, opgevolg met handuitdunning. Effektiewe uitdunning verminder set en dus die benodigde handuitdunning. Dit is belangrik aangesien die arbeidskoste verbonde aan die handuitdunning hoog is en voortdurend styg. Chemiese uitdunning is afhanklik van weerstoestande en dit kan ook omgewing-onvriendelik wees. Hierdie nadele het gelei tot 'n verskuiwing na omgewingsaanvaarbare metodes van uitdunning soos meganiese uitdun. Vanaf 2013 tot 2015 is die meganiese Darwin 300™, BAUM en Bloom Bandit™ uitdunmasjiene geëvalueer. Hierdie masjiene word gedurende volblom gebruik om blomme uit te dun en verminder die aantal blomme voor vrugset. Die doel van die proewe was om vrugset en dus die handuitdunvereiste te verminder met ‘n gepaardgaande verbetering in vruggrootte en kwaliteit sonder om opbrengs en opvolgblom nadelig te beïnvloed. Trekker en rotasiespoed is gevarieer met die Darwin 300 ™ op 'Forelle' pere en ‘Cripps’ Pink' appels, terwyl die BAUM net op 'Cripps' Pink' appels geëvalueer is. Daarbenewens was die hand-draagbare Bloom Bandit™ geëvalueer op 'Forelle', 'Cripps' Pink’, ‘Fuji’ en ‘Cripps' Red’. Die trekkergedrewe uitdunmasjiene het wisselvallige resultate opgelewer. Die mees konstante resultate op 'Forelle' is verkry met die Darwin 300™ teen 5.2 $km \cdot h^{-1}$ en 300 rpm, terwyl die BAUM nie konsekwente resultate gegee het nie. Die wisselvallige resultate van die Darwin 300™ en die BAUM is te wyte aan die boorde wat nie vir trekkergedrewe uidunmasjiene geskik is nie. Die 'Forelle’ boord, wat as 'n Palmette stelsel opgelei is, was die meeste geskik vir uitdunning, soos duidelik uit die positiewe resultate wat verkry is, maar verdere verbeterings is steeds moontlik. Die Bloom Bandit™ het peer en appel bome effektief uitgedun deur die handuitdunvereiste te verminder en vruggrootte te verbeter sonder verlies in opbrengs of opvolgblom. Meer tyd word gespandeer tydens uitdunning met hierdie toestel in vergelyking met trekkergedrewe masjiene, en dit moet in ag geneem word met oorweging van die Bloom Bandit™. Uitdunningsintensiteite van 25%, 50% en 75% van die trosse of blomme is tydens volblom toegepas op volwasse 'Forelle’ en ‘Cripps’ Red' bome. Vrugset het aansienlike variasie getoon terwyl opbrengs tot aanvaarbare vlakke verminder en vruggrootte verbeter is in 'Forelle' maar nie in 'Cripps' Red’ nie. Resultate het getoon dat die doel moet wees om tussen 25% en 50% van alle blomme in trosse in 'Forelle’ en 50% van blomme in trosse in 'Cripps’ Red’ tydens meganiese uitdunnig te verwyder. Hierdie vlakke van uitdunning het die beste resultate gegee ten opsigte van die oorblywende handuitdunvereistes en het opvolgblom in 'Forelle’ verbeter. Ons het egter net volledige trosse uitdunning gedoen en nie blomuitdunning binne die tros wat ook tydens meganiese uitdun kan plaasvind nie.

This thesis is a compilation of chapters beginning with a literature review, followed by three research papers. Each paper is prepared as a scientific article for submission to the ***HortTechnology*** journal. Repetition or duplication between chapters was sometimes necessary.

TABLE OF CONTENTS

General Introduction

Apple and pear trees develop an abundance of flowers, which cannot be sustained until full maturity for an economic crop (Costa et al., 2013). Fruit thinning is the practice through which a portion of the crop is removed, and is considered one of the most important orchard management practices (Looney, 1986). In order to remain profitable, thinning should support the production of crops of large sized, high quality fruit in sufficient volumes (Kong et al., 2009). Currently, thinning of pome fruit is dominated by hand and chemical thinning (Greene and Costa, 2013; Dennis, 2000).

Hand thinning is a very expensive orchard practice, and is only used when absolutely necessary. Generally, it is used as follow-up method for final crop load adjustments and when there are no other methods available (Dennis, 2000; Schupp et al., 2008). Chemical thinning is effective on pome fruit, but has challenges. The efficacy is dependent on environmental conditions, and the use of chemicals can have a negative effect on the environment; therefore this method is constantly being challenged (Bound, 2010; Greene and Costa, 2013). An alternative method to hand and chemical thinning is mechanical thinning (Basak et al., 2013; Greene and Costa, 2013).

In the literature review the effects and targets of thinning, as well as the different methods that are available are discussed. The current literature on mechanical thinning of pome fruit is summarized, the benefits evaluated, and an assessment made of the different mechanical thinning devices and their effects on the targeted outcomes of thinning. A range of different mechanical thinning methods have been evaluated with little commercial adoption and this review focuses on the use of string thinners (Webster, 2002).

It has been reported that mechanical thinning is able to achieve all the desired outcomes that thinning needs to achieve. Many advantages exist for mechanical thinning of pome fruit (Bertschinger et al., 1998; Damerow et al., 2007; Dennis, 2000; Webster, 2002). The main benefits over chemical thinning are that weather conditions have a lower impact on the efficacy (Seehuber et al., 2013), and effects are seen immediately, which allows further follow-up methods to be applied if required (Basak et al., 2013; Solomakhin et al. 2012). There are however certain environmental conditions such as low winter chill which can cause differences in parts of the tree reaching full bloom which can influence the efficacy of mechanical thinning. Mechanical thinning is not perfect and has associated problems (Costa et al., 2013; Greene and Costa, 2013), e.g. damage to orchards if incorrectly applied and risk of spreading disease (Damerow et al., 2007; Greene and Costa, 2013). Mechanical thinning is not as selective as hand thinning (Costa et al., 2013). In addition, orchards need to be suitable for mechanization (Greene and Costa, 2013). In South Africa, research on stone fruit has shown that the orchard floor is a critical factor amongst many needed for good results (Theron et al., 2015). Other problems exist due to flaws in the designs of machines such as the inability of the Darwin™ to penetrate deep enough into larger tree canopies for example (Bertschinger et al., 1998; Kon et al., 2013). There is limited research on mechanical thinning on pears, and most research on pome fruit has used apples as their model crop (Veal et al., 2011).

In the first paper we report on the evaluation of mechanical thinning of 'Forelle' pears over two seasons from 2013 to 2015 at Oak Valley, Elgin. 'Forelle' was chosen as it is an important blush pear cultivar in South Africa (HORTGRO, 2014), and the particular orchard is trained to a Palmette system and was therefore suitable for the Darwin 300™. The Darwin 300™ was compared to manual hand removal of 50% of flower clusters, hand thinning after physiological fruit drop and chemical thinning. In the 2014/2015 season, an additional trial was included where different chemical thinning options were compared to the Bloom Bandit™ portable thinning device on 'Forelle' at Lushof, Ceres. The efficacy of thinning treatments with regard to hand thinning requirements, fruit set, yield efficiency, fruit quality and return bloom was evaluated.

In the second paper, we report on two trials that evaluated the BAUM on 'Cripps' Pink' apples on Oak Valley, Elgin. In addition, a trial with the Darwin 300™ on 'Cripps' Pink' at Maredale, Elgin was conducted in the 2013/2014 season. These orchards were chosen due to their suitability for mechanical thinning, viz. central leader for the BAUM and a V-hedge for the Darwin 300™. In 2014/2015, an additional two trials were conducted on 'Fuji' and 'Cripps' Red' at Eikenhof, Elgin using the Bloom Bandit™. Each trial received a standard chemical treatment used on the particular farm, as well as an untreated control that were only later thinned by hand. We evaluated the efficacy of the thinning treatments in terms of hand thinning requirement, fruit set, yield efficiency, fruit quality and return bloom.

In the third paper we report on the effect of manual cluster or flower thinning at different intensities on mature 'Forelle' pear and 'Cripps' Red' apples. These trials were done to determine the level of flower or cluster removal that mechanical thinning should be aiming to achieve. Trees were thinned by removing 25%, 50% or 75% of flowers or whole flower clusters, to identify the ideal level of thinning that needs to be obtained with mechanical thinning. The efficacy of treatments was evaluated by determining fruit set, yield efficiency, fruit quality and return bloom.

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LITERATURE REVIEW: Mechanical Thinning of Pome Fruit

Table of Contents

Introduction

Crop load management is vital for the regular production of high quality fruit with adequate yields. Apple and pear trees develop an abundance of flowers and the subsequent fruit that set can often not be supported to maturity (Costa et al., 2013). Too high a set results in production of poor quality fruit, i.e. small fruit size, poor appearance and internal quality, as well as potential physical damage, resource exhaustion and lowered cold hardiness of trees (Dennis, 2000).

Poor quality fruit do not obtain premium prices and are therefore unwanted. Orchards with unregulated crop loads display alternate bearing, i.e. a fluctuating production pattern with cycles of an “on” and “off” season. This is undesirable as the overall marketable yield over the lifetime of an alternating orchard is lower compared to a more consistent bearing orchard (Pellerin et al., 2011). Excess flowering of fruit trees is reduced by natural mechanisms in the tree, but are usually not sufficient to attain desired levels of cropping. Economic benefits due to optimal crop load regulation can be obtained and this is one of the driving factors for flower or fruit thinning.

Lately, pressures on standard chemical crop load regulation due to the dwindling number of approved compounds have led to exploration of new and improved alternative methods (Bound, 2010; Seehuber et al., 2013; Veal et al., 2011). Environmentally friendly and safer chemicals and mechanical devices have been suggested as possible alternatives (Costa et al., 2013). Mechanical crop load management can be used as a complete alternative or as a compliment to chemical thinning (Seehuber et al., 2013). Mechanical thinning methods are generally used on stone fruit (Dennis, 2000). Mechanical thinning of pome fruit is a recent development. Comprehensive evaluation indicates that thinning with mechanical devices on apples and pears seems to be effective (Greene and Costa, 2013; Hehnen et al., 2012; Kon et al., 2013; Seehuber et al., 2010).

Motivation for Thinning Pome Fruit Trees

Fruit thinning manages the crop load on trees and entails the partial removal of the crop. Looney (1986) proposed that thinning is the most important technique in apple growing to improve fruit quality. Thinning results in high quality fruit with adequate size and coloration, with sufficient sugar for taste and firmness for storability (Kong et al., 2009). The effects of fruit thinning will be analyzed by discussing fruit quality, alternate bearing and yield for the remainder of this section.

EFFECTS OF THINNING ON FRUIT QUALITY. The essential fruit quality parameters that can be enhanced through thinning are fruit size, color, firmness, as well as sugar and acid content (Link, 2000). Recently the price for small and medium-sized fruits on international markets has remained constant or declined (Dennis, 2000). This stresses the importance of size as a criterion for suitable fruit quality. It should be mentioned that not all increases in fruit size adds value to the crop (Wertheim, 2000). ‘Conference’ pears for instance are adversely priced at larger size categories on certain markets. For the remainder of this review it will be assumed that the effects of increased fruit size from thinning are desirable.

Fruit size is specified through fruit weight, diameter and length. Fruit size is mostly regulated by genetics, but intra-plant factors, cultural practices such as thinning, and climatic factors also play a role in determining final fruit size (Theron, 2011). Fruit size is determined by cell number and cell size as well as the intercellular spaces between cells (Goffinet et al., 1995). Link (2000) found a negative correlation between mean fruit weight and crop load, which implies that when the crop load is reduced, mean fruit weight will increase.

Fruit growth is characterized by cell division followed by cell expansion (Lakso et al., 1995). Cell division completes 3 to 4 weeks after pollination in apple and determines the final cell number, whereas cell expansion begins soon after pollination and continues until late into fruit development (Denne, 1960). Two periods of potential limitation for apple growth have been identified, viz. the cell division phase 2 - 4 weeks after full bloom, and the last week before harvest (Lakso et al., 1998). Lakso et al. (1998) also suggested that demand for assimilates increases rapidly after bloom, and if all possible flowers are taken into account, shortages would occur soon after bloom, whereas if the number of flowers is reduced, shortages would be delayed if any and occur 2 to 3 weeks after bloom. This is also similar for pears (Zhang et al., 2005). Thus early thinning of flowers or fruit should result in more assimilates per remaining fruit being available during the critical cell division phase, as well as during cell expansion. Increased fruit size by thinning can further be explained by a higher leaf area per fruit. The availability of assimilates to the remaining fruit is enhanced and the effect is an improvement in size. When the initial set of flowers within a cluster is high, there is intense inter-fruit competition for the available assimilates (McArtney et al., 1996). The reduction of the inter-fruit competition through early thinning dramatically increases the rate of growth of remaining fruit. The distribution of fruit within the tree canopy can also affect the final fruit size, and a more uniform distribution results in improved size (Dennis, 2000). Due to this, thinning within clusters would give the best results for size.

Fruit mature earlier at lighter crop loads than heavier crop loads (Palmer et al., 1997). Provided no vegetative growth is simulated, color is increased in the earlier maturing fruit from lighter crop loads compared to heavy crop loads due to the earlier onset of anthocyanin synthesis (Faragher and Brohier, 1984). Only fruit well supplied with carbohydrates will develop good color (Link, 2000). Thinning reduces the percentage of green fruit and increases yellow ground color of yellow apple cultivars as well as the extent and intensity of surface color in red apples (Kong et al., 2009; Link, 2000; Solomakhin et al., 2012). Poor color development and color loss are two different factors influencing final fruit color (Steyn et al., 2004). The red color in pome fruits is due to production of the antioxidant anthocyanin. Anthocyanin production differs between apples and pears. Apple anthocyanin synthesis is promoted by high light levels and low temperatures, and will increase towards maturation (Steyn et al., 2005). In contrast, most pear anthocyanin is produced only in high light (although some cultivars such as ‘Rosemarie’ and ‘Forelle’ demonstrate a low temperature requirement), and peaks midseason. As pear maturation progresses the concentration of anthocyanin decreases, but continued light is still needed to reduce the dilution effect through continued synthesis of anthocyanin (Steyn et al., 2005). Better light distribution within canopies as well as within fruit clusters due to reduced crop load will assist in fruit color development (Seehuber et al., 2013). Thinning is therefore useful for color development in apple and pear cultivars that need to attain color as an important fruit quality characteristic.

Russet is a physiological disorder of apples characterized by cork formation over the epidermis following environmental stress and varies from season to season (Hirst, 2002; Jones et al., 1991). Fruit is more susceptible to russet at earlier stages of development than later (Link, 2000). Causes of russet on apple include the use of chemicals, microorganisms, and environmental factors like frost, high humidity and prolonged surface wetness (Knoche et al., 2001). Chemical thinners are applied during the most sensitive stage of fruit development and can promote russet formation depending on the chemical (Link, 2000). Carbaryl is a chemical thinner that may increase fruit rusting to unwanted levels if applied within 2 weeks after full bloom (Link, 1973). When applied at full bloom, Ethephon enhanced russet formation to unacceptable levels on ‘Fuji’ apples (Jones et al., 1991). Russet increased linearly to applications of ammonium thiosulphate (ATS) on ‘Elstar’ apples, but may have been due to vigorous shoot growth as a result of heavy thinning rather than the ATS itself (Balkhoven-Baart and Wertheim, 1997). 6-Benzyladenine (6-BA) applied at rates higher than 100 $\mu l \cdot L^{-1}$ can cause russet (Basak, 2004; Greene, 1993). Mechanical thinning is applied early in bloom, and should be able to have little negative impact on causing fruit russet.

Thinning sometimes improved fruit firmness, but results are inconsistent (Hehnen et al., 2012; Solomakhin and Blanke, 2010; Veal et al., 2011). Advanced fruit maturity is often correlated to a low crop load (Wünsche et al., 2000). Increased fruit firmness can lead to improved shelf life, but the reason for this is not fully understood (Wismer et al., 1995). It could possibly relate to the increase of soluble solids and a higher dry matter concentration (Wünsche et al., 2000). Improvements of fruit size and color through thinning are usually accompanied by higher soluble solids concentration (sugars) and titratable acid, which contribute positively to fruit quality through better taste (Link, 2000; Solomakhin and Blanke, 2010).

Effects of thinning on alternate bearing. Overcoming alternate bearing is one of the important reasons for thinning fruit trees. Alternate bearing, also known as biennial bearing, as explained above is the phenomenon of alternating "on" and "off" seasons. In "on" seasons trees produce a dense bloom with high fruit set, resulting in many small fruit of inferior quality. The following season will be an "off" season where bloom density is low and trees set very few large fruit or sometimes no fruit at all (Davis et al., 2004). Alternate bearing is therefore not desirable in fruit production. Producers face four problems from alternate bearing: 1) productivity and profitability fluctuations, 2) compromising tree health and vigor in "on" years, 3) poor fruit quality in "on" years and 4) a general adverse relationship between fruit size and crop load resulting in cumulative reduction in value of unthinned trees (Davis et al., 2004).

Alternate bearing is complex, but is generally influenced by the trees tendancy to initiate flower buds and to set fruit where the growth potential of the tree, growth of short spurs, the ratio between carbohydrate reserves and nitrogen quantities and hormonal acitivities play a role (Jonkers, 1979). From these factors the causes of alternate bearing in fruit trees are hormonal or as a result of assimilate competition (Bangerth, 2005; Taiz and Zeiger, 2006). The plant hormone gibberellic acid (GA) can suppress flower initiation or causes early floral abortion in most pome fruit when present in supra-optimal amounts during critical stages of flower bud development (Lavee, 1989). GAs produced by developing seeds in pome fruit therefore play a significant role in triggering biennial bearing (Bangerth, 2005; Webster, 2002).The auxin indoleacetic acid (IAA) plays a role through its polar transport system as a correlative second messanger with GA in inhibiting flower induction (Bangerth, 2005). Fruit trees have a self-regulating mechanism resulting in shedding of fruit that are small, weak or contain fewer seeds. This happens due to correlative driven abscission caused by competition of adjacent fruit in clusters, or with strong vegetative growth (Bangerth, 2005; Greene and Costa, 2013). The induction of alternate bearing by GA and IAA as proposed by Bangerth (2005) will occur before the natural self-regulation of fruit takes place and the inhibitory effects on the subsequent crop would have already occurred. IAA is stimulated under high concentrations of GA, and with this IAA come inhibiting factors to floral induction (Bangerth, 2005). This stresses the importance of blossom or early fruit thinning to overcome alternate bearing and achieve moderate regular yields of improved fruit size and quality (Davis et al., 2004; Hehnen et al., 2012; Link, 2000; López et al., 2011).

Effects of thinning on yield. As discussed in the previous section, the natural physiological fruit drop is usually not sufficient to remove all excess fruit, and the fruit left on the tree will be of poorer quality. Thinning is then required to adjust crop loads to guarantee a maximum commercial yield (Costa et al., 2013). It is important to consider total commercial yield when removing fruit, as it affects the final quantity of fruit harvested and marketed.

Effective thinning will shift the majority of the yield from smaller to larger fruit size categories, resulting in overall fewer kilograms of fruit, but more kilograms of larger sized fruit which should optimise income (Link, 2000). Therefore, care needs to be taken to achieve a balance between yield and fruit size (Link, 2000). This will depend on the market the fruit from a specific orchard is grown for. Usually, a large number of small fruit per tree through under-thinning is not desired, as is a small number of oversized fruit per tree as a result of over thinning.

Hehnen et al. (2012) evaluated hand thinning of apples to one fruit per 10 cm of shoot after physiological fruit drop compared to a conventional chemical and two mechanical treatments. Mechanical thinning with the BAUM was applied at full bloom with 260 rpm and 360 rpm and a tractor speed of 2.5 $km \cdot h^{-1}$ and the chemical treatment was a mix of 2% lime sulphur and Crocker's fish oil applied at 20% and again at 80% bloom, and post bloom 6-BA and carbaryl at 10 mm fruitlet size. Hand thinning was too light resulting in high set within clusters, whereas chemical and mechanical thinning was more severe and resulted in lower fruit set. The more severe chemical and mechanical thinning resulted in 30% lower yields but with increased fruit quality. Similar reductions in fruit set and yield were seen when mechanical thinning was performed on 'Gala Mondial' apples (Solomakhin and Blanke, 2010). Loss in yield in all thinning treatments was outweighed by the higher value crop due to better fruit quality (Hehnen et al., 2012; Solomakhin and Blanke, 2010). Mechanical thinning of pears gave similar results (Maas and van der Steeg, 2011). The value of a 'Conference' pear crop is greatly dependent on the size distribution at harvest. The aim of a producer would be to maximize the total percentage of fruit with a diameter of 65 mm or greater. For this to become a regular reality, crop load needs to be controlled. Additional hand thinning is often needed to remove excess fruit, especially the small and deformed fruit in order to achieve the overall effect of improved sized fruit (López et al., 2011; Maas and van der Steeg, 2011).

In general, there is a trade-off between yield and fruit size in both apples and pears, implying that an increase in fruit size is often accompanied by a reduction in total yield when fruit trees are thinned (Davis et al., 2004). Therefore, a balance needs to be found in yield and fruit size.

Methods of Thinning

Different methods of thinning exist. The method/s chosen by producers are generally influenced by cultivar, as well as the specific norms in production areas. The overall objective of thinning should determine the method(s) of thinning chosen by a producer. The following influences the descisions for choosing specific thinning methods: (1) production system- certain methods are not allowed in certain systems, i.e. chemicals in organic production, (2) effective period within which the method can be applied, (3) the costs of the method, (4) the sustainability associated with the method, (5) whether a chemical is registered on a crop and (6) weather condition during the thinning window. In this section the objectives in terms of the trade-off between fruit quality and yield, as well as return bloom will be critically evaluated for four different thinning methods.

ARTIFICIAL SPUR EXTINCTION. Winter pruning of bearing wood is the earliest form of thinning that can be applied (Costa et al., 2013). Pruning removes a significant number of competing flower buds before competition for assimilates begins after bud burst (Jones and Koen, 1986). The removal of flower buds before thinning can be used to increase fruit size, especially if weaker buds are selectively removed (Jones et al., 2000). Artificial spur extinction (ASE) is a concept currently used and researched in tree management (Tustin et al., 2011). ASE is a form of pruning where the density of all the buds is reduced in late winter or early spring (Breen et al., 2014; van Hooijdonk et al., 2014). Weak and poorly positioned bud removal can be targeted in order keep the best quality buds and to improve light distribution in the canopy (Breen et al., 2014). As a result of the ASE reducing floral bud density, the remaining floral buds will have increased fruit set (Breen et al., 2014). The allocation of finite carbon reserves and new assimilates early in the season are portioned to a lessened number of sinks after ASE which optimizes the use thereof to give improved yields with larger fruit size (van Hooijdonk et al., 2014). Reports show that ASE can increase red blush coverage on 'Scilate' apples through improved illumination of the fruit (van Hoojidonk et al., 2014). ASE is being evaluated in developing a predictive fruit set model for 'Gala' apples to accurately set crop loads, and to be used as an alternative to conventional thinning practices (Breen et al., 2014). ASE is not influenced by production system (organic vs. conventional), weather condition during and after bloom.

HAND THINNING. This method entails the physical removal of excess, unwanted flowers or fruit by hand (Webster, 2002). Although there have been major developments over the last 75 years in thinning, hand thinning remains an important cultural tool used by fruit growers (Dennis, 2000). As a result, hand thinning will stay relevant and an important method of thinning especially in countries like the Netherlands where no chemicals are registered for thinning pears (Maas and van der Steeg, 2011).

Hand thinning can be applied at any time during the growing season, but usually happens at two distinct periods. The first hand thinnning takes place during bloom when flowers are removed and the second takes place before set has occurred (Webster, 2002). Bloom flower removal is only feasible and economic when applied to young and newly planted trees where shoot growth and canopy management is vital (Webster, 2002). Using this strategy to thin older mature trees is too expensive and time consuming and is only used when no other feasible method exist. Some production areas in Washington State use hand thinning widely, and early flower thinning has been used effectively in cool production areas on small fruited cultivars in New Zealand (McArtney et al., 1996). In addition, hand flower thinning is high risk as unforeseen factors may still further reduce fruit set after thinning (Greene, 2004). The second period is traditionally the most common time for performing hand thinning, and is after fruit set and physiological fruit drop has taken place and where final crop load can be estimated (Webster, 2002). The timing allows for crop adjustment with lower risk as uncontrollable conditions such as frost in spring would have passed (McArtney et al., 1996). At this time in the season the fruitlets with poor characteristics can be selectively removed (Costa et al., 2013) allowing for better fruit quality and fruit distribution in canopies (Webster, 2002). A secondary effect hereof is that the need for sorting post-harvest is reduced and a higher percentage of fruit attains export grade quality. Hand thinning is reliable and environmentally acceptable and is allowed in organic production (Costa et al., 2013).

A negative aspect of hand thinning is large labor requirement in limited time (Schupp et al., 2008). As a result, when hand thinning is used, it adds significantly to the cost of pome fruit production. This has resulted in hand thinning being predominantly used as a follow-up thinning method for the final adjustments to crop loads. Hand thinning is thus generally applied in conjunction with another method of thinning. This has been the case both in pears and apples (Maas and van der Steeg, 2011; Schupp et al., 2008).

Chemical Thinning. The thinning of pome fruit is mostly done using chemicals (Greene and Costa, 2013), where the different production areas have different regulations regarding chemical use. In South Africa, chemical thinning is widely used for apples but to a lesser extent for pears (Theron, 2013). Reactions to chemicals differ between pome fruit types and cultivars (Garriz et al., 2004)

Chemical thinning can be performed during bloom or post-bloom. Thinning at bloom is performed using caustic chemicals that prevent fertilization and fruit set by damaging a portion of the flower (Fallahi and Fallahi, 2004). Bloom thinning when 80% of “king” flower have reached anthesis means that many “king” flowers would have been pollinated but not the lateral flowers (Greene, 2004). The mechanisms of action for these chemicals are generally through preventing pollen germination and pollen tube growth on the stigma or in the style, or stimulating the degeneration of the female ovules in the ovaries (Webster, 2002). Flower thinning on pear is not popular due to fruit set being less reliable than apples (Wertheim, 1997). Chemical thinning post-bloom is achieved by stimulating natural fruit drop (Webster, 2002). Chemicals used post-bloom are generally applied when fruit are 7 - 10 mm in diameter due to increased susceptibility of fruit at this stage (Greene, 2004). Post-bloom chemical thinning is the most common chemical thinning strategy, as growers want to be certain that fruit set is adequate (Wertheim, 2000). A brief summary of chemicals used for thinning will follow. The chemicals are grouped into four general categories: caustic sprays; plant bioregulators; insecticidal carbamates, and photosynthetic inhibitors, and combinations of these (Dennis, 2000).

ATS is used as a caustic thinning spray and as a foliar fertilizer. Fertilisation of flowers is prevented through de-activating the style or stigma of the pistil (Bound and Jones, 2004). Reductions in fruit set can be achieved when applied during bloom. ATS effectively reduced set of 'Clara Frijs' pears when applied at rates of 1 – 2% at full bloom. Fruit size was not improved and reductions in return bloom occurred due to significant leaf damage (Bertelsen, 2002). When ATS was applied at 1.0% on 'Elstar' apples at full bloom, thinning was effective, but at higher concentrations it caused leaf damage (Balkhoven-Baart and Wertheim, 1997). Lime sulphur is an organic product that can be used to thin fruit with the same mode of action as ATS by inhibiting pollen germination and tube growth in the style (Bound, 2010; Guak et al., 2004). Crop load reduction of 40% with improved fruit shape and size was achieved with lime sulphur at 2% on 'Gala' apples when applied at 20% and again at 80% bloom (Bound, 2010).

Synthetic auxins and cytokinins are regularly used as post-bloom chemical thinners and as plant bioregulators. The most important auxins used are napthaleneacetic acid (NAA) and its amide naphthaleneacetamide (NAD), which both are effective post-bloom thinning agents on pome fruit. After NAA is applied, the IAA export from fruitlets is considerably reduced (Bangerth, 2000). Thus the mode of action of NAA is believed to be through reducing IAA export out of weaker fruitlets causing them to abscise (Bangerth, 2000; Ebert and Bangerth, 1982). When NAA was applied at 45 $mg \cdot L^{-1}$ to 'Clara Frijs' pears at petal fall (±6 mm fruit diameter), no influence was seen on set, but fruit size was improved (Bertelsen, 2002). Garriz et al. (2004) found that applying NAA at 10 $\mu l \cdot L^{-1}$ at 17 days after full bloom (DAFB) to 'Abbé Fetel' pears thinned less than when applied later at 27 DAFB, as is the case for apples. NAA has been used post-bloom for decades on apples and applied up to 20 $\mu l \cdot L^{-1}$ to reduce crop load, but is often associated with smaller fruit size (Dennis, 2000). NAA is ineffective if applied after the physiological fruit drop. Some negative side effects following NAA application can be the development of "pigmy" fruit in 'Delicious' apples (Greene and Costa, 2013). NAD thinned within clusters and therefor reduced the number of clusters with more than one fruit when applied at 30 and 40 $\mu l \cdot L^{-1}$ at 8 – 10 mm fruit diameter on 'Early Bon Chrétien' (Theron et al., 2011). NAD is seen as a milder thinner compared to NAA and should be used under more favorable thinning conditions.

6-BA is a synthetic cytokinin and its mode of action is through increased competition between fruitlets and the 6-BA-stimulated lateral growth of bourse shoots that causes less IAA transport from fruitlets and the abscission of weaker fruitlets (Bangerth, 2000). 6-BA is the main cytokinin used for thinning due to its low toxicological profile (Petri et al., 2006). 6-BA applications of 50 $\mu l \cdot L^{-1}$ and 100 $\mu l \cdot L^{-1}$ at 10 mm is the most effective rates and time of application in apples (Greene, 1993). Applications of 150 $\mu l \cdot L^{-1}$ can overthin apples, cause spur elongation and asymmetrical fruit development (Greene, 1993). When 6-BA was applied to 'Clara Frijs' pears at a rate of 100 $mg \cdot L^{-1}$ at 12 mm fruitlet size, a decrease in fruit set was recorded and fruit size was increased with no adverse effect on return bloom (Bertelsen, 2002). The increase in size was due to stimulated cell divisions, which is a normal response to cytokinins (Bertelsen, 2002; Petri et al., 2006). When 6-BA was applied at the same concentration at 10 - 12 mm fruitlet diameter it increased abscission of fruitlets of numerous apple cultivars (Basak, 2004). 6-BA is reported to thin indiscriminately as it thins as many clusters carrying one fruit as clusters carrying multiple fruit but depends on the rate and the timing of application (Greene, 1993).

Ethephon ((2-chloroethyl)-phosphonic acid), also a plant bioregulator, is used for bloom thinning and has had positive thinning effects on pome fruit, but is seen as an erratic thinner (Looney, 1986; Wertheim, 2000). Ethephon is also registered for late use (17 - 25 mm diameter) on apples where susceptibility of fruits redevelops as fruit reach 16 mm in diameter (Schupp et al., 2012). The thinning effect is achieved through ethylene-induced reduction in the basipetal transport of auxin out of fruits, causing weaker fruitlets to drop (Ebert and Bangerth, 1982). Variation exists between cultivars with some such as 'Golden Delicious' being more Ethephon sensitive (Schupp et al., 2012; Wertheim, 2000).

ACC (1-aminocyclopropane carboxcylic acid) is a natural precursor for ethylene and has shown promise as a thinner on apples (Schupp et al., 2012). Applying ACC is more effective at 20 mm fruit diameter than at 10 mm, and the thinning efficacy increases linearly with increasing dose from 100 $\mu l \cdot L^{-1}$ to 500 $\mu l \cdot L^{-1}$ (Schupp et al., 2012).

Carbaryl is a carbamate insecticide and is effective for thinning most apples cultivars, but ineffective in thinning most pears (Webster, 2002). Applications of carbaryl are generally 2 – 4 weeks after full bloom (12 mm) at a rate of 750 $\mu l \cdot L^{-1}$ (Wertheim, 1997). Generally, carbaryl is considered to be a mild thinner with little chance of over thinning and is generally used in a tank mix to boost activity of other thinners (Schupp et al., 2012). Carbaryl harms beneficial orchard insects such as bees, and water organisms and for this reason is forbidden in many European countries (Webster, 2002; Wertheim, 1997). Due to this, the future of carbaryl as a chemical thinner is in question (Greene et al., 2011). Carbaryl is still registered for use in South Africa, but producers and researchers are looking for a suitable alternative (Theron, 2013).

Metamitron is a photosynthetic inhibitor that has a thinning effect on apples when applied at a fruitlet size of 10 – 12 mm (McArtney and Obermiller, 2012). Metamitron works through disrupting the photosynthetic pathway 7 - 10 days after application and reduces electron transport by 60% (McArtney and Obermiller, 2012). Many other chemicals are listed by Wertheim (2000) and Dennis (2000), but are not discussed here.

Chemical applications are quick, relatively easy at appropriate timing (depending on the chemical being used), and require little labor. The cost associated with chemical thinning is lower compared to hand thinning (Costa et al., 2013; Webster, 2002), and is the reason why chemical thinning is being examined as a cheaper alternative for pears (Maas and van der Steeg, 2011). A challenge with chemical thinning is inconsistency of response (Wertheim, 2000). Fruit tree response to chemical thinning can be inconsistent between seasons (McArtney et al., 1996). The discrepancies are mainly due to environmental conditions and cultivars (Costa et al., 2013). Weather conditions, in particular temperature and air humidity, are important when spraying and the conditions before, during and after affect the ultimate thinning response (Greene, 2002; Wertheim, 2000). Williams (1979) summarized factors that result in difficulty to thin. These include cultivar differences, i.e., ‘Granny Smith’ is easy to thin whilst ‘Fuji’ is very difficult to thin, control of orchard vigor, active pollinators, older more mature trees, high spur fruit set, fruit set singly within clusters rather than more fruit per cluster, a high bloom density possibly following an “off” year and horizontal branches. Applying chemicals in mild winter regions, such as South Africa, where blooming is prolonged and fruit set irregular proves difficult and post-bloom applications, which are generally safer, are recommended (Petri, et al., 2006; Theron, 2013). The availability and effectiveness of chemical thinning programs will vary by crop, orchard and season (Schupp et al., 2008). The inconsistent and variable responses complicate chemical thinning.

Increased concern about the environment and public health has led to the banning or phasing out of many chemical thinners (Bound, 2010). An example is Elgetol (sodium 4,6-dinitro-o-cresol) which was removed from the market in 1989 due to high costs of re-registration (Fallahi and Willemsen, 2002). Carbaryl has been withdrawn from the European Union, and NAA and NAD are being phased out in many European countries (Veal et al., 2011). Due to the restrictions on chemicals available for thinning, alternatives need to be considered and the search for new and improved chemicals continues (Bound, 2010). Mechanical thinning has been identified as a potential option for thinning pome fruit and will be further discussed in the following sections (Greene and Costa, 2013).

MECHANICAL THINNING. A range of different mechanical thinning methods have been evaluated, but limited commercial adoption has taken place in pome fruit (Webster, 2002). These methods include: (1) clubbing thinning mostly used for stone fruit, (2) high pressure spray guns, (3) hot air to remove or burn flowers or fruit off trees, (4) trunk or limb shakers to shake off fruitlet and (5) rope thinners (Dennis, 2000; Webster, 2002).

Most mechanical thinning research has been conducted during bloom, although there has been some research conducted during the post bloom or fruitlet stage. Various methods using ropes have been tried including heavy ropes dragged over the trees as the frame holding the ropes is rotated above the tree. These methods are not recommended for apples as too many spurs were knocked off and too much foliage damage was recorded (Dennis, 2000). String thinner development was done to increase the efficiency of thinning and add a tool to integrated thinning programs, with little need for additional chemical treatment and at a lower cost (Bertschinger et al., 1998). The effect and use of mechanical thinning is not as weather dependent as chemical thinning (Seehuber et al., 2013). From these first efforts, significant developments have taken place in string thinners, which will be the focus of the next section.

Mechanical Thinning of Pome Fruit using String Thinners

The search for a suitable string thinner began in the 1990's (Bertschinger et al., 1998). Since then mechanical thinning has developed to such an extent that it is now used commercially for thinning of pome fruit (Costa et al., 2013; Greene and Costa, 2013). Apples have been used as the model crop on most of the research done with mechanical string thinners, but extrapolations can be made to pears given that they are both pome fruits (Veal et al., 2011). Two main challenges exist for mechanical thinning of pome fruit. The first of these is the extent of leaf area present during bloom as considerable damage to foliage could be detrimental (Greene and Costa, 2013). In South Africa, this can be further complicated due to delayed foliation caused by a lack of winter chilling (Theron, 2013). The second of these problems is the potential threat of spreading pathogens, i.e. Fire Blight (*Erwinia amylovora*), which could be spread down a row as the fungus enters the plant through damaged leaves (Greene and Costa, 2013). This, however is not applicable in South Africa.

The main string thinners will be described after which their thinning efficacy and effect on fruit quality, alternate bearing and yield will be evaluated.

String Thinners. String thinners are currently dominated by two models, namely the Darwin™ and the BAUM (Fig.1 and 2). These implements are attached to tractors and powered through the hydraulic system, and can be set to achieve different levels of thinning (Solomakhin et al., 2012). These machines have rotors with strings attached and blossoms are knocked off when the spinning rotors pass through the trees as the tractors are driven down the tree rows. The rotor speed is usually measured as the number of revolutions per minute (rpm) (Damerow et al., 2007). The thinning efficacy can be increased through increasing rotor speed or decreasing tractor speed or both (Seehuber et al., 2013). Therefore, an increase in rotor speed versus an increase in vehicle speed has opposite effects (Solomakhin and Blanke, 2010; Solomakhin et al., 2012). The development of the integrated coefficient of thinning (ICT) was done to try and devise an optimum level of thinning through the use of string thinners (Solomakhin et al., 2012). The ICT takes the variable effects of rotor and tractor speeds, as well as fruit set before and after application into account (Seehuber et al., 2013). An ICT <8 is the level considered sub-optimal thinning and a value >50 is considered to be over thinning. It is known that within cluster thinning is more effective than reducing the number of clusters (Knight, 1980). Mechanical thinning is able to achieve this by removing 2 - 3 flowers per cluster. A further 1 - 2 flowers can be lost due to subsequent drop to leave an ideal number of flowers on the trees (Veal, et al., 2011). With this known, an ICT can be chosen that will suit the level of mechanical thinning needed.

String Thinners: Darwin™. The Darwin™ was developed in 1996 by H. Gesser, Friedrichshafen-Hirschblatt, Germany (Bertschinger et al., 1998). The machine consists of a vertical axis and depending on the model can be 2 - 3 m high and has nylon tubes 60 cm in length attached. The axis spins at different speeds to produce a curtain to hit off flowers as the implement is brought into contact with trees. At first the recommended tractor speed was 4 $km \cdot h^{-1}$ with a rotor speed of 1500 revolutions per minute (Bertschinger, et al., 1998). Currently, it is recommended that the driving speed should be between 6 $km \cdot h^{-1}$ and 18 $km \cdot h^{-1}$, and the rotor speed between 150 rpm and 450 rpm (Fruit Tec, www.fruit-tec.com). The height and angle of the vertical rotor can be adjusted according to needs of the orchard being thinned (Schupp et al., 2008).

Due to the tall and vertical structure of the Darwin™, it can only be used on certain orchard layouts and training systems. Complex and larger trees cannot be thinned effectively, whereas training systems such as the Palmette, fruiting walls and V-hedges can be thinned effectively. When the Darwin™ is used on complex, larger trees, too little thinning takes place in the tops of trees as well as central parts of trees close to the leader, while over thinning may occur in the outer canopy (Weibel et al., 2008).

String Thinners: BAUM. The BAUM is a string thinner with a similar concept to the Darwin™, but with a different structural design. The BAUM was developed between 2004 and 2006 at the University of Bonn, Germany, and comprises of three horizontal rotors with adjustable angles that are attached to a central vertical frame (Damerow et al., 2007). The arms are flexible and will smoothly move out of the tree when brought into contact with a strong branch or the trunk of a tree due to a spring mechanism that is built into the arms (Seehuber et al., 2013). The acronym BAUM stands for “Bonner Ausdünnungsmaschine” and the machine is also called the UniBonn in the USA (Basak et al., 2013; Seehuber et al., 2013). The BAUM was developed to overcome the short comings of the Darwin™, i.e. the lack of thinning inside the tree canopy and over thinning the periphery of the lower canopy.

First trials with the BAUM at 320 rpm and 2.5 $km \cdot h^{-1}$ removed a third of the peripheral and central canopy flowers with negligible risk of over thinning (Damerow et al., 2007). Basak et al. (2013) found that the BAUM, when used between 5 and 7 $km \cdot h^{-1}$ and 360 – 460 rpm, could precisely remove flowers in the canopy through the arms penetrating the canopies. The BAUM is suited to different and more complex orchard designs and training systems and is suited to thin all upright trees with flexible branches (Kong et al., 2009). The vertical tall and slender spindle type trees, as well as Solaxe and fruiting wall orchards with thinner flexible branches are suited for thinning with the BAUM (Seehuber et al., 2013).

Since the first trials with the BAUM and Darwin™, there have been significant improvements in the precision and predictability of use (Greene and Costa, 2013). Foliage damage first reported has been reduced to low levels (Basak et al., 2013). When used for the first time in established orchards, the string thinners caused complete flower bunches and spurs to be removed (Veal et al., 2011). The spur removal is to be expected as the use of the thinning machines need to “make their path” in the orchard and then in subsequent seasons are less destructive as long as the same machine settings are used. Adoption of these string thinners in pome fruit has been on trial in many countries including South Africa (Seehuber et al., 2013).

String Thinners: Hand-held Flower Thinners. Recently, portable hand-held flower thinning machines have been developed. Such a device is the Electro-flor® which was developed in France in 2009 (Jay et al., 2009). It consists of a telescope pole 3 m in length, powered by a 48 volt battery (Jay et al., 2009). The battery has sufficient power for approximately 8 – 10 hours of operation

(Mrowicki, 2012). The 30 cm tip has 5 to 8, 26 cm long cords attached and can rotate at various speeds. These cords are made of highly resistant yet flexible material. The device has been evaluated on apricots, peaches, cherries and apples. For apples the rotational speeds of 1600 – 1800 rpm are recommended (Delmas, 2007). Jay et al. (2009) found that results on apples were promising and that the device would also be suitable for use on pears.

The Bloom Bandit™ is another such device and was recently released in the USA (Fig. 3). This device was developed from a commercial weed trimmer and the initial version was powered by a gasoline engine on a pole, but was found to be too heavy and noisy (Warner, 2012). The product has since been adapted to use a 12 volt battery as power source. The device consists of a 1.8 m pole and an 18 cm rotating tip that turns at a speed of 1300 rpm. The number and length of the plastic strings can be varied as needed.

These devices are relatively simple and inexpensive mechanical thinning options (Mrowicki, 2012). The objective when using these devices should be to remove 50% of the flowers on the first pass past a branch (Delmas, 2007). The time that thinning could begin is at “pink” stage, but the best results are obtained at full bloom. These devices allow for a more targeted thinning approach and are suited to each individual tree’s needs for the specific crop load strategy (Jay et al., 2009). A problem with this device is that it will take a greater number of working hours in the orchard to achieve what is needed within the limited period that the bloom thinning can be performed (Delmas, 2007).

Effects of string thinners: Fruit quality. When first used, the Darwin™ reduced fruit set but did not enhance fruit size on apples due to the tree shape and branches that were too long (>70 cm) and could not make even contact with the rotating spindles (Bertschinger et al., 1998). The lack of thinning in the inner canopy by the Darwin™ explained above has caused lower fruit quality in these areas (Bertschinger et al., 1998). Later tests on apples with the Darwin™ showed that a rate of 245 rpm and tractor speed of 4 $km \cdot h^{-1}$ could reduce set and increase fruit size when applied at tight cluster to full pink stage (Schupp et al., 2008). When the Darwin™ was used at a similar rate of 220 rpm with twice the tractor speed (8 $km \cdot h^{-1}$), fruit weight was increased by up to 50% (Sinatsch et al., 2010). Thinning with the Darwin™ at 20% full bloom caused greater increases in fruit size than when thinning later at 80% full bloom (Schupp et al., 2008). Due to the BAUM being able to thin deeper into the canopy, the fruit quality is improved near the trunk where flower quality is usually lower (Basak, et al., 2013). Fruit size increased by 15% when apples were thinned during full bloom with the BAUM at 360 rpm and tractor speeds between 5 – 7.5 $km \cdot h^{-1}$ (Solomakhin and Blanke, 2010). The portion of apples with a diameter of 70 – 75 mm was increased by 20% when thinned with the

BAUM (Kong et al., 2009). The BAUM increased fruit size for both 'Alexander Lucas' and 'Conference' pears when thinned at 400 rpm with a tractor speed of 5 km·h^{-1} (Seehuber et al., 2010). Severe thinning with the BAUM had a positive effect on fruit size (Hehnen et al., 2012: Solomakhin et al., 2012). The size improvement is through improved source: sink relationship with a larger amount of photo-assimilates for remaining fruit (Seehuber et al., 2013).

Fruit color is enhanced with the Darwin™ and the BAUM (Kong et al., 2009; Sinatsch et al., 2010). Solomakhin and Blanke (2010) and Solomakhin et al. (2012) found that thinning with the BAUM enhanced red color and ground color of 'Golden Delicious Reinders' and 'Gala Mondial' apples. This is contrary to Basak et al. (2013) who found a slight reduction in red color in 'Sampion' and 'Jonagored' when thinned with the BAUM. Reducing crop load should accelerate maturity slightly, but this was not always the case as reduced competition among fruit may delay maturity resulting in increased firmness (Kon et al., 2013). Mechanical thinning of apples with the BAUM at 360 rpm and tractor speed of 7.5 km·h^{-1} gave firmer fruit than an unthinned control, and as a result fruit should have a longer shelf life (Solomakhin et al., 2012).

Results on titratable acids (TA) and soluble solids concentration (SSC) varied between trials in which mechanical thinning was evaluated. A higher SSC, and to a lesser extent TA will increase fruit taste, and shows increased starch breakdown for fruit from mechanically thinned trees (Bertschinger et al., 1998; Hehnen et al., 2012; Solomakhin and Blanke, 2010; Solomakhin et al., 2012). This effect can be explained through the increased PAR available for the fruit and improved light utilization (Solomakhin et al., 2012).

EFFECTS OF STRING THINNERS: ALTERNATE BEARING. Mechanical thinning is performed during bloom and as explained previously, this is the optimal time to thin to effectively overcome alternate bearing (Costa et al., 2013; Seehuber et al., 2013). Mechanical thinning at pink/red flower stage has been identified as a good time for breaking alternate bearing (Seehuber et al., 2013). Many trials have shown that return bloom is neither affected positively or negatively by mechanical treatments (Basak et al., 2013; Damerow et al., 2007; Kon et al., 2013). Where severe mechanical thinning was used with rotor speed at 360 rpm adequate return bloom of 92% was achieved (Hehnen et al., 2012).

EFFECTS OF STRING THINNERS: YIELD. The Darwin™ significantly reduced fruit set in initial trials, but large variation occurred between cultivars (Bertschinger et al., 1998). The first trials with the BAUM recorded yield losses between 5% and 10% with complementary increases in fruit size of up to 20% (Damerow et al., 2007). Later studies have shown that flower removal on apples ranged from

16% for ‘Pinova’ and ‘Jonagored’ to 35% for ‘Sampion’ compared to their controls, and did not result in significant reductions in yields (Basak et al., 2013). Mechanical thinning reduced the intensity of June drop of ‘Conference’ pears but resulted in yield losses of up to 26% but with increases in fruit size (Seehuber et al., 2010).

Reductions in yield with increases in thinning severity have been observed before (Hehnen et al., 2012; Kong et al., 2009; Schupp et al., 2008; Solomakhin and Blanke, 2010). It is important that a loss in yield is met with a beneficial increase in fruit size. Usually the unthinned controls give higher yields but of lesser value compared to mechanical thinning due to the trade off in fruit size (Hehnen et al., 2012; Solomakhin and Blanke, 2010).

Critical evaluation of string thinners. The use of string thinners on pome fruit trees could be an alternative to chemical thinning where chemicals are not available for use due to banning and/or where hand thinning costs are high and to reduce the impact on the environment from chemical use (Basak et al., 2013; Seehuber et al., 2013). Before using mechanical string thinners, tree architecture in the orchard has to be adapted to accommodate the thinning machines in use (Bertschinger et al., 1998). The effects of string thinning on fruit quality, overcoming alternate bearing, and yield are consistent with overall objectives of thinning and comparable to other methods of thinning. The reduced requirement for hand thinning of mechanically thinned trees compared to unthinned trees lowers production cost (Solomakhin and Blanke, 2010). Timing of application for these methods of thinning is generally around full bloom, allowing for effective regulation of fruit load and control of alternate bearing (Costa et al., 2013). Due to thinning being performed during bloom, with lesser dependence on timing and weather conditions, there is a longer time frame for thinning, which allows for implements to be shared between growers (Seehuber et al., 2013).

Research on pears indicated that mechanical thinning reduced the natural June drop and did not induce any subsequent drop thereby reducing the risk for either over or under thinning (Seehuber et al., 2013). When first used, the BAUM induced spur and shoot damage (Damerow et al., 2007). Damage to leaves has since been reduced and studies with even fast rotor speeds of 460 rpm have shown leaf damage of less than 10% (Basak et al., 2013; Kong et al., 2009). Higher rotor speeds are recommended for thinning efficacy, but this result in more tree damage. To reduce damage to trees, the tractor speeds should be increased (Solomakhin et al., 2012). The level of thinning from high rotor speeds and tractor speeds have given sufficient yields with high quality fruit with improved size and taste, and with good potential for the trees to overcome alternate bearing (Solomakhin et al., 2012).

Broadly speaking, mechanical thinning can only be applied selectively to certain areas of trees, and due to the lack of predictability and precision hereof will remain a risk to producers (Costa et al., 2013). This, however, is also the case for other methods of thinning such as chemical thinning. If the thinning efficacy is not good enough, further adjustments of the crop load with follow-up methods such as hand thinning is still possible (Basak et al., 2013).

Effects of string thinners: Conclusion. Kon et al. (2013) summarized most of the mechanical thinning literature and saw that in all cases fruit set was reduced and fruit size was increased. Yield was reduced in 50% of the cases and return bloom was increased in more than half of the studies.

As mentioned, the tractor speeds and rotational rates used in mechanical thinning will vary between cultivars. i.e., in 'Sampion', the best combination was high tractor speeds with low rotor rates, while in 'Pinova' it was found that lower tractor speeds with higher rotor rates performed the best (Basak, et al., 2013). Generally, it is recommended that higher tractor speeds be utilized with high rotor speeds to prevent any over thinning or harm to the trees (Veal et al., 2011). Mechanical thinning is proposed as an additional tool as suggested by Solomakhin et al. (2012), rather than a complete alternative as implied by Seehuber et al. (2013). More research is needed to better understand where mechanical thinning is able to fit into the thinning practices of different production regions for different pome fruit cultivars. Satisfactory results have been obtained with mechanical string thinners in combination with chemical thinning and hand thinning (Basak et al., 2013; Seehuber et al., 2013). Follow-up hand thinning has enhanced the effects of mechanical thinning, but results for this varied and depended on cultivar. Currently this is the best option for mechanical thinning.

Initial trials showed the Darwin™ to be effective on some cultivars like Jonica, but not on others like Golden Delicious, suggesting that different thinning requirements exist for different cultivars. This is also the case with chemical thinning, where some cultivars are considered easy to thin, and others are difficult to thin (Williams, 1979). Due to different growth habits and the slightly different flower cluster anatomy of different cultivars, it would be expected that different thinning efficacies could exist, but no literature has referred to this.

The Darwin™ has been adopted for commercial bloom thinning in many stone fruit growing regions including South Africa (Schupp et al., 2008; Theron et al., 2015). The BAUM has not been evaluated on pome fruit in South Africa. Growers are change-averse and adoption of new technologies will only occur following further local trials to demonstrate the usefulness of mechanical thinning in their management programs (Ellis et al., 2010).

Conclusion

Thinning pome fruit trees remains an important orchard management practice. The tools available to use are diminishing; the chemicals allowed are becoming less while labor is becoming less availability and more expensive. As a result mechanical thinning is considered as an alternative. In addition, thinning methods need to be more sustainable, and remain effective and efficient.

Mechanical thinning with string thinners has mostly focused on the Darwin™ and BAUM machines. These were developed and are produced in Germany, in production regions where there was pressure to find alternative methods to chemical and hand thinning. Hand-held string thinning devices are also a new option to be considered. Commercial adoption of mechanical thinning has taken place on various crops including pome fruit, but there is scope for more widespread commercial adoption on pome fruit. In areas where chemical thinning is still possible, this will remain the preferred method of thinning as it is better understood by producers and relatively inexpensive. Currently, mechanical thinning can be used as a thinning method complemented by other methods of thinning such as hand thinning, but not as a sole practice.

Effects of mechanical thinning on the fruit quality, alternate bearing and yield are consistent with the general objectives of thinning, making it an effective method of thinning. It is important to make sure that the various effects of string thinning are well understood by those using them and the effect they will have on overall thinning objectives. These will include the training of labor with the new devices, as well as understanding the rotor rotation speeds and tractor speeds that are required to achieve the desired outcome. The understanding of using the string thinner in different production systems such as the different cultivars and the different training systems requires further ‘fine-tuning’. In South Africa, research is still needed on string thinners on pome fruit to evaluate the effects of continued use of the mechanical thinners in orchards and the potential cost benefits it brings.

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Fig. 1. The Darwin 300™ mechanical bloom thinner

Fig. 2. The BAUM mechanical bloom thinner

Fig. 3. The Bloom Bandit™ hand held mechanical bloom thinner

Mechanical and Chemical Thinning of 'Forelle' Pears (*Pyrus communis* L.)

ADDITIONAL INDEX WORDS. European pear, fruit set, fruit size, fruit quality, Darwin 300™, napthaleneacetic acid, 6-benzyl adenine

SUMMARY. 'Forelle' is one of the most important blush pear cultivars in South Africa. Thinning of this cultivar is important to achieve good yields of marketable sized fruit and to control alternate bearing. The efficacy of the Darwin 300™ was evaluated at full bloom in two trials in Elgin. In the 2013/2014 season a tractor speed of 3.2 km·h^{-1} at 240 rpm and 360 rpm and at a speed of 5.2 km·h^{-1} at 300 rpm and 320 rpm were evaluated. In the 2014/2015 season the tractor speed was 5.2 km·h^{-1} at rotor speeds of 250 rpm, 300 rpm, 350 rpm and 400 rpm. A 50% hand flower removal treatment at full bloom, a standard chemical treatment at petal drop of 150 µl·L^{-1} 6-benzyladenine (6-BA) and 5 µl·L^{-1} napthaleneacetic acid (NAA), and a commercial hand-thinned control were included in both these trials. The Bloom Bandit™ hand-held mechanical thinner was evaluated in a trial in Ceres in the 2014/2015 season. In this trial the effect of 6-BA at 100 µl·L^{-1}, 150 µl·L^{-1} and NAA at 5 µl·L^{-1}, alone and in combination were evaluated, as well as a 400 µl·L^{-1} 1-aminocyclopropane carboxylic acid (ACC) treatment. All chemicals were applied at 8 - 10 mm fruitlet diameter. The Darwin 300™ thinned variably with reducing the hand thinning requirement in 2013/2014 and increasing it in 2014/2015. The fruit set on two tagged branches in the lower canopy was reduced in the 2014/2015 season by the Darwin 300™. Yield response was also very variable. Fruit size was generally increased and return bloom was only significantly reduced at higher tractor and rotor speeds. The Darwin 300™ 5.2 km·h^{-1} and 300 rpm treatment consistently gave good results in both trials. Thinning with the Darwin 300™ shows potential on 'Forelle', but for consistent and reliable results orchard design and orchard floor conditions need to be optimized. Removing 50% of flowers during full bloom reduced the commercial hand thinning requirements, increased fruit size and return bloom with little effect on yield. The Bloom Bandit™ showed adequate results as a thinner on 'Forelle'. 6-BA and NAA in combination thinned more effectively than 6-BA alone, resulting in reduced fruit set and increased fruit size and return bloom. 6-BA at 150 µl·L^{-1} or 100 µl·L^{-1} combined with 5 µl·L^{-1} NAA gave good thinning results on 'Forelle' pear trees. ACC shows promise as a chemical thinning agent, but should be applied at a lower rate as 400 µl·L^{-1} completely over thinned trees.

Profitability in pear production is influenced by total yield, which depends on fruit set and fruit size. Yield is influenced by the number and quality of flowers, the effectivity of cross pollinators, natural fruit abscission levels, cell division and enlargement (Webster, 2002a). Fruit size is an important factor influencing the price of marketable fruit (Webster, 2002a). However fruit size is negatively correlated to crop load, and average fruit size decreases with an increase in fruit set and yield (Lafer, 2008). In addition, high crop loads lead to reduced flowering in the subsequent season (Webster, 2002a). Once fruit has set, it needs to be retained in sufficient, but not excessive numbers to produce an adequate crop that develops into large, attractive fruit at harvest (Webster, 2002b). Where the natural fruit abscission is not adequate and set is excessive, the number of fruit must be reduced through thinning (Greene and Costa, 2013), which is an important practice in fruit production (Basak et al., 2013).

'Forelle' is the second most planted pear cultivar in South Africa (HORTGRO, 2014). It is a high priced, bi-colored cultivar, but obtaining good fruit size is problematic (Huysamer, 1997). This can be alleviated by earlier removal of fruitlets during the growing season resulting in early reduced competition between fruit, and thus result in larger fruit at harvest (Link, 2000).

In general, chemical thinning of pears is not as widely used as is the case for apples (Bertelsen, 2002). Currently, pears in South Africa are mostly thinned by hand and sometimes chemically with follow-up hand thinning. The choice and timing of these methods depend on the initial fruit set for the season. Hand thinning is performed after physiological fruit drop and is effective in optimizing fruit load (Webster, 2002a), and will usually be used to remove excess, under-sized and damaged fruitlets (Damerow and Blanke, 2009). Due to high costs and difficulty of obtaining able labor, hand thinning is not very economical or practical (Damerow and Blanke, 2009; Hudina and Stampar, 2008), although it is still used extensively in South Africa.

Many chemicals have been evaluated for thinning pear flowers and/or fruitlets. The synthetic auxin napthaleneacetic acid (NAA) acts variably on pears depending on cultivar, but more importantly on temperature during and after application (Hudina and Stampar, 2008; Wertheim, 2000). NAA is generally applied at 5 µl L^{-1} but can be used up to 40 µl L^{-1} depending on timing, cultivar and country, and is applied during bloom or post-bloom (Webster, 2002a). Bloom applications are highly risky as thinning is performed before final fruit set is known, and risks such as frosts damage still exist (Webster, 2002a). As a result, post-bloom applications are more frequently used and are generally applied when the fruitlets are 10 – 15 mm in diameter, i.e. 10 - 25 days after full bloom (DAFB) (Webster, 2002b). In South Africa, naphthylacetamide (NAD) (Golden Thin®), which is the amide of NAA, was evaluated at 40 mg L^{-1} on 'Early Bon Chrétien' pears when 8 – 12 mm in diameter and reduced fruit set, improved fruit size, but did not improve return bloom (Theron et al., 2011). Both NAA and NAD show ability to effectively thin pears (Garriz et al., 2004; Theron et al., 2011).

The synthetic cytokinin 6-benzyladenine (6-BA) effectively thins most apple cultivars and usually promotes return bloom (Basak et al., 2013), but has shown variable thinning efficacy on pears (Wertheim, 2000). The mode of action of 6-BA is through stimulated bourse shoot growth which competes with fruit and causes weaker fruitlets in the cluster to abscise (Bangerth, 2000). 6-BA like NAA is applied post-bloom when fruitlets are 10 – 15 mm in diameter (10 - 25 DAFB). Recent studies have shown that combinations of 6-BA and NAA at the same fruitlet stage successfully thinned 'Conference' pears (Maas and van der Steeg, 2011). Application of 6-BA at fruitlet diameter of 10 – 12 mm increased fruitlet abscission, and improved fruit size, firmness and sugar content (Basak, 2004). Applications of 150 µl L^{-1} 6-BA at 8 – 12 mm fruitlet diameter on 'Early Bon Chrétien', and at 150 – 200 µl L^{-1} at 6 – 8 mm fruitlets diameter on 'Forelle' pears in South Africa effectively lowered fruit set, increased fruit size and improved return bloom (Chabikwa, 2008; Theron et al., 2011). Earlier 6-BA applications (8 DAFB) promoted abscission of small fruit (6 – 8 mm diameter), whilst later applications (11 – 17 DAFB) inhibited the abscission of larger fruit (8 – 10 mm) (Chabikwa, 2008).

1-Aminocyclopropane carboxylic acid (ACC) is a precursor of ethylene, and is a new chemical thinner that had recently been evaluated on apples. ACC reduced fruit set linearly with increasing concentrations when applied to 'Golden Delicious' trees between 100 – 500 µg L^{-1} at 20mm fruitlet diameter (Schupp et al., 2012). The mode of action of ACC is probably related to its rapid conversion to ethylene at a time when the abscission zones of fruit are sensetive to ethylene (McArtney and Obermiller, 2012).

An interest in environmentally friendly fruit production has led to mechanical thinning methods being explored (Basak et al., 2013). Mechanical thinning not only reduces the use of chemicals, but effectiveness of thinning is less weather dependent and usually results in less labor required (Basak et al., 2013). After mechanical thinning, additional follow-up methods are used if needed, i.e. chemical or hand thinning.

Various mechanical thinning machines have been developed that use kinetic energy to knock off flowers or fruitlets. The Darwin™ (Fruit Tec, www.fruit-tec.com) was developed in Germany from 1998 (Bertschinger et al., 1998). It is an implement mounted on the front of a tractor and powered through the hydraulic system. Thinning is achieved through the rotation of a single shaft, which is either 2.0 m, 2.5 m or 3.0 m long depending on the model. The shaft has 60 cm long plastic cords or spindles attached (Schupp et al., 2008). When the rotating spindles come into contact with trees in bloom, whole flower clusters or portions of flower clusters are physically removed. The intensity of the thinning is controlled through the rotation rate of the spindles, the tractor speed (Schupp et al., 2008), as well as the arrangements and number of the cords (Schupp and Baugher, 2011). For uniform thinning, the central shaft needs to be constantly kept parallel to the vertical plane of the tree canopy (Schupp et al., 2008) and 10 cm from the tree trunk (Aasted et al., 2011).

Recently, mechanical hand-held thinning devices have come onto the market. An early device, the Electro-flor®, designed in France and released in 2009, gave promising results on apples and is suitable for use on pears (Jay et al., 2009). The device is a 3.1-m-long telescope pole powered by a 48 V battery where the 30 cm tip has 5 to 8 26-cm-long flexible wire cords attached and rotate to bring about thinning. Rotations on apples are recommended at 1600 – 1800 rpm (Delmas, 2007). The Bloom Bandit™ is a similar hand-held thinning device, developed from a commercial weed trimmer in the USA (Warner, 2012). The Bloom Bandit™ is 1.8 m long and has an 18 cm rotating tip to which spindles are attached. The spindles are made of highly resistant and flexible material, and their number and length can be varied to need. The device is powered by a 12 V, 13 A battery. These devices are moved by hand through a tree during bloom in a way that the spindles physically knock off unrequired flowers. The level of thinning can be altered by the number and length of plastic spindles on the rotating tip, as well as the time spent working on a tree.

In this paper we report on the efficacy of mechanical and chemical thinning versus hand thinning only on yield, fruit set, fruit size and quality and return bloom on the European pear 'Forelle'.

Materials and methods

PLANT MATERIAL AND SITE DESCRIPTION. During the 2013/14 and 2014/2015 seasons, thinning trials were conducted on mature 'Forelle' pear trees in orchards on Oak Valley Estate (34°10'15.7"S 19°03'35.1"E) Elgin, South Africa. This orchard was suited for mechanical thinning with the Darwin 300™ and presented in Plate 1. In 2014/2015, a thinning trial was also conducted on mature 'Forelle' trees on Lushof farm (33°18'00.9"S 19°21'13.8"E) in the Ceres area, South Africa. Additional orchard information is presented in Table 1.

TREATMENTS AND EXPERIMENTAL DESIGNS: ELGIN. During the 2013/2014 season, the Darwin 300™ was used to mechanically thin trees at tractor speeds of 3.2 km·h^{-1} with spindle rotation rates of 240 and 260 rpm, or at 5.2 km·h^{-1} with spindle rotation rates of 300 and 320 rpm A chemical thinning tank-mix treatment of 150 µl·L^{-1} 6-BA (MaxCel™, Philagro SA, Somerset West, South Africa) and 5 µl·L^{-1} NAA, (Planofix, Bayer SA, Paarl, South Africa) was applied when the average fruitlet diameter was 6 - 8 mm (petal drop/ 20 DAFB). A 50% flower removal treatment was applied at full bloom, where all flowers from every alternate flower cluster was removed by hand. The control treatment was only hand thinned commercially with the rest of the treatments at 34 DAFB.

During the 2014/2015 season the Darwin 300™ was evaluated in the same orchard with a tractor speed of 5.2 km·h^{-1} and rotation rates of 250, 300, 350, and 400 rpm The chemical thinning treatment was a tank-mix of 150 µl·L^{-1} 6-BA (MaxCel™, Philagro SA, Somerset West, South Africa) and 5 µl·L^{-1} NAA (PoMaxa™, Philagro SA, Somerset West, South Africa) when the average fruitlet diameter was 10.5 mm (petal drop/ 20 DAFB). A 50% flower removal treatment was applied at full bloom, where all flowers from every alternate flower cluster was removed by hand. A commercially hand-thinned control was included, and performed when all treatments were hand thinned at 35 DAFB.

Chemical applications were made using a motorized knapsack sprayer at 1000 L·ha^{-1}, when conditions led to slow drying. Weather conditions during and for 14 days after application for the 2013/2014 trial are presented in Fig. 1 and for the 2014/2015 trial in Fig. 2. When spraying MaxCel™ there should be no rainfall and temperature should rise above 18°C for at least three days after application (Philagro SA, Somerset West, South Africa). The commercial hand thinning entailed removing the smallest fruit from clusters that had set more than two fruitlets to leave a maximum of two fruit per cluster. The experimental designs were randomized complete block designs with five replications in the 2013/2014 season and six replications in the 2014/2015 season. Each replicate consisted of a plot of seven trees where the center three trees were used for data collection.

TREATMENTS AND EXPERIMENTAL DESIGNS: CERES. All treatments evaluated during the 2014/15 season on 'Forelle' pear trees on Lushof are summarized in Table 2. All chemical applications were performed as described above. Weather conditions during and for 14 days after application are presented in Fig. 3. The Bloom Bandit™ (Automated AG Systems, Moses Lake, Washington, USA) hand thinning device was used at full bloom for one minute per tree, 30 seconds each side. The Bloom Bandit™ had six, 27 cm long spindles evenly spaced and rotated at a speed of 210 rpm. A hand thinned control was included in the trial and applied at 40 DAFB when commercial hand thinning was performed on all trees. Buffer trees were left untreated between chemically thinned trees, and buffer rows were left between each trial row. This trial was a randomized complete block design with ten single tree repetitions. Chemical application dates and phenological stages are summarized in Table 3.

DATA COLLECTED. In the 2014/2015 trials for both Elgin and Ceres, two representative branches per tree were tagged in the lower canopy and the total number of flower clusters counted at full bloom. After treatments were applied and natural fruit drop had taken place, the total number of clusters that set fruit and fruit set within these clusters on tagged branches were counted to determine percentage of clusters failing to set fruit, the percentage of fruit set per cluster and the average number of fruit that set in a cluster. To determine efficacy of thinning, fruit removed during commercial hand thinning from all trials were weighed and the number of fruitlets counted. The dates data were collected is presented in Table 3.

At commercial harvest, trunk circumference was measured ±20 cm above the graft union. Trees were strip harvested on the dates presented in Table 3 and total yield was recorded per replicate by weighing all fruit harvested. Yield was expressed as yield efficiency (kg fruit harvested per trunk cross sectional area). A sample of 30 fruit for the Elgin trials and 50 fruit for the Ceres trial per replicate was brought to our laboratory and the following variables were recorded per fruit; weight, length, diameter, firmness, fully developed seed content, blush and ground color. The number of fruit larger than the minimum export diameter of 65 mm was determined for the Ceres trial and expressed as a percentage of the 50 sampled fruit. Fruit firmness was determined by a GÜSS texture analyzer (Guss electronic model GS 20, Strand, South Africa) fitted with an 8.0 mm probe. Blush development was assessed on a scale from 1 to 6 (1 = most blush, 6 = least blush) using the Unifruco color chart P25. Ground color was determined on a scale from 0.5 to 5 (0.5 = most green, 5 = yellow) using the Unifruco color chart for apples and pears. The following season, the return bloom was determined on the tagged branches by counting the number of sprouted vegetative and reproductive buds and expressing return bloom as a percentage of reproductive buds sprouting out of the total number of sprouted buds (vegetative plus reproductive).

STATISTICAL ANALYSIS. Data was analyzed using the linear model procedure (GLM) of the program SAS Enterprise guide 5.1 (SAS Institute Incorporated, 100 SAS Campus Drive Cary, North Carolina 27513-2414, USA), and when the F Statistic indicated significance at $P < 0.05$ the LDS test was used. Single degree of freedom, orthogonal, polynomial contrasts were fitted as described. In the 2013/2014 Elgin trial a contrast was fitted comparing the control to an average of all treatments, and one that compared the average lower tractor speed of 3.2 $km \cdot h^{-1}$ with the average higher tractor speed of 5.2 $km \cdot h^{-1}$. In the 2014/2015 trial in Elgin a contrast was fitted comparing the control to an average of all treatments, as well as linear and quadratic contrasts on the rotation speeds. The 2014/2015 Ceres trial, a contrast was fitted that compared the control to an average of all treatments as well as a contrast comparing the average of the two 6-BA treatments on their own to the average of the two combination treatments (6-BA and NAA).

Results

ELGIN TRIAL 2013-2014. In the 2013/2014 trial, no significant differences were found between treatments in the average weight and the average number of fruitlets thinned during commercial hand thinning (Table 4). Although the Darwin 300™ treatment at 5.2 km·h^{-1} and 300 rpm reduced the total weight of fruitlets that needed to be thinned at 35 DAFB by 52.4% and the average number of fruitlets thinned by 40.8% compared to the control, these reductions were not statistically significant (Table 4). The yield efficiency per plot did not differ significantly between treatments (Table 5).

No significant differences in average fruit weight were found between the treatments. Although not significant, the mechanical thinning treatment at 5.2 km·h^{-1} and 320 rpm spindle speed resulted in the heaviest average fruit weight of 148.7 g, and the control the lowest average fruit weight of 136.7 g (Table 6). The contrast between all thinning treatments and the control was nearly significant (P = 0.0625) (Table 6). Fruit length and diameter did not differ significantly between any treatments (Table 6). The highest firmness was found after the 5.2 km·h^{-1} and 300 rpm treatment and this was significantly firmer than the control, but not significantly different from other Darwin 300™ thinned treatments (Table 6). The fruit from the 50% hand flower thinning treatment were significantly less firm than control fruit (Table 6).

No differences occurred in average number of fully developed seeds per fruit (Table 7). No differences were found in average blush development or ground color, but the contrast for low versus high tractor speed was significant for ground color (P = 0.0348) and fruit from high tractor speed treatments were slightly more yellow (Table 7). The 50% hand flower removal treatment resulted in a significant increase in return bloom compared to mechanical treatments and by 12.1% compared to the control, whereas the Darwin 300™ 5.2 km·h^{-1} at 300 rpm and 320 rpm treatments significantly reduced return bloom by 9.8% and 13.6%, respectively compared to the control (Table 8).

ELGIN TRIAL 2014-2015. In the 2014/2015 trial, no significant differences were found in the average weight of fruitlets thinned, or the average number of fruitlets thinned during commercial hand thinning (Table 9). Although not significant, the 50% hand flower removal reduced total weight of fruitlets thinned and average total number of fruitlets thinned by 45.5% and 40.4%, respectively compared to the control (Table 9). The percentage of flower clusters that did not set any fruit was significantly lowered on average by all treatments compared to the control (P = 0.0003) (Table 10). This was 67% for the 50% flower cluster thinning treatment, but when taking into consideration that we removed 50% of the clusters the actual percentage of clusters that did not set any fruit was only 34% (data not shown). On average, all treatments reduced the percentage fruit set per cluster on two tagged branches compared to the control (P = 0.0183) (Table 10). The average number of fruit that set in a cluster ranged from 1.7 to 1.9 and was not significantly affected by any treatment (Table 10). An increasing linear trend in the number of fruit setting in a cluster was seen with increasing rotation speed (P = 0.0507) (Table 10). No significant differences were found in the distribution in number of fruit per cluster but very few clusters set 4 or 5 fruit (Table 11).

No treatments affected yield significantly compared to the control (Table 12). The Darwin 300™ 5.2 $km{\cdot}h^{-1}$ with 300 rpm treatment resulted in a significantly higher yield efficiency of 0.52 $kg{\cdot}cm^{-2}$ compared to the other Darwin 300™ treatments (Table 12). In general all treatments improved fruit size variables compared to the control (Table 13). A linear increase was seen with an increase in rotation speed with the Darwin 300™ in fruit weight (P = 0.0136), fruit length (P = 0.0007) and fruit diameter (P = 0.0034) (Table 13). Relative to the control, the 50% hand flower removal treatment increased fruit weight and diameter significantly by 11% and 3.5%, respectively, but did not significantly increase fruit length (Table 13). Fruit firmness generally was higher for all treatments compared to the control (P = 0.0152) (Table 13). The 50% hand flower removal treatment and Darwin 300™ 5.2 $km{\cdot}h^{-1}$ at 300 and 400 rpm treatments significantly increased average fruit firmness compared to the control while these two Darwin 300™ treatments also produced firmer fruit than the other two Darwin 300™ treatments (Table 13).

No significant influences of treatments on the average number of fully developed seeds per fruit occurred (Table 14). Blush development did not differ significantly between treatments. Ground color was significantly greener in the Darwin 300™ 5.2 $km{\cdot}h^{-1}$ at 300 rpm and 400 rpm treatments compared to the control (Table 14). The chemical treatment combination of 150 $\mu l{\cdot}L^{-1}$ 6-BA and 5 $\mu l{\cdot}L^{-1}$ NAA significantly increased return bloom compared to the control (Table 15).

CERES TRIAL 2014-2015. In the 2014/2015 trial, all treatments except NAA on its own significantly reduced the total weight of all fruitlets thinned per tree commercially compared to the control (*P* < 0.0001) (Table 16). Combining 6-BA with NAA reduced the total weight of thinned fruitlets compared to where 6-BA was used on its own (*P* = 0.0012) (Table 16). In general the average number of fruitlets thinned per tree was also reduced compared to the control, and adding NAA to the 6-BA significantly reduced the hand-thinning requirement compared to the control and compared to 6-BA alone (*P* = 0.0001 and *P* = 0.0128, respectively) (Table 16). The ACC treatment greatly reduced the hand-thinning requirement to 0.1 kg fruitlets, and the average number of fruit hand thinned to 26, which were reductions of 88% and 89%, respectively, compared to the control (Table 16). The Bloom Bandit™ and the 6-BA at 100 $\mu l \cdot L^{-1}$ and 150 $\mu l \cdot L^{-1}$ treatments alone reduced the average weight of hand-thinned fruitlets per tree significantly but not the average number of hand-thinned fruitlets (Table 16).

On average, thinning treatments significantly increased the percentage of flower clusters that did not set any fruit compared to the control (*P* = 0.0033) (Table 17). The ACC treatment caused the majority of the clusters to set no fruit with 91.9% of clusters failing, which is 49.2% more than the control (Table 17). The 6-BA and NAA combinations caused a significantly greater percentage of clusters to set no fruit than 6-BA alone (P < 0.0001) (Table 17). Generally, all treatments lowered the percentage of fruit set per cluster on the two tagged branches (*P* = 0.0008), and set even fewer fruit when NAA was combined with 6-BA than when 6-BA was applied alone (*P* < 0.0001) (Table 17). The average number of fruit that set in a cluster followed the same trend with all treatments on average setting fewer fruit in a cluster compared to the control (*P* = 0.0061). The 6-BA treatments alone set more fruit in a cluster than when it was combined with NAA (*P* = 0.0105) (Table 17). The percentage of clusters setting one fruit (singles) was increased by all treatments compared to the control (*P* = 0.0236), as was the case for the combination treatments of 6-BA and NAA when compared to treatments with only 6-BA (*P* = 0.0044) (Table 18). The percentage of clusters setting two fruit was unaffected, but there was a trend for 6-BA treatments alone to have a higher percentage doubles than when 6-BA was combined with NAA (*P* = 0.0706) (Table 18). The percentage of clusters setting three fruit was significantly lowered by treatments compared to the control (*P* = 0.0082) (Table 18). 6-BA showed significantly more clusters with three fruit than the combinations of 6-BA and NAA (*P* = 0.0003), and the percentage of clusters setting four fruit was significantly lowered by the treatments compared to the control (*P* = 0.0128) (Table 18).

The ACC treatment significantly reduced yield efficiency compared to all other treatments, while no other thinning treatments differed from the control (Table 19). Thinning treatments on average lowered yield efficiency compared to the control (P = 0.0137) (Table 19). An overall trend was observed in thinning treatments increasing fruit size in terms of weight, length and diameter (P = 0.0002, P = 0.0008, P = 0.0575, respectively) (Table 20). The ACC treatment resulted in the largest increase in fruit weight of 34% compared to the control (Table 20). The Bloom Bandit™ treatment and the 6-BA 150 $\mu l \cdot L^{-1}$ and NAA 5 $\mu l \cdot L^{-1}$ combination treatment significantly increased the average fruit weight compared to the control by 11.9% and 9.1%, respectively. Compared to the control, increases in average fruit length varied between 2.3% for the 6-BA 100 $\mu l \cdot L^{-1}$ and NAA 5 $\mu l \cdot L^{-1}$ combination treatment, and 6.6% for the ACC treatment (Table 20). The ACC treatment significantly increased fruit diameter compared to the control (Table 20). There was a significant increase in percentage fruit ≥ 65 mm for the ACC and the NAA 5 $\mu l \cdot L^{-1}$ treatments compared to the control (Fig. 4). Average fruit firmness was significantly affected by thinning treatments, but none compared to the control (Table 20). Fruit from trees thinned with 6-BA were significantly firmer than fruit thinned with 6-BA and NAA (P = 0.0261) (Table 20). No differences were obtained for average number of fully developed seeds per fruit (Table 21). Significantly more blush development was found for the ACC treatment compared to the control (Table 21). Ground color did not differ between treatments, but in general the thinning treatments reduced the yellowness of fruit compared to the control (P = 0.0034) (Table 21). Return bloom was on average significantly improved by treatments compared to the control (P = 0.0247) (Table 22). Treatments of 6-BA in combination with NAA significantly increased return bloom compared to treatments with 6-BA alone (P = 0.0067) (Table 22).

Discussion

MECHANICAL THINNING. We used two methods to determine the efficacy of thinning and resultant fruit set. The first was to determine fruit set per cluster on two tagged branches in the lower tree canopy. This gives an accurate account of fruit set on these two branches but is localized to one part of the canopy. The second set of data viz., the number of fruitlets thinned by hand gives a better indication of fruit set over the whole tree. Variable thinning effects were achieved with the Darwin 300™. In 2013/2014 the Darwin 300™ treatments tended to reduce the hand thinning requirement compared to the control, although not significantly (Table 4). Due to the large variation observed during the 2013/2014 trial the number of repetitions were increased in the 2014/2015 trial. The tractor speed of 3.2 $km \cdot h^{-1}$ in the 2013/2014 season was too slow (Veal et al., 2011) and results are usually better with faster tractor speeds (Solomakhin et al., 2012). On apple trees, the most favorable tractor speeds were between 5.0 and 7.5 km h^{-1}, where 7.5 km h^{-1} gave the best results (Solomakhin and Blanke, 2010). In the 2014/2015 the Darwin 300™ treatments tended to increase the hand thinning requirement versus the control, which was unexpected, except for the treatment at 5.2 km·h^{-1} and 250 rpm (the mildest level of mechanical thinning) although this was not significant (Table 9). This treatment had 12% more clusters that failed to set fruit compared to the control, but did not differ from the other mechanical thinning treatments, and had 21.2% less fruit per cluster compared to the control with none of these being significant (Table 10). Work done on apples showed that rotational speeds of 360 rpm and below resulted in insufficient thinning by removing too few flowers in the cluster (Solomakhin et al., 2012). The inconsistencies of hand thinning requirements and fruit set are difficult to explain as it is not consistent with what was achieved in previous research where increasing thinning intensities by increasing rotor or decreasing tractor speeds led to increased thinning efficacy (Kon et al., 2013; Schupp et al., 2008; Solomakhin and Blanke, 2010). A reason we found reduced thinning efficacy for the second trial may be due to heavy removal of flower clusters causing increased compensating set in the remaining clusters, as mechanical treatments increased the percentage of flower clusters failing to set fruit by 12% – 20% above the control (P = 0.0003) (Table 10). The percentage set per cluster was however not affected by the Darwin 300™ treatments and disproves the idea that the tree compensated for the heavier cluster removal by setting more fruit in a cluster (Table 10). This discrepancy could possibly be explained by the fact that set in a cluster was determined only on the two branches in the lower canopy while the hand thinning requirement was determined on the whole tree.

The flower clusters at full bloom on the two tagged branches were counted before the application of treatments, and after the treatments were applied one would expect that the density of flower clusters decreased but unfortunately we did not determine this. The response of the tree should be similar to where artificial spur extinction (ASE) was applied in apples, where reducing floral bud density caused a reduction in the number of clusters failing to set fruit (Breen et al., 2014). In our trials the percentage of clusters failing to set was not reduced but increased (Table 10). The Darwin 300™ 5.2 km·h^{-1} and 350 rpm resulted in similar percentage of clusters failing to set fruit to the 50% flower cluster removal treatment. Veal et al. (2011) found that mechanical thinners can precisely remove flowers in the inner or outer, upper or lower tree canopy and can cause complete flower clusters or spurs to be removed if used for the first time in an orchard although not always significantly. At the faster rotor speeds of our trial, it could be clearly seen that severe thinning had taken place with less foliage and flowers being left behind, although this was not measured. If this was the case, the percentage of clusters that failed to set fruit should have been reduced compared to the control according the ASE effect (Table 10). However, this may not be the case if the control sets well. The mechanical thinning treatments set most fruit in clusters with one or two fruit, which is the aim of mechanical thinning as it allows for additional fruit drop later in the growing season

(Damerow and Blanke, 2009). An increasing linear trend was observed with an increase in rotor speed in the average number of fruit that set in a cluster (P = 0.0507) (Table 10). Thinning efficacy is apparently more dependent on the rotor speed than the tractor speed (Solomakhin et al., 2012) and our findings are consistent with this as no differences were observed between the low and high tractor speeds (Table 4). The processes controlling European pear fruit set are complicated and affected by genetic, environment as well as tree management factors which may be the reason for the inconsistencies between seasons (Webster, 2002b).

Orchards chosen for these trials were not established with the possibility of mechanization in mind, and this was the first time that mechanical thinning had been applied as a thinning method. The orchard floor was not uniform in parts and could have caused over or under thinning between and/or within treatments, resulting in the variation observed. This was also found in similar research performed on stone fruit in South Africa (de Villiers, 2014). Uneven ridging of the Oak Valley orchard made it difficult for the tractor to maintain the Darwin 300™ in close proximity to the trunk. This was further exacerbated by the Oak Valley orchard having a slight slope making it difficult to constantly adjust to the challenging driving terrain. Therefore to keep the spindles within the recommended distance of 10 cm from the trunk was difficult (Schupp et al., 2008). The angle of the shaft could be changed as needed, and the tractor driver weaved in and out to maintain engagement with the canopy, but it was difficult for a driver with little experience of operating the Darwin 300™ while driving the tractor. Also small plots (seven trees) were thinned at a time in order for the trials to be statistically sound. Drivers find this physically and mentally tiring (Aasted et al., 2011). Another factor that could have contributed to the variation between the seasons was that two different tractors and drivers were used. In addition, the Darwin 300™ is not very specific in thinning and areas of a tree that might have required little hand thinning was as heavily thinned as areas requiring heavier thinning (Weibel et al., 2008). Seehuber et al. (2013) indicated that mechanical thinning can be effectively applied for a long period during bloom from balloon stage until the end of flowering at petal drop. Pear bloom in South Africa is very variable due to delayed foliation extending the bloom period as well as affecting the distribution in the canopy (Theron, 2013). If mechanical thinning can be applied at all the stages mentioned by Seehuber et al. (2013), then the problems encountered with thinning of trees experiencing delayed foliation can be minimized. Thinning 'Pinova' apples with the Darwin™ string thinner at 8.0 km h^{-1} and 220 rpm at the earlier stages of blooming before flowers had opened lowered the level of inter cluster thinning and left more flowers per cluster compared to thinning once flowers had opened (Sinatsch et al., 2010).

The Bloom Bandit™ treatment effectively thinned trees in the 2014/2015 Ceres trial and increased the number of clusters that did not set fruit (Table 17). Thinning is adapted to suit each individual tree and/or part of the tree (Jay et al., 2009), but extra time is required in the orchard to thin (Delmas, 2007). When used on peaches various hand-held thinners effectively reduced set (Martin-Gorriz et al., 2011). The Bloom Bandit™ shows promise as an effective mechanical thinning option for pears.

In some instances, a decrease in yield was found following mechanical thinning (Hehnen et al., 2012; Kong et al., 2009; Schupp et al., 2008; Solomakhin and Blanke, 2010) and in others no decreases were observed (Damerow et al., 2007; Veal et al., 2011). In our trials, yield efficiency generally decreased compared to the control following the Darwin 300™ and the Bloom Bandit™ treatments although not significantly (Table 5, Table 12 and Table 19). This is consistent with previous research on pears where mechanical thinning reduced yields (Seehuber et al., 2010). The Darwin 300™ treatment at 5.2 km·h^{-1} and 300 rpm was an exception and increased yield compared to the control in both seasons (Table 5 and Table 12). No discernible pattern between thinning and yields was achieved in some instances by Kon et al. (2013), and this was the case with our trials as well.

Reducing fruit set of pears is desirable in order to increase fruit size (Webster, 2002b), and if yield is lowered as a result, this can be outweighed by the higher value of the remaining fruit with better quality and size (Hehnen et al., 2012). All Darwin 300™ treatments generally increased fruit weight compared to the control and generally a linear increase was found in fruit size parameters with increased rotation speeds of the Darwin 300™ (Table 6 and Table 13). The BAUM (a thinning device similar to the Darwin 300™) was developed at the University of Bonn and consists of three horizontal rotors (Veal, et al., 2011). The BAUM caused a linear increase in fruit size with increasing rotor speed from 300 rpm to 400 rpm in 'Conference' and 'Alexander Lucas' pears with a constant tractor speed of 5.0 km h^{-1} (Seehuber et al., 2010). Solomakhin and Blanke (2010) found that unthinned controls of 'Gala Mondial' apples had larger yields of poorer fruit size than mechanically thinned trees which had lower yields of larger fruit size. In both our trials the Darwin 300™ treatment at 5.2 km·h^{-1} and 300 rpm had higher yields and heavier fruit than the control, indicating that there could be some merit in using mechanical thinning if variation can be controlled.

The fruit firmness was increased by the Darwin 300™ at 5.2 km·h^{-1} and 300 rpm treatment in both trials as well as the Darwin 300™ at 5.2 km·h^{-1} and 400 rpm treatment in the 2014/2015 trial compared to the control (Table 6 and Table 13). This is similar to what Hehnen et al. (2012) found in apples thinned at 360 rpm. Firmer fruit are probably the result of higher cell numbers in response to fewer fruits on the tree (Link, 2000) and such fruit should normally store better (Hehnan et al., 2012).

As expected seed number in remaining fruit was unaffected by most Darwin 300™ treatments (Table 7, Table 14 and Table 21). Blush development was not greatly affected in our trials, although a slightly lower blush level was found compared to the control, probably due to lower light levels in the canopy from slight stimulation of vegetative growth by the mechanical thinning (Table 7, Table 14 and Table 21). Vegetative growth was unfortunately not measured to confirm this. But could be the reason for lower blush as light levels in the canopy are important in blush development (Solomakhin and Blanke, 2010; Steyn et al., 2005). Previous trials which were done over more than one year did not measured the effects of mechanical thinning on vegetative growth but mostly focused on foliage damage (Veal et al., 2011; Weibel et al., 2008). Ground color was slightly greener for mechanically thinned fruit, but these differences were very small and have no horticultural significance. Research by Slomakhin and Blanke (2010) on apples also showed varied effects of mechanical thinning on color development and ground color.

Return bloom was generally lowered by all the Darwin 300™ treatments in both trials (Table 8 and Table 15), although only the Darwin 300™ at 5.2 $km \cdot h^{-1}$ and 320 rpm treatment significantly reduced this by 13.7% relative to the control in the 2013/2014 trial (Table 8). Similar results where return bloom was relatively unaffected or reduced slightly have been obtained with mechanical thinning on apples (Damerow et al., 2007). A large number of fruit present on trees between 7 and 14 DAFB hampers the formation of flower buds and due to the removal of flowers in full bloom we expected the bloom to be positively affected (Tromp, 2000). Leaf presence is needed to ensure adequate return bloom, and the number of leaves may have been reduced below ideal levels for flower induction for the following season due to higher spindle speeds (Tromp, 2000). Mechanical thinning with slow tractor speeds similar to that used in our trial can cause increased number of broken buds and shoots on the branch which could also have an adverse effect on the return bloom (Solomakhin and Blanke, 2010).

The 50% flower removal lowered the hand-thinning requirement. Of the 50% of clusters that remained after the treatment was applied, 34% of these failed to set fruit (data not shown). This response is more comparable to ASE on apples, as 34% of clusters failing to set after treatment is lower compared to the other treatments and shows increased number of clusters setting fruit. ASE lowering of floral density causes a similar response with fewer clusters failing to set fruit (Breen et al., 2014). Using ASE on apples, Breen et al. (2014) found an increase in the portion of clusters setting two or more fruit per cluster but in our trial there was no effect on the number of clusters with two or more fruit (Table 11). The differences seen may be due to the fact that only flower removal was done in our trials and previous ASE work involves the removal of whole spurs. Another reason may be due to a difference in response to ASE by pears compared to apples.

Although the cluster number was halved at full bloom, yield was not significantly reduced compared to the control (Table 5 and Table 12). The yield is similar to those obtained by some Darwin 300™ treatments (Table 5 and Table 12). In general, the 50% flower cluster removal increased fruit size relative to the control, but only significantly for fruit weight and diameter in the 2014/2015 trial (Table 6 and Table 13). This indicates that earlier removal of competition and increasing leaf area per fruit benefits growth of the remaining fruit (McArtney et al., 1996). Fruit quality was not significantly influenced by the 50% flower removal. The percentage return bloom was greater for the 50% flower removal treatment compared to the control, but only significant in the 2013/2014 trial (Table 8). This was expected as early thinning is known to improve return bloom (Tromp, 2000).

Chemical thinning. ACC 400 $\mu l \cdot L^{-1}$ excessively thinned trees with the greatest reduction in weight and number of fruitlets that needed to be hand thinned per tree compared to the control (Table 16). In 'Golden Delicious' apples ACC was an effective thinner when applied at 20 mm fruit diameter. A linear decrease in set and yield was found with a concomitant increase in fruit size and return bloom with increasing rate of ACC from 100 $\mu l\ L^{-1}$ to 500 $\mu l\ L^{-1}$ (Schupp et al., 2012). In our trial; the thinning effect caused a significant reduction in yield, but was too severe resulting in economic losses despite the increase in fruit size. Fruit diameter was significantly increased, as was the portion of fruit with a diameter ≥ 65 mm (Fig. 4). As expected, ACC significantly increased return bloom compared to the control due to the heavy thinning (Tromp, 2000) (Table 22). Further trials on ACC is recommended as it shows promise as a chemical thinner, but reduced concentrations should be used to achieve less aggressive thinning.

6-BA applications alone at 100 $\mu l \cdot L^{-1}$ and 150 $\mu l \cdot L^{-1}$ effectively thinned fruit in the Ceres trial with significantly less hand thinning required compared to the control (Table 16). The same was found at these rates on 'Early Bon Chretien' (Theron et al., 2011), 'Packham's Triumph' (Bound, 2015), 'Clara Frijs' (Bertelsen, 2002), and 'Williams' (Dussi et al., 2008). Chabikwa (2008) found that 6-BA only thinned at rates of 150 $\mu l\ L^{-1}$ and above on 'Forelle'. Our results indicated that a lower rate of 100 $\mu l \cdot L^{-1}$ did thin 'Forelle' (Table 16). Temperature in the orchard after 6-BA applications is an important factor to consider when evaluating thinning efficacy (Dussi, et al., 2008). On apples and pears it is recommended according to the MaxCel™ label (Philagro SA, Somerset West, South Africa) that the temperature should be above 18°C on the day of application and the following 2 to 3 days.

6-BA lacks thinning efficacy at lower temperatures, but will be more effective on pears at lower temperatures down to 11°C (Bound, 2015). In our trials the temperature did not remain above the critical level of 18°C in the first season but did so in the second when thinning was better (Fig. 1, Fig. 2 and Fig. 3).

An improvement in thinning efficacy was found when 6-BA was combined with NAA. The combinational treatment tended to reduce the hand thinning requirement compared to the control, and significantly so in the Ceres trial (Table 4, Table 9 and Table 16). This was also found in 'Conference' pears when 6-BA at 150 µl L^{-1} was combined with 5 – 10 µl L^{-1} NAA at 8 – 10 mm fruit diameter (Maas and van der Steeg, 2011). The average weight per tree of fruitlets thinned was less than the control, but the average number of fruit thinned was greater than the control showing smaller average fruitlets size in the 2014/2015 Oak Valley treatment (Table 9). NAA applied alone does not effectively thin pears (Dussi et al., 2008; Maas and van der Steeg, 2011), which was also the case with 'Forelle' in our trials (Table 16). We may have hand thinned trees too early as 6-BA takes 4 – 5 weeks to induce fruit drop in Ceres.

6-BA did not significantly increase the percentage of clusters failing to set fruit compared to the control, but it did when NAA was added to 150 µl·L^{-1} 6-BA (Table 17). Adding NAA to 6-BA caused a greater reduction in set through more clusters failing to set than when 6-BA was applied alone (P <.0001), and as a result the percentage of fruit set per cluster (P <.0001), and average fruit set in a cluster was higher for treatments with 6-BA alone than in combination with NAA (P = 0.0105) (Table 17). Importantly, the percentage of clusters setting a single fruit was significantly increased for all combinations of 6-BA and NAA versus the control, and versus the 6-BA treatments (P = 0.0044) (Table 18). This then would result in the most ideal set with a lower hand thinning requirement.

The yield was generally reduced by 6-BA, and 6-BA with NAA (Table 5, Table 12 and Table 19). This reduction in yield is a normal response to thinning, and variations do occur between cultivars as seen with greater yield of larger fruit on 'Coscia' than on 'Spadona' pears (Stern and Flaishman, 2003). The loss in yield resulted in increased fruit size in 'Conference' (Maas and van der Steeg, 2011), 'Williams' (Dussi et al., 2008) and 'Early Bon Chrétien' pears (Theron et al., 2011). This was also the case in all our trials although the increases were not always significant (Table 6, Table 13 and Table 20). This effect of 6-BA on pear fruit size has been often reported before including the cultivars 'Clara Frijs' (Bertelsen, 2002), 'Early Bon Chretien' (Theron et al., 2011), 'Spadona' and 'Coscia' (Stern and Flaishman, 2003) and 'Williams' (Dussi et al., 2008). 6-BA increases and prolongs the rate of mitotic cell division in the cortex of developing fruit, which results in increased fruit size without significant reductions in the number of fruit per tree (Webster, 2002a). Therefore the increase in fruit size could have been achieved in two ways, i.e., directly due to the effects of the cytokinin on fruit growth, or indirectly due to thinning (Stern and Flaishman, 2003). Chabikwa (2008) found increased fruit size without a thinning effect with 6-BA on 'Forelle'. However, Theron et al. (2015) concluded that 6-BA does not increase fruit weight of 'Forelle' or 'Abate Fetel'. The only 6-BA treatment significantly increasing fruit weight compared to the control in our trial was at 150 $\mu l \cdot L^{-1}$ in combination with NAA (Table 20). In our trials 6-BA and the combination treatments of 6-BA and NAA did not improve the percentage of fruit with a diameter ≥65 mm compared other treatments (Fig. 4). This confirms the findings of Theron et al. (2015) that 6-BA does not improve fruit size in 'Forelle'. But inconsistencies still exist as our trial shows a thinning effect by 6-BA at all rates and combinations and increases in fruit size predominantly at the higher combination rate of 150 $\mu l \cdot L^{-1}$ 6-BA with 5 $\mu l \cdot L^{-1}$ NAA, which is contrary to Chabikwa (2008) where 6-BA did not thin but increased fruit size of 'Forelle'. This could be due to more optimal climatic conditions in our trials.

Firmness was not markedly affected by the chemical thinning applications - significant changes in firmness were 0.1 kg at maximum and thus not of horticultural significance. 6-BA in our trials lowered firmness slightly, which was not the case in 'Packham's Triumph' pears where generally thinning increased fruit firmness (Bound, 2015). Chemical applications did not affect the seed content of remaining fruit indicating that seed abortion is not the mode of action leading to thinning (Table 7, Table 14 and Table 21). 'Forelle' sets fruit with very few seeds or even parthenocarpically indicating that seed number is not a major factor deciding fruit set (Theron, 2011). Only small, irrelevant differences were observed in blush color and ground color.

Return bloom was improved in 'Early Bon Chretien' (Theron et al., 2011), 'Forelle' (Theron et al., 2015) and 'Clara Frijs' pears (Bertelsen, 2002) when 6-BA was applied at 100 and 150 $\mu l\ L^{-1}$. Increases in return bloom can be due to the thinning effect of 6-BA by reducing the number of fruit before seeds produce gibberellins, which inhibit flower induction (Tromp, 2000), or directly by the promotion of flower induction by 6-BA (Bubán and Lakatos, 2000). In our trials we found similar results to this. When 6-BA was applied alone, only the lower rate of 100 $\mu l \cdot L^{-1}$ significantly increased return bloom (Table 22). Both rates of 6-BA combined with NAA, return bloom was significantly increased. A trend was seen that adding NAA to 6-BA gave a higher percentage return bloom than when 6-BA was applied alone (P = 0.0067) (Table 22). 6-BA generally aided return bloom, and adding NAA resulted in stronger thinning therefore further benefitting return bloom.

Conclusion

In our trials mechanical thinning results were variable. It is known that thinning is amongst others dependent on tractor and rotor speeds, whether machines have been used previously in the orchard, training system and the orchard floor condition. We probably used too low tractor speeds due to the uneven orchard surface. Therefore further evaluation in suitable orchards should be undertaken in South Africa to evaluate the long term feasibility of mechanical thinning on 'Forelle' pears. The hand held Bloom Bandit™ showed promise as it can be used more selectively, but extra time spent in the orchard should be carefully evaluated to fully understand its economic feasibility. Incorporating laborer platforms in the use of hand held thinning machines might prove beneficial. If producers would like to mechanize their production practices, training system and floor management in the orchard should be taken into account when establishing the orchard. Chemical thinning of 'Forelle' seems feasible with 6-BA at 100 $\mu l \cdot L^{-1}$ and 150 $\mu l \cdot L^{-1}$ in combination with 5 $\mu l \cdot L^{-1}$ NAA applied at 8 - 10 mm (11 DAFB), as reduced fruit set was obtained with increased fruit quality and return bloom without significant losses in yield. ACC is a new option that should be further evaluated on 'Forelle' but at lower rates than 400 $\mu l \cdot L^{-1}$. Follow-up hand thinning will probably remain a requirement to correct crop loads and remove poorer quality fruit. Evaluating mechanical thinning in combination with chemical thinning could further develop thinning practices in South Africa.

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Table 1. Details on age, rootstock, cross pollinator, spacing, planting system and previous yields of the 'Forelle' trial sites used during the 2013/2014 and 2014/2015 seasons.

	Site	
	Oak Valley Estate	Lushof
Year Planted	1997	1999
Rootstock	BP1	BP1
Cross Pollinator	'Abate Fetel' (50%)	5% 'Early Bon Chrétien' 5% 'Keiffer'
Spacing	4.0 m x 1.2 m	4.5 m x 1.5 m
Trees per Hectare	2083	1481
Training System	Palmette	Central Leader
Yield 2011/2012	55 $ton{\cdot}ha^{-1}$	49 $ton{\cdot}ha^{-1}$
Yield 2012/2013	42 $ton{\cdot}ha^{-1}$	51 $ton{\cdot}ha^{-1}$
Yield 2013/2014	50 $ton{\cdot}ha^{-1}$	74 $ton{\cdot}ha^{-1}$
Yield 2014/2015	58 $ton{\cdot}ha^{-1}$	62 $ton{\cdot}ha^{-1}$

Table 2. Thinning treatments applied at an average fruitlet diameter of 8 - 10 mm (11 DAFB) at Lushof, Ceres, during the 2014/2015 season.

Active Ingredient/s	Product/Products	Rate of active ingredient
-	Control, commercially hand thinned	
-	Bloom Bandit™	1 $min{\cdot}tree^{-1}$, (30 seconds $side^{-1}$)
Napthaleneacetic acid	PoMaxa™	5 $\mu l{\cdot}L^{-1}$
1-Aminocyclopropane carboxylic acid	VBC 30160	400 $\mu l{\cdot}L^{-1}$
6-Benzyladenine	MaxCel™	100 $\mu l{\cdot}L^{-1}$
6-Benzyladenine	MaxCel™	150 $\mu l{\cdot}L^{-1}$
6-Benzyladenine + Napthaleneacetic acid	MaxCel™ and PoMaxa™	100 $\mu l{\cdot}L^{-1}$ and 5 $\mu l{\cdot}L^{-1}$
6-Benzyladenine + Napthaleneacetic acid	MaxCel™ and PoMaxa™	150 $\mu l{\cdot}L^{-1}$ and 5 $\mu l{\cdot}L^{-1}$

Table 3. Dates of treatment application and different phenological stages of 'Forelle' trial orchards used in 2013/2014 and 2014/2015 seasons.

	Oak Valley Estate		Lushof
	2013/2014	2014/2015	2014/2015
Full Bloom	24 September 2013	12 September 2014	11 September 2014
Mechanically thinned	25 September 2013	12 September 2014	-
50% hand flower removal	24 September 2013	15 September 2014	-
Bloom Bandit Thinned	-	-	11 September 2014
Sprayed	14 October 2013	2 October 2014	22 September 2014
Hand Thinned	28 October 2013	17 October 2014	20 October 2014
Harvest	12 March 2014	25 February 2015	2 March 2015
Return Bloom Count	9 September 2014	16 September 2015	15 September 2015

Table 4. Effect of thinning treatments on total weight of and number of fruitlets thinned by hand during commercial hand thinning from 'Forelle' pear trees at Oak Valley, Elgin (2013/2014).

Treatments	Average weight of fruitlets hand thinned per plot (kg)	Average number of fruitlets hand thinned per plot
Control - hand thinned	0.43 ns	203.6 ns
50% hand flower removal	0.38	182.6
6-BA (150 µl·L^{-1}) + NAA (5 µl·L^{-1})	0.32	175.0
Darwin 300™, 3.2 km·h^{-1} @ 240 rpm	0.31	158.0
Darwin 300™, 3.2 km·h^{-1} @ 260 rpm	0.38	201.8
Darwin 300™, 5.2 km·h^{-1} @ 300 rpm	0.20	120.6
Darwin 300™, 5.2 km·h^{-1} @ 320 rpm	0.41	196.0
Significance Level	*0.2581*	*0.4996*
Control vs Treatments	*0.1925*	*0.3584*
Low vs High tractor speed	*0.5280*	*0.4914*
Treatment LSD	-	-

ns = Not significant at $P < 0.05$

Table 5. Effects of thinning treatments on average yield efficiency per plot and estimated yield of 'Forelle' pear trees at Oak Valley, Elgin (2013-2014).

Treatments	Average yield efficiency per plot ($kg \cdot cm^{-2}$)		Estimated yield ($ton \cdot ha^{-1}$)
Control - hand thinned	0.61	ns	66
50% hand flower removal	0.59		63
6-BA (150 $\mu l \cdot L^{-1}$) + NAA (5 $\mu l \cdot L^{-1}$)	0.63		65
Darwin 300™, 3.2 $km \cdot h^{-1}$ @ 240 rpm	0.55		59
Darwin 300™, 3.2 $km \cdot h^{-1}$ @ 260 rpm	0.52		63
Darwin 300™, 5.2 $km \cdot h^{-1}$ @ 300 rpm	0.65		62
Darwin 300™, 5.2 $km \cdot h^{-1}$ @ 320 rpm	0.53		58
Significance Level	*0.4328*		
Control vs Treatments	*0.5148*		
Low vs High tractor speed	*0.2951*		
Treatment LSD	-		

ns = Not significant at $P < 0.05$

Table 6. Effects of thinning treatments on average fruit size and firmness of 'Forelle' pears at Oak Valley, Elgin (2013/2014).

Treatments	Average fruit weight (g)		Average fruit length (mm)		Average fruit diameter (mm)		Average fruit firmness (kg)	
Control - hand thinned	136.7	ns	81.0	ns	61.0	ns	6.1	bc
50% hand flower removal	139.1		81.1		61.4		6.0	d
6-BA (150 $\mu l \cdot L^{-1}$) + NAA (5 $\mu l \cdot L^{-1}$)	140.4		81.7		61.6		6.0	cd
Darwin 300™, 3.2 $km \cdot h^{-1}$ @ 240 rpm	146.7		82.7		62.4		6.1	ab
Darwin 300™, 3.2 $km \cdot h^{-1}$ @ 260 rpm	143.4		81.7		61.4		6.1	ab
Darwin 300™, 5.2 $km \cdot h^{-1}$ @ 300 rpm	142.8		81.5		61.4		6.2	a
Darwin 300™, 5.2 $km \cdot h^{-1}$ @ 320 rpm	148.7		82.4		62.5		6.2	ab
Significance Level	*0.1654*		*0.5906*		*0.2389*		*0.0008*	
Control vs Treatments	*0.0625*		*0.2493*		*0.1636*		*0.7100*	
Low vs High tractor speed	*0.8296*		*0.4318*		*0.8724*		*0.1836*	
Treatment LSD	-		-		-		*0.1*	

ns = Not significant at $P < 0.05$

Table 7. Effect of thinning treatments on average number of fully developed seed content per fruit and average foreground and background fruit color of 'Forelle' pears at Oak Valley, Elgin (2013/2014).

Treatments	Average number of fully developed seeds per fruit	Average blush development[z]	Average ground color[y]
Control - hand thinned	1.2 ns	3.0 ns	2.3 ns
50% hand flower removal	1.3	3.2	2.3
6-BA (150 µl·L^{-1}) + NAA (5 µl·L^{-1})	1.5	3.1	2.3
Darwin 300™, 3.2 km·h^{-1} @ 240 rpm	1.1	3.1	2.0
Darwin 300™, 3.2 km·h^{-1} @ 260 rpm	1.0	3.3	2.2
Darwin 300™, 5.2 km·h^{-1} @ 300 rpm	1.1	3.1	2.3
Darwin 300™, 5.2 km·h^{-1} @ 320 rpm	1.1	3.3	2.5
Significance Level	*0.1994*	*0.7042*	*0.1936*
Control vs Treatments	*0.9218*	*0.2729*	*0.6376*
Low vs High tractor speed	*0.6049*	*0.9821*	*0.0348*
Treatment LSD	-	-	-

[z] Blush development determined from Unifruco P25 chart on a scale from 1 to 6 (1=most blush, 6=least blush)

[y] Ground color analyzed from Unifruco apple and pear chart on a scale from 0.5 to 5 (0.5 = most green, 5 = yellow)

ns = Not significant at $P < 0.05$

Table 8. Effects of thinning treatments on percentage return bloom on 'Forelle' pears at Oak Valley, Elgin (2013/2014).

Treatments	Percentage return bloom tagged branches
Control - hand thinned	25.9 bc
50% hand flower removal	37.9 a
6-BA (150 µl·L^{-1}) + NAA (5 µl·L^{-1})	30.7 ab
Darwin 300™, 3.2 km·h^{-1} @ 240 rpm	22.0 bcd
Darwin 300™, 3.2 km·h^{-1} @ 260 rpm	19.6 bcd
Darwin 300™, 5.2 km·h^{-1} @ 300 rpm	16.0 cd
Darwin 300™, 5.2 km·h^{-1} @ 320 rpm	12.2 d
Significance Level	*0.0025*
Control vs Treatments	*0.5270*
Low vs High tractor speed	*0.1110*
Treatment LSD	*11.8*

Table 9. Effect of thinning treatments on total weight and number of fruitlets thinned by hand during commercial hand thinning from 'Forelle' pear trees at Oak Valley, Elgin (2014/2015).

Treatments	Average weight of fruitlets hand thinned per plot (kg)	Average number of fruitlets hand thinned per plot
Control - hand thinned	0.29 ns	126 ns
50% hand flower removal	0.16	75
6-BA (150 $\mu l \cdot L^{-1}$) + NAA (5 $\mu l \cdot L^{-1}$)	0.28	142
Darwin 300™, 5.2 $km \cdot h^{-1}$ @ 250 rpm	0.25	109
Darwin 300™, 5.2 $km \cdot h^{-1}$ @ 300 rpm	0.35	142
Darwin 300™, 5.2 $km \cdot h^{-1}$ @ 350 rpm	0.35	146
Darwin 300™, 5.2 $km \cdot h^{-1}$ @ 400 rpm	0.37	148
Significance Level	*0.0829*	*0.1303*
Control vs Treatments	*0.9770*	*0.9570*
Darwin rotation linear	*0.1320*	*0.1784*
Darwin rotation quadratic	*0.4520*	*0.4440*
Treatment LSD	-	-

ns = Not significant at $P < 0.05$

Table 10. Effect of thinning treatments on percentage of clusters failing to set fruit, percentage of fruit set per full bloom cluster and average number of fruit set per cluster on tagged branches on 'Forelle' pears trees at Oak Valley, Elgin (2014/2015).

Treatments	Percentage of clusters failing to set fruit on tagged branches[z]		Percentage of fruit set per cluster on tagged branches[y]		Average number of fruit set in a cluster on tagged branches[x]	
Control - hand thinned	43.7	d	95.9	ns	1.7	ns
50% hand flower removal	67.0	a	59.4		1.8	
6-BA (150 µl·L^{-1}) + NAA (5 µl·L^{-1})	53.3	cd	79.4		1.7	
Darwin 300™, 5.2 km·h^{-1} @ 250 rpm	55.7	bc	74.7		1.7	
Darwin 300™, 5.2 km·h^{-1} @ 300 rpm	57.8	abc	76.9		1.8	
Darwin 300™, 5.2 km·h^{-1} @ 350 rpm	63.9	ab	69.8		1.9	
Darwin 300™, 5.2 km·h^{-1} @ 400 rpm	56.2	bc	83.3		1.9	
Significance Level	*0.0017*		*0.1084*		*0.1804*	
Control vs Treatments	*0.0003*		*0.0183*		*0.2608*	
Darwin rotation linear	*0.6388*		*0.6149*		*0.0507*	
Darwin rotation quadratic	*0.1681*		*0.4929*		*0.2698*	
Treatment LSD	*10.0*		-			

[z] [Number of clusters at bloom - number of clusters set)/Number of clusters at bloom]*100

[y] (Number of fruits after natural fruit drop/ number of clusters at bloom)*100

[x] Number of fruits after natural fruit drop/ number of clusters set after natural fruit drop

ns = Not significant at *P* < 0.05

Table 11. Effect of thinning treatments on the percentage of average number of fruit set within clusters setting fruit on tagged branches of 'Forelle' pears on Oak Valley, Elgin (2014/2015).

Treatments	Percentage of average number of fruit set within clusters setting				
	1 fruitlet	2 fruitlets	3 fruitlets	4 fruitlets	5 fruitlets
Control - hand thinned	49.2 ns	35.7 ns	12.3 ns	2.4 ns	0.5 ns
50% hand flower removal	47.9	34.5	13.3	3.4	0.9
6-BA (150 µl·L^{-1}) + NAA (5 µl·L^{-1})	49.1	35.7	13.2	1.7	0.3
Darwin 300™, 5.2 km·h^{-1} @ 250 rpm	52.8	32.1	11.0	3.4	0.2
Darwin 300™, 5.2 km·h^{-1} @ 300 rpm	44.7	35.7	13.4	5.1	1.1
Darwin 300™, 5.2 km·h^{-1} @ 350 rpm	38.8	38.9	17.3	3.3	1.4
Darwin 300™, 5.2 km·h^{-1} @ 400 rpm	44.0	34.6	13.0	6.4	1.4
Significance Level	0.3692	0.9144	0.6139	0.0735	0.6871
Control vs Treatments	0.5239	0.9091	0.6096	0.2070	0.5255
Darwin rotation linear	0.1035	0.4989	0.3162	0.1666	0.1824
Darwin rotation quadratic	0.1293	0.2723	0.1453	0.5184	0.4412
Treatment LSD	-	-	-	-	-

ns = Not significant at $P < 0.05$

Table 12. Effects of thinning treatments on average yield efficiency per plot and estimated yield of 'Forelle' pears trees at Oak Valley, Elgin (2014/2015).

Treatment	Average yield efficiency per 3 tree plot (kg·cm^{-2})	Estimated yield (ton·ha^{-1})
Control - hand thinned	0.46 abc	59
50% hand flower removal	0.44 abc	50
6-BA (150 µl·L^{-1}) + NAA (5 µl·L^{-1})	0.48 ab	57
Darwin 300™, 5.2 km·h^{-1} @ 250 rpm	0.44 bc	54
Darwin 300™, 5.2 km·h^{-1} @ 300 rpm	0.52 a	58
Darwin 300™, 5.2 km·h^{-1} @ 350 rpm	0.39 c	47
Darwin 300™, 5.2 km·h^{-1} @ 400 rpm	0.44 bc	52
Significance Level	*0.0417*	
Control vs Treatments	*0.8747*	
Darwin rotation linear	*0.2830*	
Darwin rotation quadratic	*0.6833*	
Treatment LSD	*0.07*	

Table 13. Effects of thinning treatments on average fruit size and firmness of 'Forelle' pears at Oak Valley, Elgin (2014/2015).

Treatments	Average fruit weight (g)		Average fruit length (mm)		Average fruit diameter (mm)		Average fruit firmness (kg)	
Control - hand thinned	129.3	c	80.1	c	60.6	c	5.8	c
50% hand flower removal	143.6	b	83.2	bc	62.7	b	6.0	ab
6-BA (150 µl·L^{-1}) + NAA (5 µl·L^{-1})	137.0	bc	81.8	c	61.7	bc	5.9	bc
Darwin 300™, 5.2 km·h^{-1} @ 250 rpm	148.3	b	83.3	bc	63.0	b	5.9	bc
Darwin 300™, 5.2 km·h^{-1} @ 300 rpm	162.1	a	83.3	bc	64.8	a	6.2	a
Darwin 300™, 5.2 km·h^{-1} @ 350 rpm	144.7	b	85.6	ab	62.5	b	5.9	bc
Darwin 300™, 5.2 km·h^{-1} @ 400 rpm	171.8	a	88.2	a	65.7	a	6.1	a
Significance Level	*<0.0001*		*0.0042*		*<0.0001*		*0.0130*	
Control vs Treatments	*<.0001*		*0.0056*		*0.0001*		*0.0152*	
Darwin rotation linear	*0.0136*		*0.0070*		*0.0334*		*0.2647*	
Darwin rotation quadratic	*0.1524*		*0.3197*		*0.2113*		*0.8275*	
Treatment LSD	*13.1*		*3.8*		*1.7*		*0.2*	

Table 14. Effect of thinning treatments on average number of fully developed seed content per fruit and average foreground and background fruit color of 'Forelle' pears at Oak Valley, Elgin (2014/2015).

Treatments	Average number of fully developed seeds per fruit		Average blush development[z]		Average ground color[y]	
Control - hand thinned	0.7	ns	2.9	ns	3.2	a
50% hand flower removal	0.9		3.1		3.1	ab
6-BA (150 µl·L^{-1}) + NAA (5 µl·L^{-1})	0.8		3.4		3.3	a
Darwin 300™, 5.2 km·h^{-1} @ 250 rpm	0.3		2.8		2.9	abc
Darwin 300™, 5.2 km·h^{-1} @ 300 rpm	0.6		3.0		2.7	bc
Darwin 300™, 5.2 km·h^{-1} @ 350 rpm	0.3		3.0		2.8	abc
Darwin 300™, 5.2 km·h^{-1} @ 400 rpm	0.3		3.0		2.5	c
Significance Level	*0.0955*		*0.6270*		*0.0357*	
Control vs Treatments	*0.4209*		*0.3948*		*0.0769*	
Darwin rotation linear	*0.6367*		*0.5002*		*0.0946*	
Darwin rotation quadratic	*0.4918*		*0.6487*		*0.9036*	
Treatment LSD	-		-		*0.6*	

[z] Blush development determined from Unifruco P25 chart on a scale from 1 to 6 (1=most blush, 6=least blush)

[y] Ground color analyzed from Unifruco apple and pear chart on a scale from 0.5 to 5 (0.5 = most green, 5 = yellow)

ns = Not significant at $P < 0.05$

Table 15. Effects of thinning treatments on return bloom of 'Forelle' pears at Oak Valley, Elgin (2014/2015).

Treatments	Percentage return bloom on tagged branches	
Control - hand thinned	22.7	bc
50% hand flower removal	29.8	ab
6-BA (150 $\mu l \cdot L^{-1}$) + NAA (5 $\mu l \cdot L^{-1}$)	35.1	a
Darwin 300™, 5.2 $km \cdot h^{-1}$ @ 250 rpm	19.4	bc
Darwin 300™, 5.2 $km \cdot h^{-1}$ @ 300 rpm	18.0	c
Darwin 300™, 5.2 $km \cdot h^{-1}$ @ 350 rpm	14.6	c
Darwin 300™, 5.2 $km \cdot h^{-1}$ @ 400 rpm	12.3	c
Significance Level	*0.0028*	
Control vs Treatments	*0.7923*	
Darwin rotation linear	*0.1748*	
Darwin rotation quadratic	*0.9067*	
Treatment LSD	*11.5*	

Table 16. Effect of thinning treatments on total weight and number of fruitlets hand thinned during commercial hand thinning from 'Forelle' pear trees at Lushof, Ceres (2014/2015).

Treatments	Average weight of fruitlets hand thinned per tree (kg)		Average number of fruitlets hand thinned per tree	
Control – hand thinned	1.2	a	251	a
Bloom Bandit™ 1 minute	0.8	bc	199	abc
NAA (5 µl·L^{-1})	1.0	ab	212	ab
ACC (400 µl·L^{-1})	0.1	d	26	d
6-BA (100 µl·L^{-1})	0.9	b	201	abc
6-BA (150 µl·L^{-1})	0.9	b	208	ab
6-BA (100 µl·L^{-1}) + NAA (5 µl·L^{-1})	0.7	c	158	bc
6-BA (150 µl·L^{-1}) + NAA (5 µl·L^{-1})	0.7	c	151	c
Significance Level	*<.0001*		*<.0001*	
Control vs Treatments	*<.0001*		*0.0001*	
6-BA vs 6-BA+NAA	*0.0012*		*0.0128*	
Treatment LSD	*0.2*		*55*	

Table 17. Effect of thinning treatments on percentage of clusters failing to set fruit, percentage of fruit set per full bloom cluster and average number of fruit set per cluster on tagged branches on 'Forelle' pears trees at Lushof, Ceres (2014/2015).

Treatments	Percentage of clusters failing to set fruit on tagged branches[z]		Percentage of fruit set per cluster on tagged branches[y]		Average number of fruit set in a cluster on tagged branches[x]	
Control – hand thinned	42.7	def	110.6	ab	1.9	a
Bloom Bandit™ 1 minute	52.0	cd	89.2	bc	1.8	a
NAA (5 µl·L^{-1})	40.7	ef	101.4	b	1.7	ab
ACC (400 µl·L^{-1})	91.9	a	11.6	e	1.2	c
6-BA (100 µl·L^{-1})	32.7	f	127.7	a	1.9	a
6-BA (150 µl·L^{-1})	44.7	ed	97.6	b	1.8	ab
6-BA (100 µl·L^{-1}) + NAA (5 µl·L^{-1})	58.1	bc	71.8	cd	1.7	ab
6-BA (150 µl·L^{-1}) + NAA (5 µl·L^{-1})	63.7	b	53.5	d	1.5	b
Significance Level	*<.0001*		*<.0001*		*<0.0001*	
Control vs Treatments	*0.0033*		*0.0008*		*0.0061*	
6-BA vs 6-BA+NAA	*<.0001*		*<.0001*		*0.0105*	
Treatment LSD	*10.5*		*23.6*		*0.3*	

[z] [Number of clusters at bloom - number of clusters set)/Number of clusters at bloom]*100

[y] (Number of fruits after natural fruit drop/ number of clusters at bloom)*100

[x] Number of fruits after natural fruit drop/ number of clusters set after natural fruit drop

Table 18. Effect of thinning treatments on the percentage of average number of fruit set within clusters setting fruit on tagged branches of 'Forelle' pears at Lushof, Ceres (2014/2015).

Treatments	Percentage of average number of fruit set within clusters									
	1 fruitlet		2 fruitlets		3 fruitlets		4 fruitlets		5 fruitlets	
Control – hand thinned	40.4	d	35.1	ns	17.2	c	6.4	a	0.6	ns
Bloom Bandit™ 1 minute	46.7	dc	32.8		13.1	bcd	5.2	ab	1.9	
NAA (5 µl·L^{-1})	50.3	bcd	33.6		13.4	bcd	1.9	bc	0.5	
ACC (400 µl·L^{-1})	65.7	a	22.0		1.9	e	0.4	c	0.0	
6-BA (100 µl·L^{-1})	40.3	d	36.0		19.1	a	4.1	abc	0.6	
6-BA (150 µl·L^{-1})	50.1	cd	30.6		14.6	abc	4.2	ab	0.6	
6-BA (100 µl·L^{-1}) + NAA (5 µl·L^{-1})	55.3	abc	30.2		10.3	cd	1.9	bc	1.5	
6-BA (150 µl·L^{-1}) + NAA (5 µl·L^{-1})	64.8	ab	24.2		8.8	d	2.2	bc	0.0	
Significance Level	*0.0030*		*0.0690*		*<.0001*		*0.0360*		*0.2969*	
Control vs Treatments	*0.0236*		*0.1768*		*0.0082*		*0.0128*		*0.8768*	
6-BA vs 6-BA+NAA	*0.0044*		*0.0706*		*0.0003*		*0.1146*		*0.8662*	
Treatment LSD	*14.7*		*-*		*4.5*		*3.7*		*-*	

ns = Not significant at $P < 0.05$

Table 19. Effects of thinning treatments on average yield efficiency per tree and estimated yield of 'Forelle' pears trees at Lushof, Ceres (2014/2015).

Treatment	Average yield efficiency per tree (kg·cm^{-2})		Estimated yield (ton·ha^{-1})
Control – hand thinned	0.18	a	68.3
Bloom Bandit™ 1 minute	0.15	a	54.5
NAA (5 µl·L^{-1})	0.16	a	59.9
ACC (400 µl·L^{-1})	0.07	b	27.6
6-BA (100 µl·L^{-1})	0.15	a	53.8
6-BA (150 µl·L^{-1})	0.16	a	55.5
6-BA (100 µl·L^{-1}) + NAA (5 µl·L^{-1})	0.16	a	59.8
6-BA (150 µl·L^{-1}) + NAA (5 µl·L^{-1})	0.14	a	54.0
Significance Level	*<0.0001*		
Control vs Treatments	*0.0133*		
6-BA vs 6-BA+NAA	*0.8270*		
Treatment LSD	*0.04*		

Table 20. Effect of thinning treatments on average fruit size and firmness of 'Forelle' pears at Lushof, Ceres (2014/2015).

Treatments	Average fruit weight (g)		Average fruit length (mm)		Average fruit diameter (mm)		Average fruit firmness (kg)	
Control – hand thinned	151.5	c	77.1	d	65.5	b	6.0	abc
Bloom Bandit™ 1 minute	169.5	b	80.8	abc	66.4	b	6.1	a
NAA (5 µl·L^{-1})	160.6	bc	79.7	abc	66.1	b	6.2	a
ACC (400 µl·L^{-1})	202.6	a	82.2	a	68.7	a	6.1	ab
6-BA (100 µl·L^{-1})	162.5	bc	80.4	abc	65.6	b	6.0	bc
6-BA (150 µl·L^{-1})	162.1	bc	79.5	bcd	65.8	b	6.1	a
6-BA (100 µl·L^{-1}) + NAA (5 µl·L^{-1})	158.2	bc	78.9	cd	65.6	b	6.0	bc
6-BA (150 µl·L^{-1}) + NAA (5 µl·L^{-1})	165.1	b	82.0	ab	66.0	b	5.9	c
Significance Level	*<.0001*		*0.0036*		*<.0001*		*0.0040*	
Control vs Treatments	*0.0002*		*0.0008*		*0.0575*		*0.8068*	
6-BA vs 6-BA+NAA	*0.8773*		*0.5962*		*0.7667*		*0.0261*	
Treatment LSD	*11.6*		*2.5*		*1.2*		*0.2*	

Table 21. Effect of thinning treatments on average number of fully developed seed content per fruit and average foreground and background color per fruit of 'Forelle' pears at Lushof, Ceres (2014/2015).

Treatments	Average number of fully developed seeds per fruit		Average blush development[z]		Average ground color[y]	
Control – hand thinned	0.2	ns	4.1	a	2.5	ns
Bloom Bandit™ 1 minute	0.2		4.2	a	2.3	
NAA (5 µl·L^{-1})	0.1		4.1	a	2.3	
ACC (400 µl·L^{-1})	0.4		3.0	b	2.3	
6-BA (100 µl·L^{-1})	0.5		4.3	a	2.3	
6-BA (150 µl·L^{-1})	0.2		4.1	a	2.3	
6-BA (100 µl·L^{-1}) + NAA (5 µl·L^{-1})	0.2		4.2	a	2.3	
6-BA (150 µl·L^{-1}) + NAA (5 µl·L^{-1})	0.3		4.3	a	2.2	
Significance Level	*0.3783*		*<0.0001*		*0.1480*	
Control vs Treatments	*0.8431*		*0.6125*		*0.0034*	
6-BA vs 6-BA+NAA	*0.4282*		*0.8723*		*0.7521*	
Treatment LSD	-		*0.5*		-	

[z] Blush development determined from Unifruco P25 chart on a scale from 1 to 6 (1=most blush, 6=least blush)

[y] Ground color analyzed from Unifruco apple and pear chart on a scale from 0.5 to 5 (0.5 = most green, 5 = yellow)

ns = Not significant at $P < 0.05$

Table 22. Effects of thinning treatments on return bloom of 'Forelle' pears at Lushof, Ceres (2014/2015).

Treatments	Percentage return bloom on tagged branches
Control – hand thinned	25.1 c
Bloom Bandit™ 1 minute	21.3 c
NAA (5 µl·L^{-1})	23.1 c
ACC (400 µl·L^{-1})	47.0 a
6-BA (100 µl·L^{-1})	36.5 b
6-BA (150 µl·L^{-1})	25.5 c
6-BA (100 µl·L^{-1}) + NAA (5 µl·L^{-1})	45.0 ab
6-BA (150 µl·L^{-1}) + NAA (5 µl·L^{-1})	36.1 b
Significance Level	*<.0001*
Control vs Treatments	*0.0247*
6-BA vs 6-BA+NAA	*0.0067*
Treatment LSD	*9.6*

Plate 1. Oak Valley 'Forelle' Orchard thinned with Darwin 300™ in 2013/2014 and 2014/2015 trials.

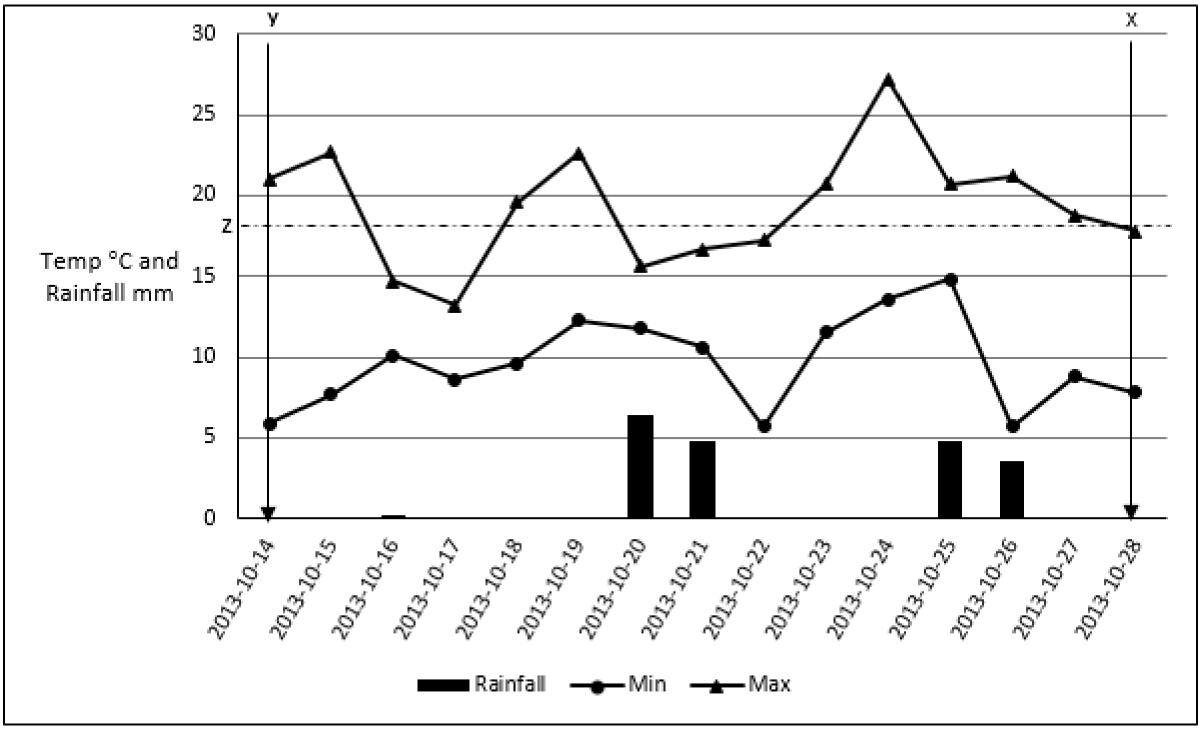

Fig. 1. Minimum and maximum temperatures and rainfall data during and 14 days after treatment application, Oak Valley, Elgin (2013/2014).

[z]18°C; [y] Application date all chemical applications; [x] Hand thinning date

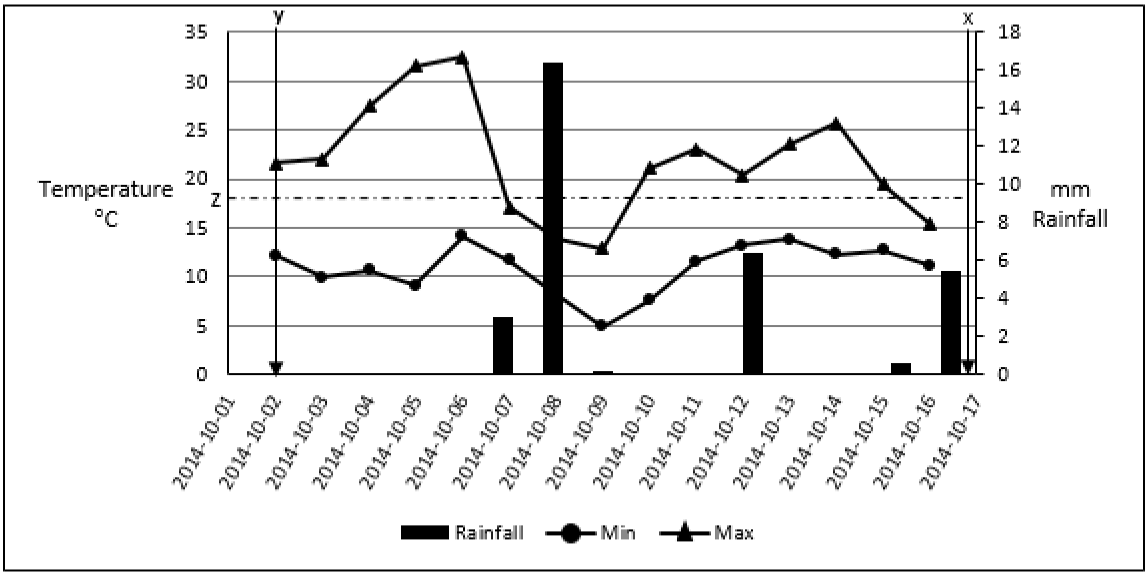

Fig. 2. Minimum and maximum temperature and rainfall data during and 14 days after treatment application, Oak Valley, Elgin (2014/2015).

[z]18°C; [y] Application date all chemical applications; [x] Hand thinning date

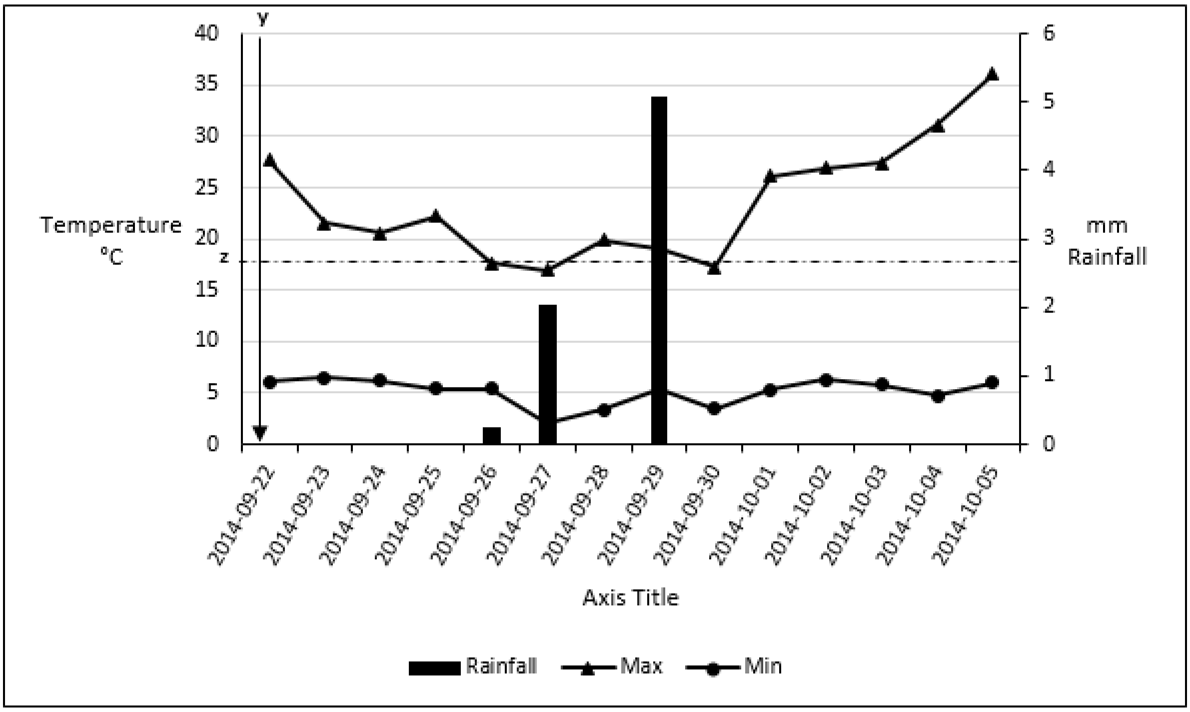

Fig. 3. Minimum and maximum temperature and rainfall data during and 14 days after treatment application, Lushof, Ceres (2014/2015).

^{z}18°C; ^{y} Application date all chemical applications

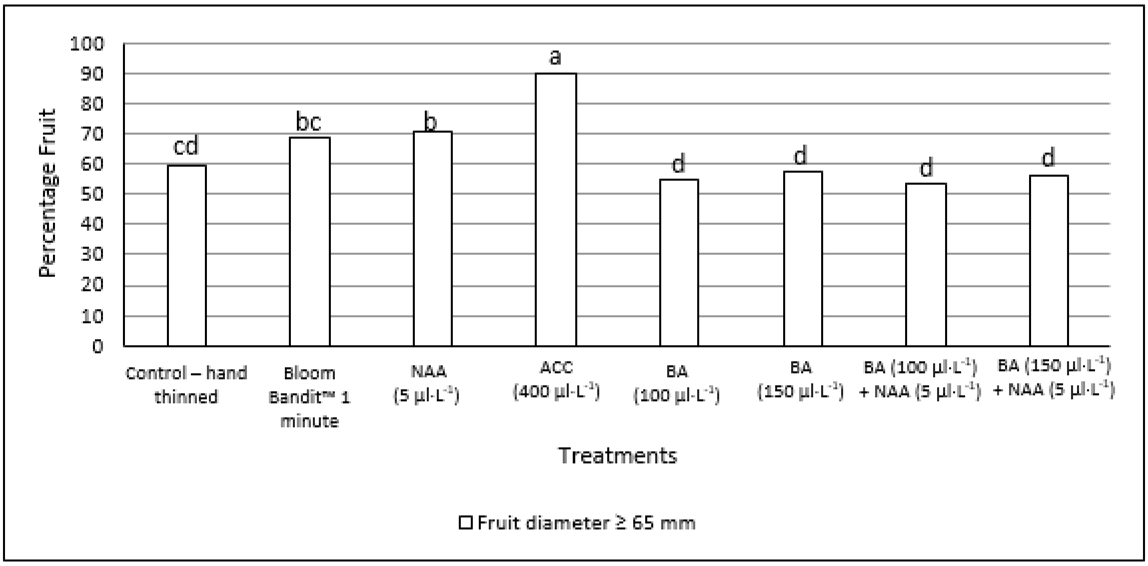

Fig. 4. Effect of thinning treatments on percentage of 'Forelle' fruit with diameter ≥ 65 mm at Lushof, Ceres (2014/2015).

Mechanical Thinning of Apples (*Malus domestica* Borkh.)

ADDITIONAL INDEX WORDS. BAUM, Darwin 300™, Bloom Bandit™, chemical thinning, fruit set, fruit quality, return bloom

SUMMARY. Thinning of apples is necessary to improve returns for producers through lowering the hand thinning requirement, and giving a high yielding crop with increased fruit quality and adequate return bloom. Mechanical thinning is relatively new in South Africa and these are the first experiments where the tractor-driven BAUM and Darwin 300™, as well as the Bloom Bandit™ hand-held thinner were evaluated on apples. The BAUM was tested on 'Cripps' Pink' in two trials; four treatments were applied in the first trial in the 2013/2014 season at 30% petal drop, with tractor speeds of 3.0 km·h^{-1} and 4.0 km·h^{-1}, and rotation rates of 350 rpm and 400 rpm. A late (18 mm fruit diameter) chemical application of 6-BA 150 µl·L^{-1} and an unthinned control included. The second trial received four mechanical treatments at full bloom in the 2014/2015 season, with tractor speeds of 2.7 km·h^{-1} and 3.3 km·h^{-1} with 300 rpm rotation rate, and 3.0 km·h^{-1} with 400 rpm rotation rate, and the Bloom Bandit™ for 1 min tree^{-1}. A untreated control was included and commercial hand thinning with all other treatments. The Darwin 300™ was evaluated in the 2013/2014 season on 'Cripps' Pink' at 4 mm fruit diameter with three treatments; a tractor speed of 3.0 km·h^{-1} and rotation rates of 200 rpm and 220 rpm, and at 4.0 km·h^{-1} with 240 rpm. A late (15 mm fruit diameter) chemical application of 6-BA 100 µl·L^{-1} and an unthinned control was included. The Bloom Bandit™ was tested in two trials in the 2014/2015 season on 'Fuji' and 'Cripps' Red', and used for 1 or 2 min tree^{-1}. A standard farm chemical application of carbaryl 700 mg·L^{-1} and NAA 5 µl·L^{-1} was applied at 6 - 7 mm fruit diameter. The control was untreated, and was hand-thinned commercially with all other treatments. Mechanical thinning with the BAUM and Darwin 300™ was not able to give consistent results in reducing set and hand thin requirement, as well as yield, fruit size, fruit quality or return bloom. It is suspected that the unreliable results are due to the lack of orchard suitability for mechanical thinning. The Bloom Bandit™ effectively thinned apples and improved fruit size and quality without major losses in yield at both 1 min and 2 min with better results at the more intense 2 min level. It also improved return bloom in 'Cripps' Red' but not in 'Fuji'. 6-BA applied at 100 µl·L^{-1} or 150 µl·L^{-1} did not improve fruit size well. Spray conditions remain important for chemical applications. The carbaryl 700 mg·L^{-1} and NAA 5 µl·L^{-1} remains an effective chemical combination for thinning 'Fuji' and 'Cripps' Red'.

Fruit thinning is one of the most important orchard management practices in apple cultivation. Thinning is performed to enhance fruit size, improve yield and ensures adequate return bloom to overcome alternate bearing (Greene and Costa, 2013; Solomakhin et al., 2012). Approximately 7% of apple flowers need to set for a sufficient crop (Solomakhin and Blanke, 2010). All commercial apple cultivars benefit from thinning (Greene and Costa, 2013). Thinning can be applied at different phenological stages, from bloom until when fruitlets are ±18 mm in diameter (Greene and Costa, 2013). Hand thinning on apples is usually performed after natural fruit drop has occurred (McArtney et al., 1996), and is the most reliable, but the most expensive method of thinning apples (Costa et al., 2013).

In general, apples are thinned chemically. A wide range of chemicals exist of which the most commonly used are 2-chlorophosphonic acid (ethephon), ammonium thiosulfate (ATS), lime sulphur, the synthetic auxins napthaleneacetic acid (NAA) and naphthylacetamide (NAD), the synthetic cytokinin 6-benzyladenine (6-BA) and the insecticide carbaryl (Greene and Costa, 2013). Generally the choice of thinning compound depends on cultivar and production region. Apart from bloom thinners like ATS and lime sulphur, most chemicals are applied between 7 - 10 mm fruitlet diameter, which is slightly later in the season as producers want to ensure adequate set has occurred before applying any thinning agent (Greene, 2004). The use of chemical thinning has long been established but use thereof is slowly decreasing due to a number of reasons (Damerow and Blanke, 2009). Unwanted phytotoxicity of chemicals is experienced (Greene, 2004), as well as erratic and unreliable results from chemical thinning agents due to adverse weather conditions, specifically temperature (Veal et al., 2011). Increased environmental concerns have led to the search for non-persistent chemicals with low toxicity as the some chemicals do not always fit into the requirements of sustainable fruit production (Bound, 2010; Wertheim, 1997).

Depending on cultivar, NAA is usually applied as a post bloom thinner at rates up to 20 $\mu l \cdot L^{-1}$ when fruitlets are 6 – 16 m in diameter (Dennis, 2000). NAA applied alone does not always have a positive effect on fruit size, and can lead to the formation of pigmy fruit (Theron, 2013; Wertheim, 2000). To optimize fruit size it is recommended that earlier applications are made at 5 days after full bloom (DAFB) (Wertheim, 2000). 6-BA should be applied at 50 – 75 $\mu l \cdot L^{-1}$ on easy-to-thin cultivars and from 75 – 100 $\mu l \cdot L^{-1}$ on difficult-to-thin cultivars when fruitlets are 10 mm in diameter (Wertheim, 2000). In South Africa 6-BA is registerd to be applied at higher rates. 6-BA increases fruit size and promotes return bloom (Wertheim, 2000; Wismer et al., 1995). The combination of 6-BA (100 $\mu l \cdot L^{-1}$) and NAA (10 $\mu l \cdot L^{-1}$) at a fruitlet diameter of 11 mm is a good option for thinning difficult to thin cultivars such as 'Fuji' (Dorigoni and Lezzer, 2007). This combination is registered for use in

South Africa on ‘Fuji’ and generally applied at petal drop (Theron, 2013). Carbaryl is an insecticide and the recommended application rate is 750 $\mu l \cdot L^{-1}$ but the rate also depends on cultivar. In apples it is usually applied between 14 and 28 DAFB (Wertheim, 2000). Carbaryl was removed from the European market in 2007 due to it being a wide spectrum insecticide and its continued use in South Africa is doubtful (Dorigoni and Lezzer, 2007; Theron, 2013). Thinning more selective with carbaryl compared to 6-BA, but it is less environmentally friendly and can sometimes lead to fruit russet formation (Basak, 2004; Theron, 2013). NAA, 6-BA and carbaryl reduced set and yield per tree, and increased fruit size and return bloom in ‘Elstar’ apples (Wismer et al., 1995).

Growers are finding it increasingly difficult to find a workforce to hand thin crops (Schupp et al, 2008) and due to the aforementioned problems associated with chemical thinning, there is a shift to more environmentally friendly methods of apple thinning (Basak et al., 2013; Solomakhin and Blanke, 2010). Mechanical thinning is seen as a promising alternative as it is less weather dependent, requires less time and is cheaper than hand or chemical thinning and has less environmental impact. In addition, results from mechanical thinning are visible immediately and can be further adjusted after bloom by an additional follow up thinning method (Basak et al., 2013). Two general problems with mechanical thinning in pome fruit are the possibility of leaf damage due to the presence of foliage during bloom, and a risk of spreading diseases (Greene and Costa, 2013). Mechanical thinning does not thin selectively in tree canopies, and only general areas of whole orchards can be targeted i.e. the outer rather than the inner canopy or more of the upper than lower branches (Costa et al., 2013).

The Darwin™ is a mechanical string thinner that was the first of its kind to be developed and evaluated on apples in 1998 (Bertschinger et al., 1998). The device was developed to overcome the shortcomings of chemical thinning and depending on the model consist of a 2 – 3 m long vertical shaft with rotating spindles attached. Successful thinning has been obtained on apples where fruit set was lowered, and fruit size and return bloom increased (Kon et al., 2013). A similar device called the BAUM was developed in 2007 and is a string thinner with three adjustable rotating horizontal arms (Damerow et al., 2007). The BAUM was developed to overcome limitations of the Darwin™, specifically to remove flowers close to the tree trunk and not only in the periphery of the canopy (Veal et al., 2011). Flower removal close to the trunk is often desirable as these flowers produce fruit of poorer quality compared to other parts of the canopy (Kong et al., 2009). This is made possible by the adjustment of the rotors according to the position of the branches (Basak et al., 2013). The BAUM reduced fruit set, improved fruit quality and controlled alternate bearing in ‘Elstar’, ‘Braeburn’, ‘Gala’ and ‘Golden Delicious’ apples (Kong et al., 2009; Veal et al., 2011).

Both the Darwin™ and the BAUM are mounted onto a tractor and powered through the hydraulic system, which can be set to achieve different thinning intensities (Solomakhin et al., 2012). Thinning efficacy can be increased through increasing rotor speed or decreasing tractor speed, or both (Seehuber et al., 2013). Rotational rates and tractor speeds differ depending on experiences in different production regions, but generally are between 260 – 460 rpm and 2.5 – 8 km·h^{-1} (Basak et al., 2013; Hehnen et al., 2012; Seehuber et al., 2013). The precision and predictability of the thinning response for the Darwin™ and the BAUM have been significantly improved since initial trials (Greene and Costa, 2013). The BAUM is adapted to many tree training system such as a spindle, Solaxe, vertical axis or fruiting wall (Kong, et al., 2009). Mechanical thinning does sometimes damage spurs and shoots, but this damage has been reduced to as low as 8% – 10% (Basak et al., 2013; Damerow et al., 2007; Kong, et al., 2009; Veal, et al., 2011).

Recently, portable hand-held flower thinning machines have been developed. The Electro-flor® is such a device that was developed in France in 2009 (Jay et al., 2009). The Electro-flor® is a telescope pole 10 feet (3 m) long with a 30 cm rotating tip with cords. For apples the rotational speed of 1600 – 1800 rpm is recommended (Delmas, 2007), and results on apples were promising (Jay et al., 2009). The Bloom Bandit™ is another such device that has recently been released in the USA. This device was developed from commercial weed trimmers and initially powered by a gasoline engine on a pole, but this was found to be too heavy and noisy (Warner, 2012). The product has since been adapted and is now powered by a 12 V, 13 A battery, and is 1.8-m-long with an 18 cm rotating tip which turns at a speed of 1300 rpm. The number and length of strings arranged on the tip of the Bloom Bandit™ can be varied as needed. These devices provide simple and inexpensive mechanical thinning options (Mrowicki, 2012). The objective should be to remove 50% of flowers in the first pass over a branch (Delmas, 2007). Targeted thinning can be performed to suit individual tree needs (Jay et al., 2009), but this could result in an increased number of working hours (Delmas, 2007).

The objective of this paper was to investigate the effects of various mechanical thinning methods on a number of apple cultivars under South African orchard conditions.

Materials and methods

PLANT MATERIAL AND SITE DESCRIPTION. Five trials were conducted in Elgin, South Africa, two during the 2013/2014 season, and three during the 2014/2015 season. The first 2013/2014 trial was conducted on mature ‘Cripps’ Pink’ trees at Oak Valley Estate, (34°10'25.8"S 19°03'40.3"E) (Plate.1) while the second was on mature ‘Cripps’ Pink’ trees on Maredale farm (34°11'16.1"S 19°02'06.5"E) (Plate. 2). The first trial in 2014/2015 was also conducted at Oak Valley on mature ‘Cripps’ Pink’, but in a different but similar structured orchard to 2013/2014 (34°10'31.0"S 19°03'35.2"E). These orchards were chosed due to their layout suitability for mechanically thinning with the respective thinners and are presented in Plate 1, 2 and 3. The last two trials in 2014/2015 were conducted on Eikenhof farm, the first on mature ‘Fuji’ trees (34°07'25.6"S 19°03'32.4"E) and the second on mature ‘Cripps’ Red’ trees (34°07'22.2"S 19°03'32.5"E). Further orchard details are presented in Table 1.

TREATMENT AND EXPERIMENTAL DESIGN: 2013-2014. During the 2013/2014 season in Trial 1, the BAUM was utilized at 30% petal drop for four mechanical thinning treatments. Tractor speeds of either 3 km·h^{-1} or 4 km·h^{-1} was combined with spindle rotational speeds of 350 rpm or 400 rpm. A chemical thinning treatment of 150 µl·L^{-1} 6-BA (MaxCel™, Philagro SA, Somerset West, South Africa) was applied 24 DAFB (18 mm fruitlet diameter) and compared to an untreated control. In Trial 2, three mechanical thinning treatments with the Darwin 300™ was evaluated at 4 mm fruitlet diameter (petal drop). A tractor speed of 3 km·h^{-1} at rotational speeds of 200 rpm and 220 rpm and a tractor speed of 4 km·h^{-1} at a rotational speed of 240 rpm was evaluated. A chemical thinning treatment of 6-BA at 100 µl·L^{-1} applied at 21 DAFB (15 mm fruitlet diameter) and an untreated control also included. Relevant phenological stages and dates for thinning and harvest activities of these two trials are presented in Table 2. Weather conditions during and for 14 days after application for the two trials are presented in Fig. 1 and 2. Ideally there should be no rainfall and the temperature should be above 18°C for at least three days after application (Philagro SA, Somerset West, South Africa). No commercial hand-thinning was performed as set was low. The experimental design was a randomized complete block with five replications. Every replicate consisted of seven trees, and the center three trees were used to collect data.

TREATMENT AND EXPERIMENTAL DESIGN: 2014-2015. Trial 1 on ‘Cripps’ Pink’ included a mechanical thinning treatment at full bloom using the Bloom Bandit™ (Automated AG Systems, 999 Road M S.E., Moses Lake, WA 98837) hand thinning device. Trees were thinned for one min per tree (30 sec. each side). The Bloom Bandit™ was fitted with six evenly spaced 27-cm-long plastic strings and rotated at a speed of 1200 rpm. The BAUM was used in three mechanical thinning treatments at full bloom: tractor speed of 2.7 km·h^{-1} at a rotational rate of 300 rpm, 3.0 km·h^{-1} at a rotational rate of 400 rpm and at 3.3 km·h^{-1} at a rotational rate of 300 rpm. No chemical thinning was done due to low flower density. An untreated control was also added to this trial, and hand thinned with the rest of the treatments after physiological fruit drop. The trial design was the same as 2013/2014 trials with an added replication making a total of six replicates.

Trial 2 on 'Fuji' and Trial 3 on 'Cripps' Red' apples received identical treatments. Two mechanical thinning treatments were applied at full bloom using the Bloom Bandit™ as described above. The first treatment was thinned for 1 min per tree (30 sec. each side) and the second treatment 2 min per tree (60 sec. each side). A chemical thinning tank-mix treatment of 700 $mg \cdot L^{-1}$ carbaryl (1-naphthyl methyl carbamate) (Sevin XLR, Villa Crop Protection, Kempton Park, South Africa) and 5 $\mu l \cdot L^{-1}$ 2-(1-naphthyl)acetic acid (NAA) (Planofix, Bayer SA, Paarl, South Africa) was included in these trials and applied to 'Fuji' 11 DAFB (7 mm fruitlet diameter) and 'Cripps' Red' 10 DAFB (6 mm fruitlet diameter). Weather conditions during and for 14 days after chemical applications are presented in Fig. 3 and 4. An untreated control was included in both trials, which received only commercial hand thinning after physiological fruit drop together with the rest of the treatments. Relevant phenological stages and dates for thinning and harvest activities for the 2014/2015 trials are presented in Table 3. The experimental design for these trials was a randomized complete block design with ten single tree repetitions.

DATA COLLECTED. For the 2014/2015 trials, two representative branches per tree were tagged and the total number of flower clusters counted at full bloom. After treatments were applied and natural physiological fruit drop occurred, the total number of fruit that set and fruit set within clusters counted on each tagged branch to determine percentage clusters failing to set fruit, percentage fruit set and the average number of fruit set in a cluster. Fruit removed during commercial hand thinning were weighed and counted to determine overall efficacy of thinning.

At commercial harvest, trunk circumferences were measured ±20 cm above the graft union to determine yield efficiency. The total yield was recorded per replicate by weighting all fruit harvested at each harvest date. When enough fruit was present, samples of 30 fruit per replicate were brought to our laboratory for further fruit quality analysis. Harvest time required for the 2013/2014 trials and the 2014/2015 'Cripps' Pink' trial was determined and the productivity in bins per man-day calculated. The fruit quality was determined by recording the following variables for each fruit: weight, length, diameter, firmness, fully developed and aborted seed content, blush color and ground color. Fruit firmness was determined by a GÜSS texture analyzer (Guss electronic model GS 20, Strand, South Africa) fitted with a 11.0 mm probe. Color development on 'Cripps' Pink' apples was determined using the Pink Lady® color chart on a scale of 1 to 12 (1 = least color, 12 = most color). For 'Fuji' apples the Unifruco chart A45 was used for color on a scale from 1 to 12 (1 = most color, 12 = least color). 'Cripps' Red' color was determined by classifying fruit as exportable (60% red color +) or not. Ground color for all trials was determined with the Unifruco color chart for apples and pears from 0.5 to 5 (0.5 = most green, 5 = yellow). Return bloom was determined in spring 2015 for the 2014/2015 trials by counting the number of vegetative and reproductive buds that sprouted. The total reproductive buds were expressed as a percentage of the total buds that sprouted.

STATISTICAL ANALYSIS. Data were analyzed using the linear model procedure (GLM) of the program SAS Enterprise guide 5.1 (SAS Institute Incorporated, 100 SAS Campus Drive Cary, North Carolina 27513-2414, USA), and when the F Statistic indicated significance at P < 0.05 the LSD test was used. Single degree of freedom, orthogonal, polynomial contrasts were fitted as described. In the 2013/2014 trial on Oak Valley, a contrast was fitted comparing the control to the average of all treatments, one that compared the average lower rotational rate of 350 rpm with the average higher rotational rate of 400 rpm, and one that compared the average lower tractor speed of 3.0 $km \cdot h^{-1}$ with the average higher tractor speed of 4.0 $km \cdot h^{-1}$. In the remainder of the trails in 2013/2014 and 2014/2015, a contrast was fitted comparing the controls to the average of all treatments.

Results

OAK VALLEY 2013-2014. The temperature was within recommended range of 18°C when applying treatments, however rainfall was unexpectedly recorded on the day of and after application which was not advantageous (Fig. 1). On average, the yield efficiency of all treatments was significantly reduced relative to the control at both harvests dates and for the combined yield efficiency compared to the control (first harvest P = 0.0417, second harvest P = 0.0424, and combined harvests P = 0.0123) (Table 4). At least 49% or more of the fruit were harvested during the second harvest (Table 4).The average time required by seven laborers to pick the fruit during the first harvest was almost significantly reduced by treatments compared to the control (P = 0.0716) (Table 5). The time required to pick the second harvest nor the total harvest was affected by the treatments. This is also reflected in the bins picked per man-day (Table 5).

Average fruit weight was unaffected by treatments at both harvest dates as well as for the combined harvest (Table 6). Average fruit length was nearly significantly increased by the BAUM treatments at low tractor speeds versus higher tractor speeds (P = 0.0599), and fruit length for the combined harvest was increased on average by all treatments compared to the control (P = 0.0450) (Table 7). Average fruit diameter was not significantly affected by the treatments (Table 8). At the first harvest an increase in fruit firmness for high tractor speeds compared to low tractor speeds was obtained (P = 0.0029) (Table 9). This was again the case at the second harvest (P = 0.0110), and on average all treatments increased the fruit firmness at the second harvest compared to the control (P

= 0.0434) (Table 9). In the second harvest, the BAUM treatment at 4.0 km·h-1 and 400 rpm fruit firmness was significantly increased compared to the control (Table 9). The fruit firmness for the combined harvest was significantly increased by higher tractor speeds compared to lower tractor speeds (*P* = 0.0006) (Table 9). The BAUM treatment at 4.0 km·h-1 and 350 rpm increased fruit firmness compared to the control (Table 9).

No effect was obtained on average number of fully developed seeds per fruit (Table 10). The average number of aborted seeds per fruit of the first harvest date was significantly lower at lower tractor speeds than higher speeds (*P* = 0.0141) (Table 10). At the second harvest date aborted seed content per fruit was on average lower for all treatments compared to the control (*P* = 0.0023), and fewer following thinning at lower tractor speeds than higher speeds (*P* = 0.0027) (Table 10). The combined harvest also had a fewer aborted seeds for the low tractor speed treatments compared to high tractor speed (*P* = 0.0006) (Table 10). The only effect on fruit color development or ground color was in the second harvest where on average all treatments increased red color development compared to the control (*P* = 0.0108), and the BAUM at 3 km·h-1 and 350 rpm, and at 4 km·h-1 at both 350 rpm and 400 rpm significantly increased the color development compared to the control (Table 11).

MAREDALE 2013-2014. No adverse weather conditions were recorded for this trails chemical applications (Fig. 2). The yield efficiency at the first harvest date was significantly reduced by the Darwin 300™ treatment at 4.0 km·h-1 and 240 rpm compared to the control (Table 12). Yield efficiency of the combined harvests was on average decreased by all treatments, and as much as 50% by the Darwin 300™ treatment at 4.0 km·h-1 and 240 rpm compared to the control (*P* = 0.0450) (Table 12). No significant differences were found in the time three laborers needed to harvest the different treatments (Table 13).

Average fruit weight was not affected by treatments at the first harvest date (Table 14). At the second harvest, increases in average fruit weight were recorded for all treatments on average compared to the control (*P* = 0.0009), the Darwin 300™ treatment at 3.0 km·h-1 and 220 rpm was the only treatment not to differ significantly from the control (Table 14). The combined average fruit weight was significantly increased on average by all treatments compared to the control (*P* = 0.0177), with the greatest significant increase of 10% (10 g per fruit) obtained following thinning with the Darwin 300™ at 4.0 km·h^{-1} and 240 rpm (Table 14). The average fruit length was significantly increased by 7% (3.5 mm) by the Darwin 300™ at 4.0 km·h^{-1} and 240 rpm treatment at the first harvest (Table 15). For the second harvest date, the Darwin 300™ at 4.0 $km \cdot h^{-1}$ and 240 rpm treatment increased fruit length significantly by 4% (2 mm) compared to the control (Table 15). For the combined harvests, fruit length was significantly increased by the Darwin 300™ at 4.0 $km \cdot h^{-1}$ and 240 rpm treatment by 5% (2.7 mm) compared to the control (Table 15). There was no effect on fruit diameter at the first harvest date. For the second harvest date all treatments on average significantly increased fruit diameter compared to the control (P = 0.0003), but the Darwin 300™ treatment at 3.0 km·h-1 and 220 rpm did to differ significantly from the control (Table 16). This was again the case on the combined harvest fruit diameter (P = 0.0149), but only the Darwin 300™ treatment at 4.0 km·h-1 and 240 rpm differed significantly from the control (Table 16). No significant results or trends were recorded for fruit firmness by any treatments (Table 17).

The average number of fully developed seeds per fruit was unaffected by treatments (Table 18). The average number of aborted seeds per fruit was very low, but was on average increased by treatments compared to the controls for the first harvest, and the combined harvests (P = 0.0197 and P = 0.0117, respectively) (Table 18). No treatment influenced red fruit color development or ground color (Table 19).

OAK VALLEY 2014-2015. The weight of fruit hand thinned was not significantly affected (Table 20). On average treatments almost significantly lowered the average number of fruit thinned during commercial hand-thinning (P = 0.0726) (Table 20). There were however no significant differences in fruit set per cluster, the average number of fruitlets that set in a cluster or the percentage of clusters that failed to set fruit (Table 21). The percentages of clusters setting different fruit numbers were also not significantly affected, except for 5 fruitlets per cluster which was higher for the control compared to treatments (P = 0.0593) (Table 22), nor were yield efficiency and harvest time (Table 23). Generally no significant differences were found in fruit size, except for fruit diameter which was increased by treatments compared to the control (P = 0.0764) (Table 24). Fruit firmness at harvest was also unaffected by treatments compare to the control (Table 24). A trend was observed that slightly more fully developed seeds were present per fruit following the thinning treatments, while the trend was reversed for the number of aborted seeds per fruit (P = 0.0767 and P = 0.0582, respectively) (Table 25). Fruit blush color development was on average better for all treatments compared to the control (P = 0.0637) (Table 25). The average ground color of fruit was not affected by any treatments (Table 25). On average the return bloom was increased by treatments compared to the control (Table 26).

EIKENHOF 'FUJI' 2014-2015. Temperature was in the required range for chemical applications, and no adverse rain was recorded soon after application (Fig. 3). Chemical thinning significantly lowered set by reducing the weight and the number of fruit hand thinned by 41% and 44% respectively, compared to the control (Table 27). This then resulted in a 52% increase in more clusters failing to set compared to the control from 23.9% to 36.3%, 35% less fruit set per cluster from the control of 177.9% to 116% and a significantly lower number of fruit set of 1.80 fruit per cluster (Table 28). The Bloom Bandit™ 1 min treatment reduced set by 18% in both weight and number of fruit hand thinned compared to the control, but only weight of fruit hand thinned was significantly lowered (Table 27). The percentage of clusters failing to set was increased by 49% from the control of 23.9% to 35.5%, whilst the percentage of fruit set per cluster was decreased by 20% compared to the control of 117.9% to 141.5%, which resulted in an average fruit set of 2.15 fruit in a cluster, none of these were statically significant differences (Table 28). The Bloom Bandit™ 2 min treatments also significantly reduced set as seen in a reduction of 29% in the weight and 31% in the number of fruit hand thinned (Table 27). The percentage of clusters that failed to set fruit was 69% more than the control from 23.9% to 40.3%, and 37% less fruit per cluster compared to the control of 117.9% to 111.3%, and a lower number of fruit to set in a cluster of 1.86 fruit (Table 28).

The chemical treatment resulted in an increase of 15.9% more clusters with only one fruitlet compared to the control, while no differences were found in this regard following thinning with the Bloom Bandit™ (Table 29). The number of clusters setting two or four fruit was not significantly affected by treatments (Table 29). The occurrence of three-fruitlet clusters was lowered by the chemical treatment compared to both the Bloom Bandit™ treatments, but not the control (Table 29). Five and six fruitlets setting per cluster was on average significantly reduced by all treatments compared to the control (P = 0.0092 and P = 0.0032, respectively) (Table 29). For all treatments, the occurrence of one fruitlet per cluster was dominant (Table 29).

Yield efficiency at the first harvest date was not significantly affected by any treatment (Table 30). At the second harvest date, yield efficiency was significantly reduced by the chemical thinning treatment by 44% compared to the control (Table 30). The combined yield efficiency was not statistically affected by any treatment (Table 30). Average fruit weight was on average significantly greater for all treatments compared to the control at the first harvest (P = 0.0065), second harvest (P = 0.0009) and the combined total harvest (P = 0.0008) (Table 31). Similar effects were seen on average fruit length, which was significantly increased by treatments compared to the control at the first harvest (P <.0001), second harvest (P = 0.0003) and in the combined harvest (P <.0001) (Table 32). No significant effect was found on the average fruit diameter at the first harvest, but at the second harvest and combined harvest the treatments on average increased fruit diameter significantly compared to the control (*P* = 0.0016 and *P* = 0.0323, respectively) (Table 33). Average fruit firmness was unaffected by thinning treatments (Table 34).

The average number of fully developed seeds per fruit at the first harvest was lowered significantly overall by treatments (*P* = 0.0008), unaffected by treatments at the second harvest and lowered in the combined harvest (*P* = 0.0016) (Table 35). Very few to zero aborted seeds were found in fruit (data not shown) (Table 35). The blush color development was not affected by any treatments (Table 36), while the ground color on average was slightly greener for the treatments compared to the control at the first harvest date (*P* = 0.0517) (Table 36). At the second harvest the Bloom Bandit™ 1 min treatment had significantly greener fruit than the control and other treatments (Table 36). Overall for both harvest, however the fruit ground color was unaffected by any of the treatments (Table 36). The chemical treatment significantly increased the percentage return bloom compared to the Bloom Bandit™ and the control (*P* = 0.0005) (Table 37).

EIKENHOF 'CRIPPS' RED' 2014-2015. Temperature was in the required range for chemical applications, but rain soon after application could have a negative effect on the efficacy (Fig. 4). Chemical thinning lowered set by reducing the weight and the number of fruit hand thinned compared to the control by 37% and 47%, respectively (Table 38). An increase of 21.2% of clusters failing to set fruit, 57.4% less fruit set per cluster compared to the control, and a significantly lower number of 1.79 fruit set in a cluster was observed (Table 39). The Bloom Bandit™ 1 min treatment reduced set by 17% for weight and by 14% for the number of fruit hand thinned compared to the control, but none of these reductions were statistically significant (Table 38). The percentage of clusters failing to set was increased by 12.7%, whilst the percentage of fruit set per cluster was decreased by 45.2% compared to the control, and this gave an average fruit set of 1.74 fruit per cluster (Table 39). The Bloom Bandit™ 2 min treatment reduced set as seen in a decreased weight of fruit thinned by 37%, and a reduction of 30% for the number of fruit hand thinned compared to the control (Table 38). The percentage of clusters that failed to set fruit was increased by 20.5% and this resulted in a reduction of 56.5% in fruit per cluster compared to the control, and lowered the number of fruit that set in a cluster to 1.75 fruit (Table 39). The percentage of clusters setting one fruitlet per cluster was significantly increased by all treatments compared to the control (*P* = 0.0054), while the clusters with four fruitlets was reduced (*P* = 0.0021) (Table 40). The percentage of clusters setting two, three, five or six fruit per cluster was not affected, (Table 40).

The yield efficiency was lowered significantly by all treatments compared to the control at the first harvest (*P* = 0.0031) (Table 41). At the second harvest a trend was observed that the average yield efficiency was reduced by all treatments compared to the control (*P* = 0.0660), but significantly so by the chemical thinning treatment by 45% compared to the control (Table 41). The combined yield efficiency was reduced significantly by all thinning treatments compared to the control (*P* <.0001) (Table 41). The majority of fruit were harvest at the first date and therefore only fruit from this harvest date were sampled and taken to the laboratory for further analysis. The average fruit weight, length and diameter were on average significantly increased by all treatments compared to the control (*P* = 0.0002, *P* = 0.0001 and *P* = 0.0001, respectively), but the increase was not significant for the 1 min Bloom Bandit™ treatment (Table 42). The chemical thinning treatment resulted in the biggest increases in fruit size with 19% (24 g) for fruit weight, 8% (4 mm) for fruit length and 3% (2 mm) for fruit diameter (Table 42). Fruit firmness was unaffected by treatments (Table 42).

The number of fully developed seeds per fruit was not affected by any treatments (Table 43). The number of aborted seeds per fruit was on average almost significantly lowered by all treatments compared to the control (*P* = 0.0513) (Table 43). No significant difference was found in the number of fruit with more than 60% red color (Table 43). For all treatments the ground color was significantly yellower at the first harvest date compared to the control (*P* = 0.0003) (Table 43). All thinning treatments significantly increased the percentage return bloom compared to the control (*P* <.0001) (Table 44).

Discussion

MECHANICAL THINNING: BAUM AND DARWIN 300™. Unfortunately no fruit set data were recorded in the two trials conducted in 2013/2014. In the 2014/2015 Oak Valley trial where fruit set and hand-thinning requirement was determined, the BAUM reduced the commercial hand thinning requirement compared to the control albeit not significantly (Table 20). The reduction was greater for the slower rotor speeds of 300 rpm than for the faster rotor speed of 400 rpm. This was surprising as the BAUM at faster rotor speeds of 360 rpm thinned more effectively that lower rotations speeds of 260 rpm (Hehnen et al., 2012). We found no reduction in fruit set per cluster on the two tagged branches in the lower canopy of the trees (Table 21). Basak et al. (2013) however found that the BAUM reduced fruit set from 35% to 16% depending on the apple cultivar, as well as the combination of tractor speed versus rotor speeds, showing that a number of factors contribute to the efficacy of mechanical thinning reducing fruit set.

Another possible explanation for the lack of a significant thinning effect could be through artificial spur extinction (ASE). ASE reduces the density of flower buds manually before buds burst in spring (Breen et al., 2014). ASE has shown an inverse correlation between bloom density and percentage of clusters setting fruit, and a positive correlation between the number of clusters failing to set fruit and the fruit set per cluster (Breen et al., 2015; Tustin et al., 2012). When mechanical thinners are used for the first time in an orchard, whole clusters and spurs can be removed (Veal et al., 2011). It can be speculated that at some levels of mechanical thinning this removal may imitate the effects seen with ASE through removing whole clusters or spurs. This should be the case at higher rotor speeds (Damerow et al., 2007; Solomakhin et al., 2012). To combat this damage, it is recommended that tractor speeds be increased, and in our trial, tractor speeds were not fast enough, thus supporting the idea that we caused damage by removing full clusters or spurs (Solomakhin et al., 2012). There was no significant difference in the number of clusters that failed to set fruit compared to the control (Table 21). No influence was seen on the percentage fruit set, or the number of fruit set per cluster, which disproves the idea that an effect similar to ASE was achieved (Tustin et al., 2012). Counting clusters after mechanical thinning would have enabled determination of percentage of clusters removed during thinning, which would have been beneficial to this study, this was unfortunately not done. Trees chosen for the trial were not ideally shaped for mechanically thinning with the BAUM and this resulted in considerable variation between trees and plots in the thinning efficacy obtained (Plate 1). Bloom density was low, eliminating the need for the grower to apply chemical thinning.

In the two trials during the first season the yield efficiency was generally lowered by the BAUM and the Darwin 300™ treatments at all harvest dates. The combined yield efficiency was reduced between 43% and 29% by the BAUM, and between 54% and 15% by the Darwin 300™ compared to their controls (P = 0.0123 and P = 0.0459, respectively) (Table 4 and Table 12). Large variation between replicates was found in the 2013/2014 trials and one replication was added in the 2014/2015 trial to try and minimize this. The BAUM in the 2014/2015 trial had no significant effect on yield efficiency and only the treatment with the slowest tractor speed of 2.7 $km \cdot h^{-1}$ and 300 rpm tended to reduced yield compared to the control (Table 23). This could be due to more contact time between rotors and the trees at this lower tractor speed (Damerow and Blanke, 2009; Veal et al., 2011). Previously, the Darwin 300™ and the BAUM resulted in reductions in yield efficiency at various tractor speeds and rpm's, as is expected (Hehnen et al., 2012; Kong et al., 2009; Schupp et al., 2008; Solomakhin et al., 2012). Some trials also found no reduction in yield efficiency (Veal et al., 2011).

There were no major differences recorded in the worker harvest productivity or time spent harvesting (Table 5, Table 13 and Table 23). This has been reported before on stone fruit in South Africa where reduced hand thinning requirements did not result in a reduce time spent to thin. It was ascribed to the time required to pick up and move as well as climb up and down ladders, which was not reduced and termed the “ladder effect” (Theron et al., 2015).

It is expected that a reduction in crop load should result in an increase in average fruit size due to the negative correlation that often exists between the two variables (Link, 2000). Minor reductions in yield are acceptable if met with increases in fruit size that have a positive overall economic benefit (Kon et al., 2013). Generally this was achieved by the mechanical thinning treatments (Table 4, Table 12 and Table 23), although not always significantly so, but this is expected as we did not find very effective thinning. Damerow et al. (2007) showed that the BAUM increased fruit weight up to 20%, in ‘Braeburn’ apples. In our trials the tractor speed might have been too slow at 3.0 km·h^{-1} and 4.0 km·h^{-1} and not in the recommended 5.0 km·h^{-1} to 7.0 km·h^{-1} range (Damerow and Blanke, 2009). In South Africa, due to poor orchard floor surface, driving tractors at high speeds is often not possible. The BAUM rotation speeds fit within the recommended rates of between 300 rpm and 400 rpm, but that of the Darwin 300™ may have been too slow (Veal et al., 2011). Slower rotation rates may have reduced leaf damage, but this was not measured in our trials and no severe damage was observed in any of the mechanical treatments. The lack of damage to foliage supports increases in fruit size due to the larger leaf:fruit ratio increasing the amount of assimilates partitioned to fruit (McArtney et al., 1996). Earlier thinning with the Darwin™ at 20% full bloom versus 80% full bloom caused greater increases in fruit size (Schupp et al., 2008). Sinatsch et al. (2010) found that the Darwin™ at 8.0 km·h^{-1} and 220 rpm at earlier stages of blooming before flowers had opened lowered the level of inter cluster thinning and left more flowers per cluster compared to thinning after flowers had opened at full bloom (Sinatsch et al., 2010). The best timing for mechanical thinning was identified as at full bloom, our timing of thinning at 30% petal drop was not optimal in the 2013/2014 BAUM trial and was at an even worse stage in the 2013/2014 Darwin 300™ trial at 4 mm fruitlet diameter, adding to the variation seen (Seehuber et al., 2013).

Differences in fruit firmness following thinning with the BAUM were very small and of no horticultural importance (Table 9 and Table 24). Firmness was not affected by all levels of thinning with the BAUM on ‘Buckeye Gala’, (Hehnen et al., 2012). The Darwin 300™ has shown to increase fruit firmness linearly with increasing rotational speeds (Kon et al., 2013). This was however not found in our trials where no influence of the Darwin 300™ treatments on fruit firmness was seen (Table 17). With effective thinning and reduced crop load, fruit mature earlier (Palmer et al., 1997). When thinning with the Darwin™, reduced competition delayed fruit maturity and increase apple fruit firmness (Kon et al., 2013). Improvements in fruit firmness can lead to fruit with a better shelf life, but the reason for this is not fully understood (Wismer et al., 1995).

Seed number was slightly affected by mechanical thinning treatment to such a small extent that it has no horticultural consequence (Table 10, Table 18 and Table 25). The development of the red blush of bicolored apples such as 'Cripps' Pink' is important to achieve optimal economic returns (Marais, et al., 2001). The BAUM increased the color development of fruit slightly in both trials although the only significant increase was at the second harvest date in the 2013/2014 trial (Table 11 and Table 25). Color development was not affected by the Darwin 300™ (Table 19). Better color development is often found at lower crop loads (Kong et al., 2009; Link, 1973). Anthocyanin production in apples rises under high light and low temperatures and increases towards maturation (Saure, 1990). Earlier maturing fruit due to lighter crop loads have increased color because anthocyanin synthesis is initiated sooner (Faragher and Brohier, 1984). Ground color was not affected by the mechanical thinning from the BAUM or Darwin 300™. Previously, mechanical thinning increased the yellow ground color and reduced the percentage of green fruit, and the extent and intensity of surface color in red apples (Kong et al., 2009; Link, 2000; Solomakhin et al., 2012).

Return bloom is usually improved by blossom or early fruitlet thinning through the earlier removal of hormones that inhibit flower induction such as gibberellins (Tromp, 2000). This has been reported following mechanical thinning with the Darwin 300™ between 10.0 $km \cdot h^{-1}$ and 12.0 $km \cdot h^{-1}$ and a rotor speed of 300 rpm (Weibel et al., 2008; Wismer et al., 1995). In our trials the BAUM treatments did not increase return bloom (Table 26). There have been reports where return bloom was reduced or remained unaffected with mechanical thinning (Damerow et al., 2007; Hehnen et al., 2012). This usually happens when trees were badly damaged by the thinning action, especially in 'Jonagold' apple (Adolf Betz, Fruit Tec, personal communication).

The variation seen in thinning efficacy on fruit set can be due to the tractor speeds that were too slow (Veal et al., 2011). Orchards chosen were the most suited for mechanical thinning that could be found, but as mentioned before were still not ideal as they were not established with mechanization in mind. In the case of Maredale farm, the angle of the V-training system (Plate 2) was too wide for the angle that the Darwin 300™ can tilt from the vertical and this resulted in the strings not making optimal contact in the lower canopy of the tree. There are various factors that directly affect the thinning efficacy of mechanical thinners including an uneven orchard surface causing implements to fail to keep the correct distance from the trunks for an even thinning, high and wide ridging, which also results in trees that are very high and implements do not always reach the top of trees, and strong scaffold branches that protrude into the orchard row that the tractor needs to avoid (Theron at al., 2015). All of these problems were also experienced in these trials. Therefore, until orchards are better prepared from establishment onwards for mechanization, mechanical thinning will result in variable responses.

Mechanical thinning: Bloom Bandit™. The Bloom Bandit™ reduced fruit set and hand thinning requirements more so on 'Fuji' and 'Cripps' Red' than on 'Cripps' Pink'. In the 'Fuji' and 'Cripps' Red' trials where 1 min and 2 min per tree treatments with the Bloom Bandit™ were used, 2 min treatments required less hand thinning as expected (Table 20, Table 27 and Table 38), and all the Bloom Bandit™ treatments increased the percentage of clusters failing to set fruit compared to the controls (Table 21, Table 28 and Table 39). Reduction in set was greater for the 2 min treatments than the 1 min treatments, although only significantly so in 'Cripps' Red'. The percentage of fruit per cluster and number of fruit set per cluster was reduced. The percentage of clusters setting one or two fruit was not markedly increased in 'Cripps' Pink' or 'Fuji' but was for the 'Cripps' Red' compared to the controls. The number of clusters setting multiple fruit was reduced for all cultivars compared to the controls, but more significantly in 'Cripps' Red' (Table 22, Table 29 and Table 40). This was expected as in these treatments less hand thinning after physiological fruit drop was needed due to trees setting the ideal number of fruit as one and two per clusters compared to the controls. The objective should be to remove 50% of flowers on the first pass of a branch (Delmas, 2007). Early removal of fruit should positively influence final fruit size (Dennis, 2000). The Electro-flor® has effectively reduced set on cherries (Spornberger et al., 2014), and this was also the case with the Bloom Bandit™ in our trials on apples. Earlier and stronger thinning improves final fruit size and return bloom more than later or light thinning (Wertheim, 2000). The Bloom Bandit™ requires more working hours in the orchard to achieve a desired level of thinning in the limited thinning period compared to other machines like the Darwin™, the BAUM or chemical thinning (Delmas, 2007). The time that the device is used in an orchard in order to achieve 50% thinning will depend on the level of branching and complexity of trees. Differences in flower anatomy may make it easier for or more difficult for mechanical thinning with hand-held devices and will depend on the cultivar. It was observed that flowers from 'Cripps' Pink' and 'Fuji', which were less tough and had longer stems, were easier to thin than the 'Cripps' Red' flowers. We also noticed when thinning with the Bloom

Bandit™ that thinning trees where the orchard floor had been ridged was more difficult than on a flat surface. This will ultimately affect productivity and efficacy. This difficulty was also picked up for devices drawn by tractors (Theron et al., 2015). Trees that are too high also made the thinning tiresome as the Bloom Bandit weighs 3.8 kg and the battery 6.9 kg, which makes working and lifting above head height cumbersome. The use hereof should either be restricted to smaller trees or used with a platform (Theron et al., 2015).

Yield efficiency was reduced by the Bloom Bandit™ treatments on all cultivars at all harvest dates and also the total yield efficiency was reduced, although this was not always significant (Table 23, Table 30 and Table 41). The 2 min treatments reduced yield more than the 1 min treatments in 'Fuji' and 'Cripps' Red' (Table 30 and Table 41). A reduction in yield efficiency is expected when fruit set is reduced and was also found with the Electroflor®, which reduced yield on sweet cherries by 21.1% (Spornberger et al., 2014). Fruit size was increased significantly as expected in 'Fuji' and 'Cripps' Red' but not in 'Cripps' Pink'. The more severe 2 min treatment increased size more than the 1 min treatment, with the thinning intensity related to the time spent thinning (Martin-Gorriz et al., 2011). When the Electro-flor® was used on sweet cherries, increases in fruit weight of up to 9.2% were recorded (Spornberger et al., 2014). Fruit firmness was not influenced with Bloom Bandit™ thinning, whereas when used on sweet cherries the Electro-flor® increased fruit firmness by 8.7% (Spornberger et al., 2014).

In 'Fuji' the number of fully developed seeds was significantly lowered by 0.9 by the 2 min treatment compared to the control, but aborted seeds per fruit were not affected (Table 35). No change in the fully developed or aborted seed number was seen in 'Cripps' Red' (Table 43). These differences are, however, of no horticultural relevance. Color development was slightly enhanced in 'Cripps' Pink', unaffected in 'Fuji', and the percentage of exportable fruit with 60% color development reduced in 'Cripps' Red' by 10% compared to the control (Table 25, Table 36 and Table 43). Generally, one would have expected an improvement in red color with a reduction in yield (Sinatsch et al., 2010). This will only be the case if there is no vegetative growth stimulation causing shading of fruit. Ground color was not affected in 'Cripps' Pink', greener in the 1 min treatment on 'Fuji', and generally was more yellow in the 'Cripps' Red' fruit, but these differences were very small and of little horticultural importance (Table 25, Table 36 and Table 43). Return bloom is negatively affected by a large number of fruit present between 7 and 14 DAFB in the season (Tromp, 2000). As we reduced the fruit during bloom with the Bloom Bandit™, we would expect the return bloom to be improved. However this was only the case on 'Cripps' Red' where return bloom was significantly increased by the Bloom Bandit™ treatments, but not 'Fuji' (Table 37 and 44). Fuji is well known as a cultivar more prone to alternate bearing and the Bloom Bandit™ thinning was probably not severe enough.

Chemical thinning. Chemical thinning was added as a treatment in the various mechanical thinning trials as a comparison as generally the efficacy of these treatments are well known under South African growing conditions. The chemical thinning treatment chosen was the one the grower used as a commercial treatment in the rest of the orchard. 6-BA is synthetic cytokinin and used as a chemical thinner on apples (Basak et al., 2013; Bubán and Lakatos, 2000; Petri et al., 2006). The mode of action of 6-BA is through stimulated bourse shoot growth, which competes with fruitlets causing weaker fruits to abscise (Bangerth, 2000). 6-BA is generally applied when fruit are 10 mm in diameter, as this gives the most effective thinning response (Greene, 1993). Previously, adequate thinning was achieved with rates of 150 6-BA µl L^{-1} on the apple cultivar 'Elstar' when applied at 10 – 12 mm diameter (Maas, 2006). In our trials 6-BA was included in the first season but in both trials at a later stage (15 - 18 mm fruitlet diameter) and was not aimed at thinning as bloom densities were low, but rather to enhance fruit size directly by stimulating cell division and improve return bloom (Greene, 1993; McArtney et al., 1996).

Small increases in fruit size (weight, length and diameter) were seen with the 150 µl·L^{-1} 6-BA application at Oak Valley. Fruit weight in the second harvest on Maredale was significantly increased by the 100 µl·L^{-1} 6-BA. The average fruit weight of the combined harvest was increased, but not significantly. Therefore the use of 6-BA in these two trials to improve average fruit size directly was only moderately successful. 6-BA has been found to increase fruit size in many apple cultivars at various rates either directly through the cytokinin action or indirectly through thinning (Bound et al., 1997; Bubán and Lakatos, 2000; Ferree, 1996; Petri et al., 2006; Webster 2002). The timing of 6-BA application, as well as weather conditions during and after application influences its effectiveness (Petri et al., 2006). Late applications did not have much thinning effect but did show increase in size which will be due to increased cellular division caused by 6-BA (Petri et al., 2006). Rainfall recorded soon after application would have negatively influenced the results obtained through the product being rained off of leaves (Fig. 1). Earlier applications would have reduced set and better environmental conditions when spraying would have further aided in increasing fruit size (Petri et al., 2006).

Reductions in seed content has been reported with 6-BA, but no horticultural significant effect on seed number was seen in our trials (Yuan and Greene, 2000). Generally, color was unaffected although more color was recorded in the Maredale trial. This increase was probably due to the angles of the trees and the trellis system of the orchard where thinning could have resulted in more light penetrating into the canopy and reaching fruit, as this influences anthocyanin production of apples (Saure, 1990).

A number of years ago, carbaryl and NAA were the most commonly used chemical thinners on apples (Greene, 1993), but carbaryl has since been withdrawn in the EU due to the negative effects it has on beneficial insects and water organisms (Veal et al., 2011; Wertheim, 1997). It is, however, still registered for use on certain cultivars in South Africa and is generally applied post blossom (Costa et al., 2004; Theron, 2013). The combination of carbaryl and NAA significantly reduced the hand thinning requirement in 'Fuji' and 'Cripps' Red' (Table 27 and Table 38). This was further seen through an increased percentage of clusters failing to set fruit in both cultivars. The percentage of fruit per cluster and the fruit in a cluster was reduced as a result. There was an increase in the number of clusters setting one fruit per cluster compared to the control (Table 28 and Table 39). A reduction in the number of clusters setting multiple fruit was seen and this is one of the objectives of thinning, and is a known response to carbaryl, which selectively thin and break up clusters (Greene, 1993). Carbaryl is a consistent and mild thinning agent compared to NAA (Wertheim, 1997). The combination of carbaryl and NAA can be used to thin difficult to thin cultivars such as Fuji (Costa et al., 2004; Dennis, 2000; Greene, 2002) and is as such registered in South Africa on 'Fuji' (Theron, 2013).

The combination of carbaryl and NAA effectively thins apples (Grauslund, 1981; Greene, 1993; Greene, 2002). The mode of action is through direct inhibition of auxin transport, which affects the sink strength of fruits causing weaker fruits to abscise (Ebert and Bangerth, 1982; Wertheim, 1997). The timing of the application at 7 mm fruit diameter for 'Fuji' and 6 mm fruit diameter for 'Cripps' Red' is generally the correct time to achieve strong thinning, as was found in our trials (Theron, 2013; Greene, 2002). Weather conditions after applications were favorable in both trials (Fig. 3 and Fig. 4).

In 'Fuji' yield was slightly reduced albeit not significantly, whereas in 'Cripps' Red' yield was reduced significantly. The expected yield per hectare was reduced by carbaryl and NAA which suggests that this treatment would have over thinned and was too severe. This resulted in fruit size (weight, length and diameter) being significantly increased. This is the expected result of thinning (Wismer et al., 1995.). Carbaryl may impair seed development, but this was not found in our trials, as the only change in seed content was the slight reduction in fully developed seeds in 'Fuji' fruit at the first harvest and therefore the total harvest (Wertheim, 2000). Color was slightly better in chemically thinned fruit in 'Fuji' as would be expected due to lower crop load (Faragher and Brohier, 1984). However, in 'Cripps' Red' the percentage of exportable fruit with 60% color development was 10%

lower compared to the control. This could be due to stimulated shoot growth causing less light into copies to allow for color development (Saure, 1990). 'Fuji' ground color was unaffected, and the ground color on 'Cripps' Red' was significantly more yellow than the control, but this was very little and with no horticultural consequences. Increased return bloom has been recorded before with carbaryl and NAA on 'Gala' apples (Basak, 2006), and this was the case in our trials for both cultivars (Table 34 and Table 44).

Conclusion

Mechanical thinning with the BAUM or Darwin 300™ did not give reliable reductions in fruit set, hand thinning requirement, but generally increased fruit size and quality. The unreliability of thinning was probably due to apple orchards in South Africa not being developed and designed for mechanization and therefore not adapted to the machines. Orchards first need to be adapted for these machines before further evaluation can take place in South Africa. The Bloom Bandit™ showed promise for thinning apples due to its more selective nature, but extra time spent in the orchard should be carefully evaluated to fully understand its economic feasibility. Combining use of the Bloom Bandit™ with platforms may prove beneficial from an ergonomic and efficiency perspective. The chemical thinning treatment included in the 'Fuji' and 'Cripps' Red' trials confirmed that these are viable options and currently the best technique for growers to reduce hand thinning requirements, optimize yield, fruit size and return bloom, although on 'Cripps' Red' reduced yield per hectare greatly which is of concern and should be applied at a slightly reduced rate in future. Further evaluations can explore the possibilities of combining mechanical and chemical thinning together.

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Table 1. Details of orchard age, rootstock, spacing, training system and previous yields for apple trial sites, 2013-2015.

	Site				
	Oak Valley 2013/2014	Maredale 2013/2014	Oak Valley 2014/2015	Eikenhof 2014/2015	
Cultivar	'Cripps' Pink'	'Cripps' Pink'	'Cripps' Pink'	'Fuji'	'Cripps' Red'
Year Planted	1996	1999	1997	1995	1999
Rootstock	MM109	MM109	M109	M793	M793
Spacing	4.0 X 1.5 m	3.5 x 0.75 m	4.0 x 1.5 m	4.0 x 1.4 m	4.0 x 1.5 m
Trees per Ha	1667	3810	1667	1786	1667
Training System	Central Leader	V hedge	Central Leader	Central Leader	Central Leader
Cross pollinizer	'Cripps' Red' (10%)	'Granny Smith' (10%)	'Cripps' Red' (10%)	'Cripps' Pink' (43%)	'Cripps' Pink' (77%)
Area planted of cross cultivar	10%	10%	10%	50%	50%
Yield 10/11 t ha^{-1}	62	83	96	24	54
Yield 11/12 t ha^{-1}	50	90	96	74	94
Yield 12/13 t ha^{-1}	78	138	108	119	93
Yield 13/14 t ha^{-1}	42	80	74	39	107

Table 2. Dates of treatment application and different phenological stages of orchards in 2013/2014 trials.

	Site	
	Oak Valley 2013/2014 'Cripps' Pink'	Maredale 2013/2014 'Cripps' Pink'
Full Bloom	27 October 2013	21 October 2013
Mechanically thinned	30 October 2013	30 October 2013
Chemical application	20 November 2013	11 November 2013
Harvest/s	23 April 2014	24 April 2014
	2 May 2014	5 May 2014

Table 3. Dates of treatment application and different phenological stages of orchards in 2014/2015 trials.

	Site		
	Oak Valley 2014/2015 'Cripps' Pink'	Eikenhof 2014/2015 'Fuji'	Eikenhof 2014/2015 'Cripps' Red'
Full Bloom	13 October 2014	16 October 2014	30 September 2014
Mechanically thinned	14 October 2014	-	-
Bloom Bandit thinned	13 October 2014	16 October 2014	30 September 2014
Chemical application	-	27 October 2014	10 October 2014
Hand Thinned	25 November 2014	11 November 2014	11 November 2014
Harvest/s	23 April 2014	25 March 2015	4 May 2015
	-	7 April 2015	12 May 2015
Return Bloom Count	6 October 2015	19 October 2015	6 October 2015

Table 4. Effect of thinning on the average yield efficiency per plot of first, second and combined harvests and estimated yield of 'Cripps' Pink' apples at Oak Valley, Elgin (2013/2014).

Treatment	Average yield efficiency first harvest per 3 tree plot		Average yield efficiency second harvest per 3 tree plot		Average yield efficiency combined per 3 tree plot ($kg \cdot cm^{-2}$)	Estimated yield ($ton \cdot ha^{-1}$)
	($kg \cdot cm^{-2}$)	% of total harvest	($kg \cdot cm^{-2}$)	% of total harvest		
Control (unthinned)	0.08 ns	(41)	0.12 ns	(59)	0.21 ns	40
6-BA (150 $\mu l \cdot L^{-1}$)	0.06	(33)	0.12	(67)	0.17	37
BAUM, 3.0 $km \cdot h^{-1}$ @ 400 rpm	0.04	(32)	0.09	(68)	0.14	30
BAUM, 3.0 $km \cdot h^{-1}$ @ 350 rpm	0.06	(38)	0.08	(62)	0.14	30
BAUM, 4.0 $km \cdot h^{-1}$ @ 400 rpm	0.08	(51)	0.08	(49)	0.16	31
BAUM, 4.0 $km \cdot h^{-1}$ @ 350 rpm	0.05	(38)	0.08	(62)	0.12	29
Significance Level	*0.0581*		*0.1338*		*0.0840*	
Control vs Treatment	*0.0417*		*0.0424*		*0.0123*	
Low vs High rpm	*0.2600*		*0.6925*		*0.4016*	
Low vs High tractor speed	*0.2108*		*0.6047*		*0.8055*	
Treatment LSD	-		-		-	

ns = Not significant at $P < 0.05$

Table 5. Effect of thinning treatments on average harvest time for first, second and combined harvests and labor output of 'Cripps' Pink' apples at Oak Valley, Elgin (2013/2014).

Treatment	Average harvest time first harvest with 7 laborers per 3 tree plot (min)	Average harvest time second harvest with 4 laborers per 3 tree plot (min)	Harvest time combined per 3 tree plot (min)	Bins·MD^{-1} [z]
Control (unthinned)	6.3 ns	6.4 ns	12.7 ns	0.8 ns
6-BA (150 µl·L^{-1})	4.5	6.8	11.3	0.9
BAUM, 3.0 km·h^{-1} @ 400 rpm	5.6	5.5	11.1	0.7
BAUM, 3.0 km·h^{-1} @ 350 rpm	5.1	5.4	10.6	0.8
BAUM, 4.0 km·h^{-1} @ 400 rpm	5.5	4.8	10.3	0.8
BAUM, 4.0 km·h^{-1} @ 350 rpm	5.3	5.4	10.7	0.7
Significance Level	*0.3074*	*0.5458*	*0.6959*	*0.7328*
Control vs Treatment	*0.0716*	*0.3744*	*0.1314*	*0.9920*
Low vs High rpm	*0.5291*	*0.7523*	*0.9525*	*0.8938*
Low vs High tractor speed	*0.9221*	*0.6648*	*0.7799*	*0.6379*
Treatment LSD	-	-	-	-

[z] 9 hour work day and 350 kg bin

ns = Not significant at $P < 0.05$

Table 6. Effect of thinning treatments from the first, second and combined average fruit weight of 'Cripps' Pink' apples on Oak Valley, Elgin (2013/2014).

Treatment	Average fruit weight first harvest (g)	Average fruit weight second harvest (g)	Average fruit weight combined (g)
Control (unthinned)	121.7 ns	113.4 ns	117.6 ns
6-BA (150 µl·L^{-1})	120.4	114.5	117.5
BAUM, 3.0 km·h^{-1} @ 400 rpm	122.6	118.8	120.7
BAUM, 3.0 km·h^{-1} @ 350 rpm	128.5	123.1	125.8
BAUM, 4.0 km·h^{-1} @ 400 rpm	124.5	118.6	121.6
BAUM, 4.0 km·h^{-1} @ 350 rpm	120.9	120.2	120.6
Significance Level	*0.2076*	*0.2695*	*0.1717*
Control vs Treatment	*0.5323*	*0.1062*	*0.1647*
Low vs High rpm	*0.6494*	*0.3399*	*0.3885*
Low vs High tractor speed	*0.2478*	*0.6273*	*0.3610*
Treatment LSD	-	-	-

ns = Not significant at $P < 0.05$

Table 7. Effect of thinning treatments from the first, second and combined harvest on the average fruit length of 'Cripps' Pink' apples at Oak Valley, Elgin (2013/2014).

Treatment	Average fruit length first harvest (mm)	Average fruit length second harvest (mm)	Average fruit length combined (mm)
Control (unthinned)	56.5 ns	56.1 ns	56.3 ns
6-BA (150 µl·L^{-1})	57.0	56.5	56.7
BAUM, 3.0 km·h^{-1} @ 400 rpm	56.9	57.2	57.1
BAUM, 3.0 km·h^{-1} @ 350 rpm	58.2	57.6	57.9
BAUM, 4.0 km·h^{-1} @ 400 rpm	57.0	56.9	56.9
BAUM, 4.0 km·h^{-1} @ 350 rpm	56.4	57.2	56.8
Significance Level	*0.0673*	*0.4465*	*0.0692*
Control vs Treatment	*0.1701*	*0.1234*	*0.0450*
Low vs High rpm	*0.3663*	*0.5181*	*0.2946*
Low vs High tractor speed	*0.0599*	*0.4818*	*0.0945*
Treatment LSD	-	-	-

ns = Not significant at $P < 0.05$

Table 8. Effect of thinning treatments from the first, second and combined harvests on the average fruit diameter of 'Cripps' Pink' apples at Oak Valley, Elgin (2013/2014).

Treatment	Average fruit diameter first harvest (mm)	Average fruit diameter second harvest (mm)	Average fruit diameter combined (mm)
Control (unthinned)	64.7 ns	63.6 ns	64.1 ns
6-BA (150 µl·L^{-1})	64.8	63.7	64.2
BAUM, 3.0 km·h^{-1} @ 400 rpm	65.1	64.6	64.8
BAUM, 3.0 km·h^{-1} @ 350 rpm	66.2	65.2	65.7
BAUM, 4.0 km·h^{-1} @ 400 rpm	65.2	64.2	64.7
BAUM, 4.0 km·h^{-1} @ 350 rpm	64.5	64.8	64.7
Significance Level	*0.2664*	*0.3126*	*0.2296*
Control vs Treatment	*0.3908*	*0.1573*	*0.1753*
Low vs High rpm	*0.6048*	*0.2715*	*0.3282*
Low vs High tractor speed	*0.1395*	*0.4791*	*0.2060*
Treatment LSD	-	-	-

ns = Not significant at $P < 0.05$

Table 9. Effect of thinning treatments from first, second and combined harvests on average fruit firmness of 'Cripps' Pink' apples at Oak Valley, Elgin (2013/2014).

Treatment	Average fruit firmness first harvest (kg)	Average fruit firmness second harvest (kg)	Average fruit firmness combined (kg)
Control (unthinned)	9.6 ab	9.1 b	9.3 bc
6-BA (150 µl·L^{-1})	9.5 b	9.3 ab	9.4 abc
BAUM, 3.0 km·h^{-1} @ 400 rpm	9.3 b	9.2 b	9.3 c
BAUM, 3.0 km·h^{-1} @ 350 rpm	9.4 b	9.1 b	9.2 c
BAUM, 4.0 km·h^{-1} @ 400 rpm	9.6 ab	9.4 a	9.5 ab
BAUM, 4.0 km·h^{-1} @ 350 rpm	9.8 a	9.3 ab	9.5 a
Significance Level	*0.0458*	*0.0267*	*0.0190*
Control vs Treatment	*0.5954*	*0.0434*	*0.4478*
Low vs High rpm	*0.2407*	*0.0740*	*0.9053*
Low vs High tractor speed	*0.0029*	*0.0110*	*0.0006*
Treatment LSD	*0.3*	*0.2*	*0.2*

Table 10. Effect of thinning treatments from first, second and combined harvests on the average number of fully developed fully developed seeds and aborted seeds content per fruit of 'Cripps' Pink' apples at Oak Valley, Elgin (2013/2014).

Treatment	Average number fully developed seeds first harvest	Average number fully developed seeds second harvest	Average number fully developed seeds combined	Average number aborted seeds first harvest	Average number aborted seeds second harvest	Average number aborted seeds combined
Control (unthinned)	6.2 ns	5.6 ns	5.9 ns	0.3 ns	0.5 a	0.4 a
6-BA (150 µl·L^{-1})	5.7	5.1	5.4	0.4	0.3 c	0.4 ab
BAUM, 3.0 km·h^{-1} @ 400 rpm	5.9	5.2	5.6	0.3	0.4 bc	0.3 bc
BAUM, 3.0 km·h^{-1} @ 350 rpm	5.8	5.0	5.4	0.3	0.3 c	0.3 c
BAUM, 4.0 km·h^{-1} @ 400 rpm	6.2	5.2	5.7	0.4	0.5 ab	0.4 a
BAUM, 4.0 km·h^{-1} @ 350 rpm	6.1	5.5	5.8	0.4	0.4 ab	0.4 a
Significance Level	*0.4334*	*0.3723*	*0.2051*	*0.0798*	*0.0017*	*0.0091*
Control vs Treatment	*0.2832*	*0.0876*	*0.0742*	*0.8273*	*0.0023*	*0.0762*
Low vs High rpm	*0.5764*	*0.9752*	*0.7546*	*1.0000*	*0.1505*	*0.3942*
Low vs High tractor speed	*0.1849*	*0.2964*	*0.1371*	*0.0141*	*0.0027*	*0.0006*
Treatment LSD	-	-	-	-	*0.1*	*0.1*

ns = Not significant at $P < 0.05$

Table 11. Effect of thinning treatments from the first, second and combined harvests on the average color development and ground color of 'Cripps' Pink' apples at Oak Valley, Elgin (2013/2014).

Treatment	Average color development first harvest[z]		Average color development second harvest[z]		Average color development combined[z]		Average ground color first harvest[y]		Average ground color second harvest[y]		Average ground color combined[y]	
Control (unthinned)	8.1	ns	5.8	c	6.9	ns	3.3	ns	3.1	ns	3.2	ns
6-BA (150 µl·L^{-1})	7.8		6.1	bc	6.9		3.5		3.1		3.3	
BAUM, 3.0 km·h^{-1} @ 400 rpm	8.1		6.2	bc	7.2		3.2		3.0		3.1	
BAUM, 3.0 km·h^{-1} @ 350 rpm	8.3		6.7	ab	7.5		3.3		3.0		3.1	
BAUM, 4.0 km·h^{-1} @ 400 rpm	8.2		6.7	ab	7.4		3.0		3.1		3.1	
BAUM, 4.0 km·h^{-1} @ 350 rpm	7.9		7.1	a	7.5		3.0		3.0		3.0	
Significance Level	*0.8868*		*0.0132*		*0.3011*		*0.4949*		*0.2840*		*0.2878*	
Control vs Treatment	*0.9390*		*0.0108*		*0.1766*		*0.5612*		*0.1226*		*0.3245*	
Low vs High rpm	*0.8654*		*0.0953*		*0.4406*		*0.8598*		*0.2891*		*0.9065*	
Low vs High tractor speed	*0.5847*		*0.1002*		*0.6185*		*0.3732*		*0.7938*		*0.4239*	
Treatment LSD	-		*0.7246*		-		-		-		-	

[z] Pink Lady® color chart on a scale of 1 to 12 (1 = least color, 12 = most color)

[y] Ground color analyzed from Unifruco apple and pear chart on a scale from 0.5 to 5 (0.5 = most green, 5 = yellow)

ns = Not significant at $P < 0.05$

Table 12. Effect of thinning treatments from the first, second and combined harvest on the average yield efficiency per plot and estimated yield of 'Cripps' Pink' apples trees at Maredale, Elgin (2013/2014).

Treatments	Average yield efficiency per 3 tree plot first harvest		Average yield efficiency per 3 tree plot second harvest		Average yield efficiency combined per 3 tree plot ($kg \cdot cm^{-2}$)	Estimated yield ($ton \cdot ha^{-1}$)
	($kg \cdot cm^{-2}$)	% of total harvest	($kg \cdot cm^{-2}$)	% of total harvest		
Control (unthinned)	0.15 a	(41)	0.23 ns	(59)	0.38 a	79
6-BA (100 $\mu l \cdot L^{-1}$)	0.15 a	(46)	0.22	(54)	0.37 a	76
Darwin 300™, 3.0 $km \cdot h^{-1}$ @ 220 rpm	0.13 ab	(45)	0.17	(55)	0.30 ab	69
Darwin 300™, 3.0 $km \cdot h^{-1}$ @ 200 rpm	0.13 ab	(43)	0.19	(57)	0.32 a	72
Darwin 300™, 4.0 $km \cdot h^{-1}$ @ 240 rpm	0.10 b	(54)	0.09	(46)	0.19 b	52
Significance Level	*0.0445*		*0.0667*		*0.0141*	
Control vs Treatments	*0.0837*		*0.1032*		*0.0450*	
Treatment LSD	*0.04*				*0.11*	

ns = Not significant at $P < 0.05$

Table 13. Effect of thinning treatments from the first, second and combined harvests on the average harvest time and labor output of 'Cripps' Pink' apples on Maredale, Elgin (2013/2014).

Treatments	Average harvest time first harvest with 3 laborers per 3 tree plot (min)		Average harvest time second harvest with 3 laborers per 3 tree plot (min)		Average harvest time combined per 3 tree plot (min)		Bins·MD^{-1Z}	
Control (unthinned)	2.7	ns	5.8	ns	8.5	ns	1.9	ns
6-BA (100 µl·L^{-1})	2.8		6.0		8.7		1.8	
Darwin 300™, 3.0 km·h^{-1} @ 220 rpm	2.7		4.5		7.2		2.1	
Darwin 300™, 3.0 km·h^{-1} @ 200 rpm	2.6		4.6		7.2		2.1	
Darwin 300™, 4.0 km·h^{-1} @ 240 rpm	2.2		3.2		5.4		2.1	
Significance Level	*0.1367*		*0.1421*		*0.1065*		*0.1225*	
Control vs Treatments	*0.5751*		*0.1918*		*0.1964*		*0.3664*	
Treatment LSD	-		-		-		-	

[z] 9 hour work day and 350 kg bin

ns = Not significant at $P < 0.05$

Table 14. Effect of thinning treatments from the first, second and combined harvests on the average fruit weight of 'Cripps' Pink' apples at Maredale, Elgin (2013/2014).

Treatments	Average fruit weight first harvest (g)		Average fruit weight second harvest (g)		Average fruit weight combined (g)	
Control (unthinned)	94.5	ns	102.2	c	98.3	b
6-BA (100 µl·L^{-1})	95.9		109.4	a	102.7	b
Darwin 300™, 3.0 km·h^{-1} @ 220 rpm	95.9		104.5	bc	100.2	b
Darwin 300™, 3.0 km·h^{-1} @ 200 rpm	96.8		109.0	ab	102.9	b
Darwin 300™, 4.0 km·h^{-1} @ 240 rpm	103.0		113.3	a	108.1	a
Significance Level	*0.2271*		*0.0008*		*0.0122*	
Control vs Treatments	*0.2676*		*0.0009*		*0.0177*	
Treatment LSD	-		*4.5*		*5.2*	

ns = Not significant at $P < 0.05$

Table 15. Effect of thinning treatments from the first, second and combined harvest on the average fruit length of 'Cripps' Pink' apples at Maredale, Elgin (2013/2014).

Treatments	Average fruit length first harvest (mm)		Average fruit length second harvest (mm)		Average fruit length combined (mm)	
Control (unthinned)	50.3	b	54.2	b	52.3	b
6-BA (100 µl·L^{-1})	51.1	b	54.9	ab	53.0	b
Darwin 300™, 3.0 km·h^{-1} @ 220 rpm	51.5	b	53.8	b	52.7	b
Darwin 300™, 3.0 km·h^{-1} @ 200 rpm	51.4	b	54.9	ab	53.1	b
Darwin 300™, 4.0 km·h^{-1} @ 240 rpm	53.8	a	56.2	a	55.0	a
Significance Level	*0.0090*		*0.0257*		*0.0053*	
Control vs Treatments	*0.0287*		*0.1714*		*0.0339*	
Treatment LSD	*1.8*		*1.5*		*1.4*	

Table 16. Effect of thinning treatments from the first, second and combined harvests on the average fruit diameter of 'Cripps' Pink' apples at Maredale, Elgin (2013/2014).

Treatments	Average fruit diameter first harvest (mm)		Average fruit diameter second harvest (mm)		Average fruit diameter combined (mm)	
Control (unthinned)	59.5	ns	61.3	b	60.4	b
6-BA (100 µl·L^{-1})	59.7		62.9	a	61.3	ab
Darwin 300™, 3.0 km·h^{-1} @ 220 rpm	59.9		62.0	b	60.9	b
Darwin 300™, 3.0 km·h^{-1} @ 200 rpm	60.0		62.8	a	61.4	ab
Darwin 300™, 4.0 km·h^{-1} @ 240 rpm	61.5		63.4	a	62.4	a
Significance Level	*0.1598*		*0.0006*		*0.0179*	
Control vs Treatments	*0.2235*		*0.0003*		*0.0149*	
Treatment LSD	-		*0.9*		*1.1*	

ns = Not significant at $P < 0.05$

Table 17. Effect of thinning treatments from the first, second and combined harvests on the average fruit firmness of 'Cripps' Pink' apples at Maredale, Elgin (2013/2014).

Treatments	Average fruit firmness first harvest (kg)		Average fruit firmness second harvest (kg)		Average fruit firmness combined (kg)	
Control (unthinned)	9.4	ns	8.6	ns	9.0	ns
6-BA (100 µl·L^{-1})	9.5		8.6		9.0	
Darwin 300™, 3.0 km·h^{-1} @ 220 rpm	9.2		8.8		9.0	
Darwin 300™, 3.0 km·h^{-1} @ 200 rpm	9.1		8.5		8.8	
Darwin 300™, 4.0 km·h^{-1} @ 240 rpm	9.3		8.7		9.0	
Significance Level	*0.2622*		*0.8824*		*0.7896*	
Control vs Treatments	*0.4502*		*0.9456*		*0.7627*	
Treatment LSD	-		-		-	

ns = Not significant at $P < 0.05$

Table 18. Effect of thinning treatments from the first, second and combined harvests on the average number of fully developed and aborted number of seeds per fruit of 'Cripps' Pink' apples at Maredale, Elgin (2013/2014).

Treatments	Average number fully developed seeds first harvest	Average number fully developed seeds second harvest	Average number fully developed seeds combined	Average number aborted seeds first harvest	Average number aborted seeds second harvest	Average number aborted seeds combined
Control (unthinned)	6.7 ns	6.9 ns	6.8 ns	0.1 c	0.1 ns	0.1 c
6-BA (100 $\mu l \cdot L^{-1}$)	7.2	7.1	7.1	0.2 ab	0.2	0.2 ab
Darwin 300™, 3.0 $km \cdot h^{-1}$ @ 220 rpm	7.0	7.1	7.1	0.2 abc	0.2	0.2 ab
Darwin 300™, 3.0 $km \cdot h^{-1}$ @ 200 rpm	7.4	7.0	7.2	0.1 bc	0.1	0.1 bc
Darwin 300™, 4.0 $km \cdot h^{-1}$ @ 240 rpm	6.8	7.0	6.9	0.2 a	0.2	0.2 a
Significance Level	*0.1577*	*0.9806*	*0.5146*	*0.0416*	*0.3513*	*0.0393*
Control vs Treatments	*0.0817*	*0.6762*	*0.1936*	*0.0197*	*0.0890*	*0.0117*
Treatment LSD	-	-	-	*0.1*	-	*0.1*

ns = Not significant at $P < 0.05$

Table 19. Effect of thinning treatments from first, second and combined harvests on the average color development and ground color of 'Cripps' Pink' apples at Maredale, Elgin (2013/2014).

Treatments	Average color development first harvest[z]	Average color development second harvest[z]	Average color development combined[z]	Average ground color first harvest[y]	Average ground color second harvest[y]	Average ground color combined[y]
Control (unthinned)	8.2 ns	7.6 ns	7.9 ns	3.3 ns	3.4 ns	3.4 ns
6-BA (100 µl·L^{-1})	7.8	7.4	7.6	3.2	3.6	3.4
Darwin 300™, 3.0 km·h^{-1} @ 220 rpm	8.1	7.7	7.9	3.5	3.4	3.5
Darwin 300™, 3.0 km·h^{-1} @ 200 rpm	8.4	7.1	7.7	3.2	3.2	3.2
Darwin 300™, 4.0 km·h^{-1} @ 240 rpm	9.1	8.1	8.6	3.5	3.4	3.5
Significance Level	*0.1671*	*0.7295*	*0.4777*	*0.1403*	*0.1862*	*0.1144*
Control vs Treatments	*0.8219*	*0.9768*	*0.9046*	*0.7136*	*0.9095*	*0.8690*
Treatment LSD	-	-	-	-	-	-

[z] Pink Lady® color chart on a scale of 1 to 12 (1 = least color, 12 = most color)

[y] Ground color analyzed from Unifruco apple and pear chart on a scale from 0.5 to 5 (0.5 = most green, 5 = yellow)

ns = Not significant at $P < 0.05$

Table 20. Effect of thinning treatments on the total weight of fruitlets thinned and average number of fruitlets thinned of 'Cripps' Pink' apples at Oak Valley, Elgin (2014/2015).

Treatments	Average weight of fruitlets hand thinned per 3 tree plot (kg)	Average number of fruitlets hand thinned per 3 tree plot
Control (hand thinned)	1.7 ns	124.3 ns
Bloom Bandit™ 1 min	1.3	91.8
BAUM, 2.7 km·h^{-1} @ 300 rpm	1.1	76.7
BAUM, 3.0 km·h^{-1} @ 400 rpm	1.8	117.7
BAUM, 3.3 km·h^{-1} @ 300 rpm	1.0	74.3
Significance Level	*0.0952*	*0.1270*
Control vs Treatments	*0.1157*	*0.0726*
Treatment LSD	-	-

ns = Not significant at $P < 0.05$

Table 21. Effect of thinning treatments on percentage of clusters failing to set fruit, percentage of fruit set per full bloom cluster and average number of fruit set per cluster on tagged branches on 'Cripps' Pink' apples at Oak Valley, Elgin (2014/2015).

Treatments	Percentage of clusters failing to set fruit on tagged branches[z]	Percentage of fruit set per cluster on tagged branches[y]	Average number of fruit set per cluster on tagged branches[x]
Control (hand thinned)	76.0 ns	34.5 ns	1.44 ns
Bloom Bandit™ 1 min	80.9	25.8	1.35
BAUM, 2.7 km·h^{-1} @ 300 rpm	76.2	32.2	1.34
BAUM, 3.0 km·h^{-1} @ 400 rpm	75.3	37.7	1.46
BAUM, 3.3 km·h^{-1} @ 300 rpm	72.6	37.6	1.36
Significance Level	*0.3653*	*0.3766*	*0.6321*
Control vs Treatments	*0.9309*	*0.8199*	*0.4114*
Treatment LSD	-	-	-

[z] [Number of clusters at bloom - number of clusters set)/Number of clusters at bloom]*100

[y] (Number of fruits after natural fruit drop/ number of clusters at bloom)*100

[x] Number of fruits after natural fruit drop/ number of clusters set after natural fruit drop

ns = Not significant at $P < 0.05$

Table 22. Effect of thinning treatments on the percentage of average number of fruit set within clusters setting fruit on tagged branches of 'Cripps' Pink' apples on Oak Valley, Elgin (2014/2015).

Treatments	Percentage of average number of fruit set within clusters				
	1 fruitlet	2 fruitlets	3 fruitlets	4 fruitlets	5 fruitlets
Control (hand thinned)	66.8 ns	24.3 ns	7.0 ns	1.4 ns	0.5 ns
Bloom Bandit™ 1 min	69.8	25.7	4.0	0.5	0.0
BAUM, 2.7 $km \cdot h^{-1}$ @ 300 rpm	72.9	21.1	4.6	1.4	0.0
BAUM, 3.0 $km \cdot h^{-1}$ @ 400 rpm	64.9	26.6	6.2	2.3	0.0
BAUM, 3.3 $km \cdot h^{-1}$ @ 300 rpm	68.8	26.2	5.0	0.0	0.0
Significance Level	*0.8325*	*0.9042*	*0.7282*	*0.5519*	*0.4307*
Control vs Treatments	*0.6958*	*0.9091*	*0.3032*	*0.7670*	*0.0593*
Treatment LSD	-	-	-	-	-

ns = Not significant at $P < 0.05$

Table 23. Effect of thinning on average yield efficiency per plot, estimated yield and average harvest time per plot of 'Cripps' Pink' apples at Oak Valley, Elgin (2014/2015).

Treatments	Average yield efficiency per 3 tree plot ($kg \cdot cm^{-2}$)	Estimated yield ($ton \cdot ha^{-1}$)	Average harvest time per plot with 6 laborers per 3 tree plot (min)	$Bins \cdot MD^{-1\,z}$
Control (hand thinned)	0.27 ns	60	9.4 ns	3.0 ns
Bloom Bandit™ 1 min	0.26	51	9.0	2.7
BAUM, 2.7 $km \cdot h^{-1}$ @ 300 rpm	0.21	42	6.2	3.2
BAUM, 3.0 $km \cdot h^{-1}$ @ 400 rpm	0.30	60	9.3	3.0
BAUM, 3.3 $km \cdot h^{-1}$ @ 300 rpm	0.27	56	8.9	2.9
Significance Level	*0.1062*		*0.2751*	*0.2597*
Control vs Treatments	*0.7137*		*0.4050*	*0.7406*
Treatment LSD	-		-	

[z] 9 hour day and 350 kg bin

ns = Not significant at $P < 0.05$

Table 24. Effect of thinning on the average fruit weight, length, diameter and firmness of 'Cripps' Pink' apples at Oak Valley, Elgin (2014/2015).

Treatments	Average fruit weight (g)	Average fruit length (mm)	Average fruit diameter (mm)	Average fruit firmness (kg)
Control (hand thinned)	153.5 ns	64.0 ns	59.3 ns	8.4 ns
Bloom Bandit™ 1 min	160.3	64.2	60.1	8.3
BAUM, 2.7 km·h^{-1} @ 300 rpm	157.9	63.6	59.8	8.2
BAUM, 3.0 km·h^{-1} @ 400 rpm	159.7	63.9	59.8	8.2
BAUM, 3.3 km·h^{-1} @ 300 rpm	159.1	63.7	59.8	8.3
Significance Level	*0.6499*	*0.9388*	*0.3843*	*0.7552*
Control vs Treatments	*0.1519*	*0.8288*	*0.0764*	*0.3466*
Treatment LSD	-	-	-	-

ns = Not significant at $P < 0.05$

Table 25. Effect of thinning on the average fully developed and aborted seed content, and color development and ground color of 'Cripps' Pink' apples at Oak Valley, Elgin (2014/2015).

Treatments	Average number fully developed seeds	Average number aborted seeds	Average color development[z]	Average ground color[y]
Control (hand thinned)	5.0 ns	0.6 ns	6.4 ns	3.7 ns
Bloom Bandit™ 1 min	5.2	0.4	7.0	3.8
BAUM, 2.7 km·h^{-1} @ 300 rpm	5.4	0.5	6.6	3.7
BAUM, 3.0 km·h^{-1} @ 400 rpm	5.5	0.4	7.2	3.6
BAUM, 3.3 km·h^{-1} @ 300 rpm	5.5	0.4	6.8	3.7
Significance Level	*0.3126*	*0.2751*	*0.2053*	*0.2420*
Control vs Treatments	*0.0767*	*0.0582*	*0.0637*	*0.8183*
Treatment LSD	-	-	-	-

[z] Pink Lady® color chart on a scale of 1 to 12 (1 = least color, 12 = most color)

[y] Ground color analyzed from Unifruco apple and pear chart on a scale from 0.5 to 5 (0.5 = most green, 5 = yellow)

ns = Not significant at $P < 0.05$

Table 26. Effect of thinning on the percentage return bloom of 'Cripps' Pink' apples at Oak Valley, Elgin (2014/2015).

Treatments	Percentage return bloom on tagged branches
Control (hand thinned)	50.0
Bloom Bandit™ 1 min	63.7
BAUM, 2.7 km·h^{-1} @ 300 rpm	63.9
BAUM, 3.0 km·h^{-1} @ 400 rpm	60.3
BAUM, 3.3 km·h^{-1} @ 300 rpm	54.5
Significance Level	*0.0718*
Control vs Treatments	*0.0219*
Treatment LSD	-

Table 27. Effect of thinning on the total weight of fruitlets thinned, average number of fruitlets removed from 'Fuji' apples at Eikenhof, Elgin (2014/2015).

Treatments	Average weight of fruitlets hand thinned per tree (kg)		Average number of fruitlets hand thinned per tree	
Control (hand thinned)	1.7	a	476.4	a
Carbaryl (700 mg·L^{-1}) + NAA (5 µl·L^{-1})	1.0	c	266.7	c
Bloom Bandit™ 1 min	1.4	b	392.1	ab
Bloom Bandit™ 2 min	1.2	bc	328.5	bc
Significance Level	*<.0001*		*0.0004*	
Control vs Treatments	*<.0001*		*0.0003*	
Treatment LSD	*0.3*		*88.9*	

Table 28. Effect of thinning treatments on percentage clusters failing to set fruit, percentage of fruit set per full bloom cluster and average number of fruit set per cluster on tagged branches on 'Fuji' apples at Eikenhof, Elgin (2014/2015).

Treatments	Percentage of clusters failing to set fruit on tagged branches[z]	Percentage of fruit set per cluster on tagged branches[y]	Average number of fruit set per cluster on tagged branches[x]
Control (hand thinned)	23.9 ns	177.9 a	2.31 a
Carbaryl (700 $mg \cdot L^{-1}$) + NAA (5 $\mu l \cdot L^{-1}$)	36.3	116.0 b	1.80 b
Bloom Bandit™ 1 min	35.5	141.5 ab	2.15 ab
Bloom Bandit™ 2 min	40.3	111.3 b	1.86 b
Significance Level	*0.1000*	*0.0128*	*0.0280*
Control vs Treatments	*0.0186*	*0.0031*	*0.0174*
Treatment LSD	-	*42.5*	*0.38*

[z] [Number of clusters at bloom - number of clusters set)/Number of clusters at bloom]*100

[y] (Number of fruits after natural fruit drop/ number of clusters at bloom)*100

[x] Number of fruits after natural fruit drop/ number of clusters set after natural fruit drop

ns = Not significant at $P < 0.05$

Table 29. Effect of thinning treatments on the percentage of average number of fruit set within clusters setting fruit on tagged branches of 'Fuji' apples at Eikenhof, Elgin (2014/2015).

Treatment	Percentage of average number of fruit set within clusters					
	1 fruitlet	2 fruitlets	3 fruitlets	4 fruitlets	5 fruitlets	6 fruitlets
Control (hand thinned)	37.5 b	28.2 ns	14.7 ab	9.9 ns	6.4 a	3.5 a
Carbaryl (700 $mg \cdot L^{-1}$) + NAA (5 $\mu l \cdot L^{-1}$)	53.4 a	27.6	7.8 b	8.3	2.9 ab	0.0 b
Bloom Bandit™ 1 min	38.6 b	28.2	19.7 a	8.2	4.1 a	1.3 ab
Bloom Bandit™ 2 min	43.8 ab	33.7	16.3 a	5.5	0.4 b	0.3 a
Significance Level	*0.0365*	*0.2109*	*0.0147*	*0.4053*	*0.0142*	*0.0180*
Control vs Treatments	*0.1046*	*0.5336*	*0.9889*	*0.2353*	*0.0092*	*0.0032*
Treatment LSD	*11.7*	-	*7.1*	-	*3.5*	*2.3*

ns = Not significant at $P < 0.05$

Table 30. Effect of thinning on the average yield efficiency on the first, second and combined harvest, and the estimated yield of 'Fuji' apples at Eikenhof, Elgin (2014/2015).

Treatment	Average yield efficiency first harvest per tree		Average yield efficiency second harvest per tree		Average yield efficiency per tree ($kg \cdot cm^{-2}$)	Estimated yield ($ton \cdot ha^{-1}$)
	($kg \cdot cm^{-2}$)	% of total harvest	($kg \cdot cm^{-2}$)	% of total harvest		
Control (hand thinned)	0.14 ns	(47)	0.16 a	(53)	0.30 ns	92
Carbaryl (700 $mg \cdot L^{-1}$) + NAA (5 $\mu l \cdot L^{-1}$)	0.14	(61)	0.09 b	(39)	0.23	74
Bloom Bandit™ 1 min	0.15	(50)	0.15 a	(50)	0.30	103
Bloom Bandit™ 2 min	0.12	(46)	0.14 a	(54)	0.26	93
Significance Level	*0.3237*		*0.0054*		*0.6970*	
Control vs Treatments	*0.6985*		*0.0950*		*0.2574*	
Treatment LSD	-		*0.04*		-	

ns = Not significant at $P < 0.05$

Table 31. Effect of thinning on the average fruit weight form the first, second and combined harvests of 'Fuji' apples at Eikenhof, Elgin (2014/2015).

Treatment	Average fruit weight first harvest (g)		Average fruit weight second harvest (g)		Average fruit weight combined (g)	
Control (hand thinned)	95.8	b	102.0	b	98.9	b
Carbaryl (700 mg·L^{-1}) + NAA (5 µl·L^{-1})	109.6	a	114.7	a	112.2	a
Bloom Bandit™ 1 min	105.9	ab	111.0	a	108.4	a
Bloom Bandit™ 2 min	110.4	a	116.1	a	113.3	a
Significance Level	*0.0399*		*0.0056*		*0.0052*	
Control vs Treatments	*0.0065*		*0.0009*		*0.0008*	
Treatment LSD	*11.0*		*8.1*		*8.2*	

Table 32. Effect of thinning on the average fruit length from first, second and combined harvests of 'Fuji' apples at Eikenhof, Elgin (2014/2015).

Treatment	Average fruit length first harvest (mm)		Average fruit length second harvest (mm)		Average fruit length combined (mm)	
Control (hand thinned)	48.4	c	49.9	b	49.2	b
Carbaryl (700 mg·L^{-1}) + NAA (5 µl·L^{-1})	52.2	a	52.5	a	52.3	a
Bloom Bandit™ 1 min	50.6	b	51.8	a	51.2	a
Bloom Bandit™ 2 min	51.7	ab	52.5	a	52.1	a
Significance Level	*0.0001*		*0.0023*		*0.0002*	
Control vs Treatments	*<.0001*		*0.0003*		*<.0001*	
Treatment LSD	*1.5*		*1.4*		*1.4*	

Table 33. Effect of thinning on the average fruit diameter from first, second and combined harvests of 'Fuji' apples at Eikenhof, Elgin (2014/2015).

Treatment	Average fruit diameter first harvest (mm)		Average fruit diameter second harvest (mm)		Average fruit diameter combined (mm)	
Control (hand thinned)	62.6	ns	63.8	b	63.2	b
Carbaryl (700 mg·L^{-1}) + NAA (5 µl·L^{-1})	71.5		66.2	a	68.9	a
Bloom Bandit™ 1 min	65.0		65.4	ab	65.2	ab
Bloom Bandit™ 2 min	65.7		66.4	a	66.1	ab
Significance Level	*0.1006*		*0.0082*		*0.0441*	
Control vs Treatments	*0.1088*		*0.0016*		*0.0323*	
Treatment LSD	-		*1.6*		*3.9*	

ns = Not significant at $P < 0.05$

Table 34. Effect of thinning on the average fruit firmness from first, second and combined harvests of 'Fuji' apples at Eikenhof, Elgin (2014/2015).

Treatment	Average fruit firmness first harvest (kg)		Average fruit firmness second harvest (kg)		Average fruit firmness combined (kg)	
Control (hand thinned)	8.2	ns	7.6	ns	7.9	ns
Carbaryl (700 mg·L^{-1}) + NAA (5 µl·L^{-1})	8.2		7.6		7.9	
Bloom Bandit™ 1 min	8.0		7.5		7.8	
Bloom Bandit™ 2 min	8.4		7.6		8.0	
Significance Level	*0.0996*		*0.8988*		*0.4258*	
Control vs Treatments	*0.9908*		*0.7437*		*0.8686*	
Treatment LSD	-		-		-	

ns = Not significant at $P < 0.05$

Table 35. Effect of thinning on the number of fully developed seeds per fruit from first, second and combined harvests of 'Fuji' apples at Eikenhof, Elgin (2014/2015).

Treatment	Average number fully developed seeds first harvest		Average number fully developed seeds second harvest		Average number fully developed seeds combined	
Control (hand thinned)	8.3	a	8.0	ns	8.2	a
Carbaryl (700 mg·L^{-1}) + NAA (5 µl·L^{-1})	6.8	c	7.8		7.3	c
Bloom Bandit™ 1 min	7.8	ab	8.3		8.1	ab
Bloom Bandit™ 2 min	7.4	b	8.0		7.7	b
Significance Level	*0.0003*		*0.0881*		*<.0001*	
Control vs Treatments	*0.0008*		*0.8641*		*0.0016*	
Treatment LSD	*0.62*		-		*0.34*	

ns = Not significant at $P < 0.05$

Table 36. Effect of thinning on the average color development and ground color from first, second and combined harvests of 'Fuji' apples for at Eikenhof, Elgin (2014/2015).

Treatment	Average color development first harvest[z]		Average color development second harvest[z]		Average color development combined[z]		Average ground color first harvest[y]		Average ground color second harvest[y]		Average ground color combined[y]	
Control (hand thinned)	5.6	ns	5.7	ns	5.6	ns	2.1	ns	2.1	a	2.1	ns
Carbaryl (700 mg·L^{-1}) + NAA (5 µl·L^{-1})	5.2		5.5		5.4		1.9		2.2	a	2.1	
Bloom Bandit™ 1 min	5.6		5.6		5.6		2.0		2.0	b	2.0	
Bloom Bandit™ 2 min	5.6		5.3		5.5		1.9		2.1	a	2.0	
Significance Level	*0.3998*		*0.7771*		*0.5713*		*0.0834*		*0.0035*		*0.3413*	
Control vs Treatments	*0.6521*		*0.5509*		*0.4507*		*0.0517*		*0.7379*		*0.1324*	
Treatment LSD	-		-		-		-		*0.1*		-	

[z] Color development assessed through Unifruco chart A45 on a scale from 1 to 12 (1 = most color, 12 = least color).

[y] Ground color analyzed from Unifruco apple and pear chart on a scale from 0.5 to 5 (0.5 = most green, 5 = yellow)

ns = Not significant at $P < 0.05$

Table 37. Effect of thinning on the percentage return bloom on tagged shoots of 'Fuji' apples at Eikenhof, Elgin (2014/2015).

Treatment	Percentage return bloom of tagged branches
Control (hand thinned)	17.3 b
Carbaryl (700 mg·L^{-1}) + NAA (5 µl·L^{-1})	29.7 a
Bloom Bandit™ 1 min	16.2 b
Bloom Bandit™ 2 min	13.6 b
Significance Level	*0.0005*
Control vs Treatments	*0.3858*
Treatment LSD	*7.3*

Table 38. Effect of thinning on the total weight and average number of fruitlets thinned from 'Cripps' Red' apples at Eikenhof, Elgin (2014/2015).

Treatments	Average weight of fruitlets hand thinned per tree (kg)	Average number of fruitlets hand thinned per tree
Control (hand thinned)	3.5 a	420.2 a
Carbaryl (700 mg·L^{-1}) + NAA (5 µl·L^{-1})	2.2 b	222.9 c
Bloom Bandit™ 1 min	2.9 ab	363.2 ab
Bloom Bandit™ 2 min	2.2 b	294.3 bc
Significance Level	*0.0018*	*0.0002*
Control vs Treatments	*0.0007*	*0.0006*
Treatment LSD	*0.7*	*81.3*

Table 39. Effect of thinning treatments on percentage clusters failing to set fruit, percentage of fruit set per full bloom cluster and average number of fruit set per cluster on tagged branches on 'Cripps' Red' apples at Eikenhof, Elgin (2014/2015).

Treatments	Percentage of clusters failing to set fruit on tagged branches[z]	Percentage of fruit set per cluster on tagged branches[y]	Average number of fruit set per cluster on tagged branches[x]
Control (hand thinned)	33.1 b	140.3 a	2.07 a
Carbaryl (700 $mg \cdot L^{-1}$) + NAA (5 $\mu l \cdot L^{-1}$)	54.9 a	82.9 b	1.79 b
Bloom Bandit™ 1 min	45.8 a	95.1 b	1.74 b
Bloom Bandit™ 2 min	53.6 a	83.8 b	1.75 b
Significance Level	*0.0029*	*0.0017*	*0.0324*
Control vs Treatments	*0.0006*	*0.0002*	*0.0039*
Treatment LSD	*11.9*	*30.6*	*0.25*

[z] [Number of clusters at bloom - number of clusters set)/Number of clusters at bloom]*100

[y] (Number of fruits after natural fruit drop/ number of clusters at bloom)*100

[x] Number of fruits after natural fruit drop/ number of clusters set after natural fruit drop

Table 40. Effect of thinning treatments on the percentage of average number of fruit set within clusters setting fruit on tagged branches of 'Cripps' Red' apples at Eikenhof, Elgin (2014/2015).

Treatment	Percentage of average number of fruit set within clusters											
	1 fruitlet		2 fruitlets		3 fruitlets		4 fruitlets		5 fruitlets		6 fruitlets	
Control (hand thinned)	41.4	b	28.4	ns	17.5	ns	8.8	a	2.7	ns	1.2	ns
Carbaryl (700 mg·L^{-1}) + NAA (5 µl·L^{-1})	52.3	a	26.6		13.6		5.0	b	2.1		0.3	
Bloom Bandit™ 1 min	52.7	a	29.0		11.9		5.2	b	0.8		0.4	
Bloom Bandit™ 2 min	54.9	a	27.3		10.7		3.4	b	2.8		0.9	
Significance Level	*0.0408*		*0.8943*		*0.3428*		*0.0119*		*0.4444*		*0.7540*	
Control vs Treatments	*0.0054*		*0.7821*		*0.0985*		*0.0021*		*0.4917*		*0.3882*	
Treatment LSD	*9.9*		-		-		*3.2*		-		-	

ns = Not significant at $P < 0.05$

Table 41. Effect of thinning on yield efficiency from first, seconds and combined harvests and estimated yield of 'Cripps' Red' apples at Eikenhof, Elgin (2014/2015).

Treatment	Average yield efficiency per tree first harvest			Average yield efficiency per tree second harvest			Average yield efficiency ($kg \cdot cm^{-2}$)		Estimated yield ($ton \cdot ha^{-1}$)
	($kg \cdot cm^{-2}$)		% of total	($kg \cdot cm^{-2}$)		% of total			
Control (hand thinned)	0.47	a	(73)	0.17	a	(27)	0.64	a	101
Carbaryl (700 $mg \cdot L^{-1}$) + NAA (5 $\mu l \cdot L^{-1}$)	0.33	b	(79)	0.09	b	(21)	0.42	b	73
Bloom Bandit™ 1 min	0.35	b	(73)	0.13	a	(27)	0.48	b	86
Bloom Bandit™ 2 min	0.31	b	(69)	0.14	a	(31)	0.45	b	82
Significance Level	*0.0223*			*0.0261*			*0.0006*		
Control vs Treatments	*0.0031*			*0.0660*			*<.0001*		
Treatment LSD	*0.11*			*0.05*			*0.10*		

Table 42. Effect of thinning on average fruit weight, length, diameter and firmness of 'Cripps' Red' apples at Eikenhof, Elgin (2014/2015).

Treatment	Average fruit weight (g)		Average fruit length (mm)		Average fruit diameter (mm)		Average fruit firmness (kg)	
Control (hand thinned)	131.2	c	57.3	c	57.9	c	8.9	ns
Carbaryl (700 mg·L^{-1}) + NAA (5 µl·L^{-1})	155.5	a	61.7	a	59.8	a	8.9	
Bloom Bandit™ 1 min	138.1	bc	58.6	bc	58.5	bc	9.0	
Bloom Bandit™ 2 min	140.8	b	59.1	b	58.7	a	9.0	
Significance Level	*<.0001*		*<.0001*		*<.0001*		*0.5975*	
Control vs Treatments	*0.0002*		*0.0001*		*0.0001*		*0.5180*	
Treatment LSD	*7.8*		*1.4*		*0.6*		-	

ns = Not significant at $P < 0.05$

Table 43. Effect of thinning on the average number of fully developed and aborted seed content per fruit, percentage fruit exportable fruit with > 60% color developed and ground color of 'Cripps' Red' apples at Eikenhof, Elgin (2014/2015).

Treatment	Average number of fully developed seeds per fruit		Average number of aborted seeds per fruit		Percentage of fruit > 60% color developed[z]		Average ground color[y]	
Control (hand thinned)	4.9	ns	0.4	ns	70	ns	3.5	c
Carbaryl (700 mg·L^{-1}) + NAA (5 µl·L^{-1})	4.9		0.3		60		3.8	ab
Bloom Bandit™ 1 min	4.9		0.3		70		4.0	a
Bloom Bandit™ 2 min	5.1		0.3		59		3.7	b
Significance Level	*0.6544*		*0.1307*		*0.1270*		*0.0004*	
Control vs Treatments	*0.5686*		*0.0513*		*0.1763*		*0.0003*	
Treatment LSD	-		-		-		*0.2*	

[z] 60% color development = export color development minimum

[y] Ground color analyzed from Unifruco apple and pear chart on a scale from 0.5 to 5 (0.5 = most green, 5 = yellow)

ns = Not significant at $P < 0.05$

Table 44. Effect of thinning on the percentage return bloom on tagged shoots of 'Cripps' Red' apples at Eikenhof, Elgin (2014/2015).

Treatment	Percentage return bloom of tagged branches
Control (hand thinned)	36.1 b
Carbaryl (700 mg·L^{-1}) + NAA (5 µl·L^{-1})	55.8 a
Bloom Bandit™ 1 min	50.0 a
Bloom Bandit™ 2 min	52.8 a
Significance Level	*<.0001*
Control vs Treatments	*<.0001*
Treatment LSD	*6.2*

Plate. 1. Central leader 'Cripps' Pink' orchard mechanically thinned with the BAUM, Oak Valley (2013/2014).

Plate. 2. V-hedge 'Cripps' Pink' orchard mechanically thinning with the Darwin 300™, Maredale (2013/2014).

Plate. 3. Central leader 'Cripps' Pink' orchard mechanically thinned with the BAUM, Oak Valley (2014/2015).

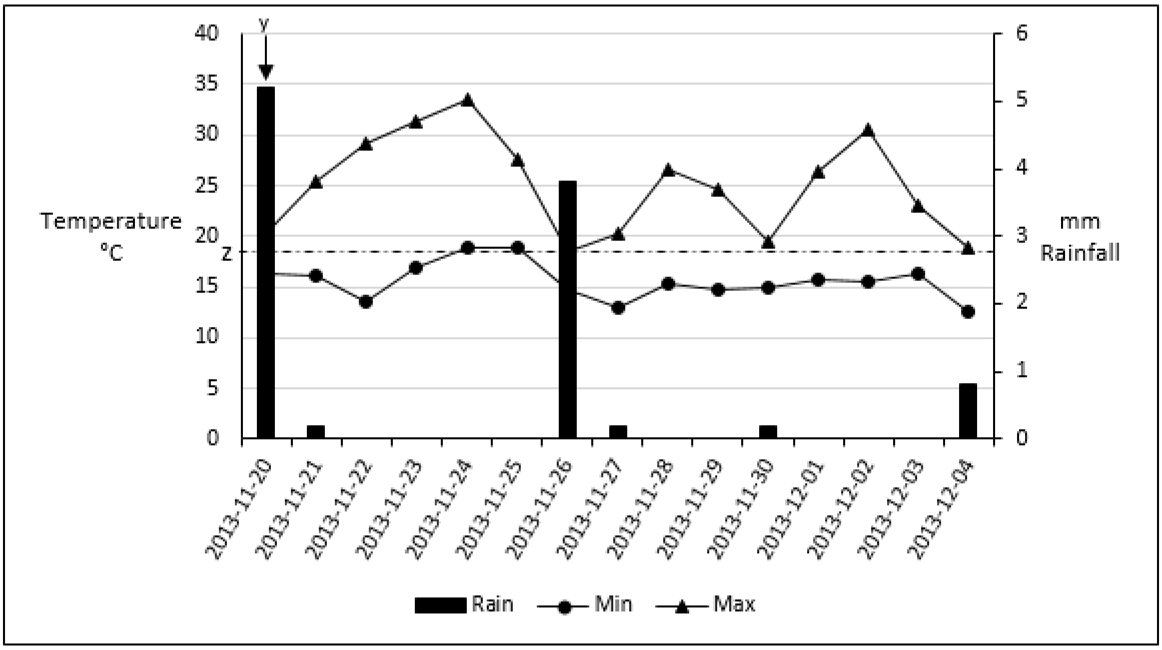

Fig. 1. Minimum and maximum temperatures and rainfall data during and 14 days after treatment application, Oak Valley, Elgin (2013/2014).

^{z}18^{o}C; ^{y}Chemical application date

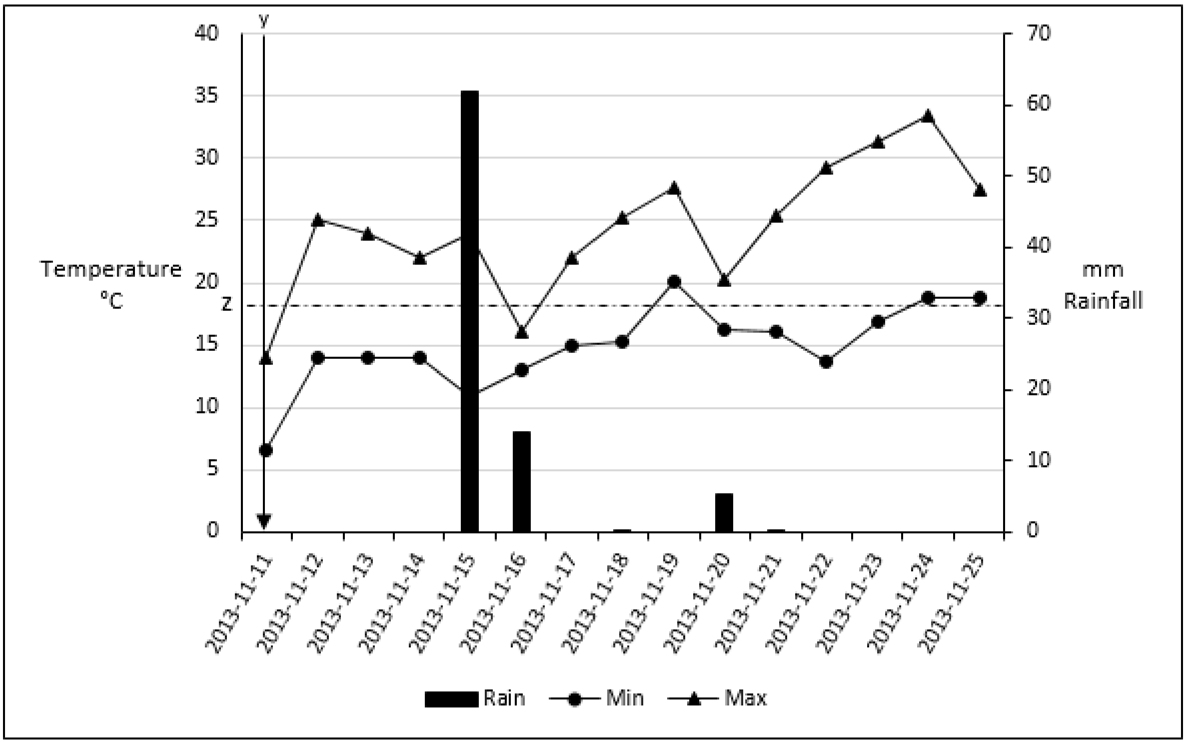

Fig. 2. Minimum and maximum temperatures and rainfall data during and 14 days after treatment application, Maredale, Elgin (2013/2014).

^{z}18^{o}C; ^{y}Chemical application date

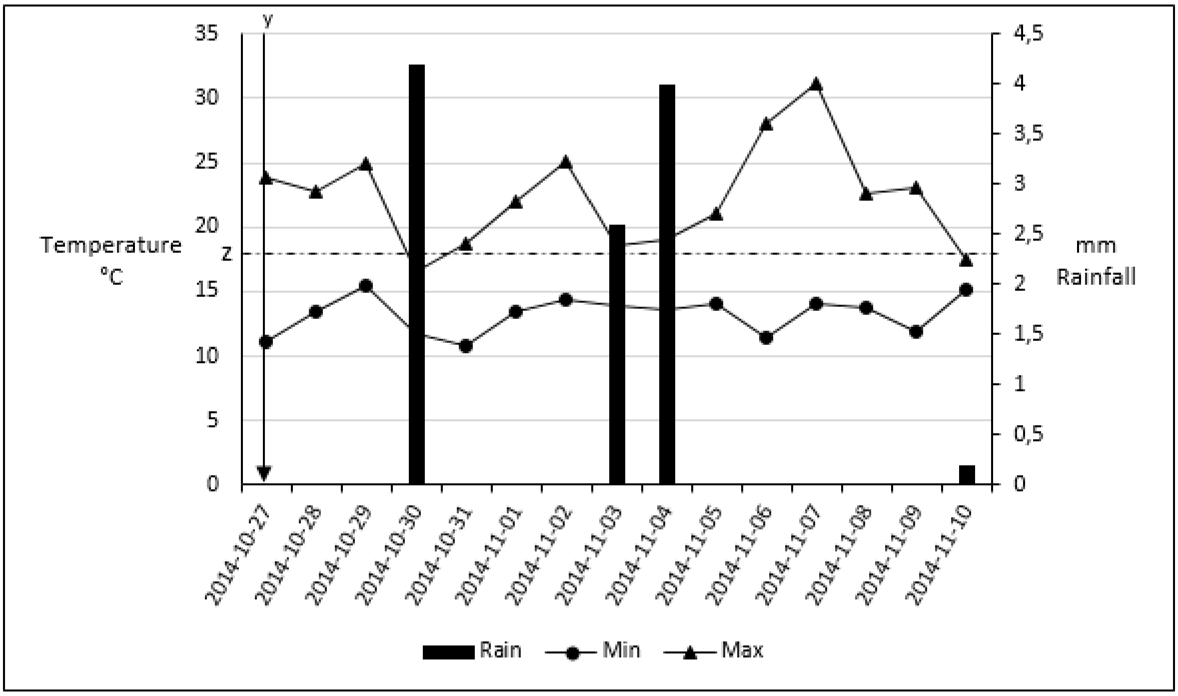

Fig. 3. Minimum and maximum temperatures and rainfall data during and 14 days after chemical treatment application on 'Fuji', Eikenhof, Elgin (2014/2015).

ᶻ18°C; ʸChemical application date

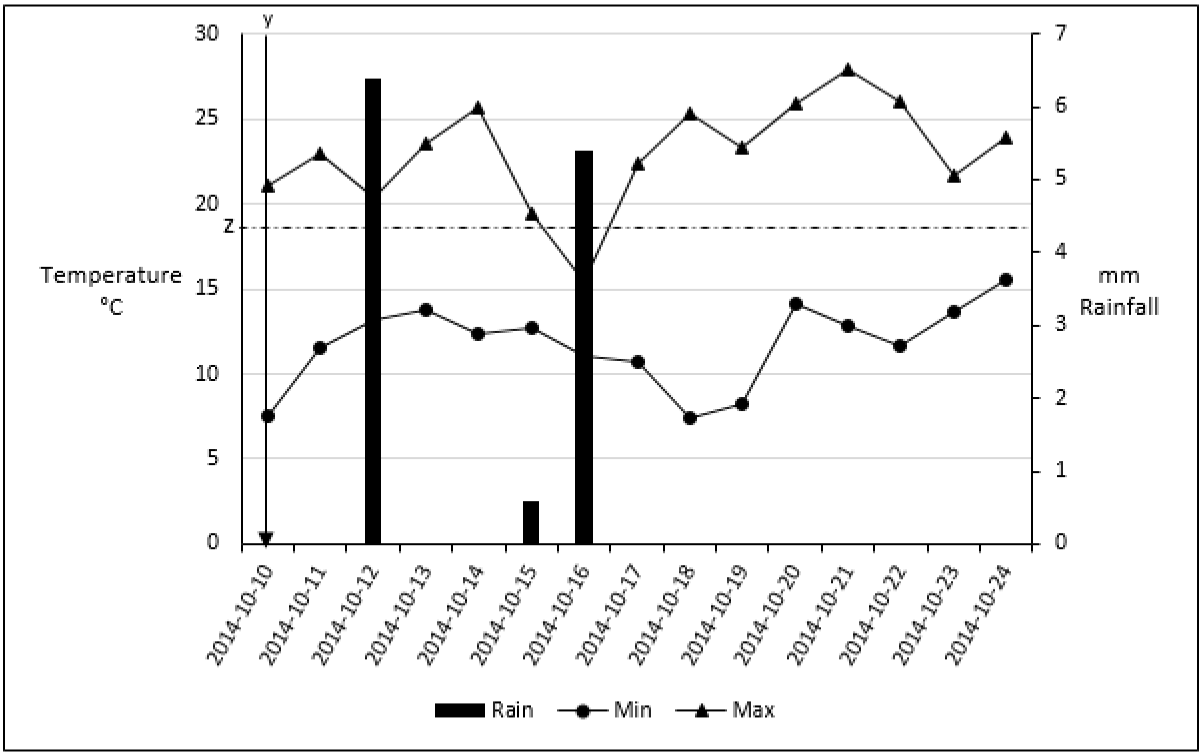

Fig. 4. Minimum and maximum temperatures and rainfall data during and 14 days after chemical treatment application on 'Cripps' Red', Eikenhof, Elgin (2014/2015).

ᶻ18°C; ʸChemical application date

Crop Load Manipulations of 'Forelle' Pears (*Pyrus communis* L.) and 'Cripps' Red' Apples (*Malus domestica* Borkh.) to Determine Optimum Thinning Levels for Mechanical Thinning

ADDITIONAL INDEX WORDS. Artificial spur extinction, flower removal, fruit set, fruit quality, return bloom

SUMMARY. Thinning is an important cultural practice in pome fruit production. Understanding the levels of required thinning and the responses of trees will be valuable in predicting outcomes of mechanical thinning. In the 2014/2015 season, 'Forelle' pears and 'Cripps' Red' apples were used to investigate three different levels of cluster and flower removal. Twenty-five percent, 50% and 75% thinning was applied by hand at full bloom, and compared to an unthinned control. Flower clusters and fruit set were counted on tagged branches. Trees were then subsequently hand-thinned commercially and the weights and number of fruit thinned were determined to check thinning efficacy. Yield and fruit quality was determined at harvest and return bloom counted in the following spring. Hand thinning requirement was increased by the 25% removal and decreased by the 50% and 75% removal, thus resulting in a quadratic response to cluster removal in 'Forelle', and was reduced linearly with increased cluster thinning intensity in 'Cripps' Red'. All treatments increased the percentage of clusters failing to set fruit compared to the control in 'Forelle', and cluster removal had a greater effect than flower removal. The percentage of 'Forelle' clusters that failed to set fruit was increased by all treatments compared to the control, and the cluster removal treatments lowered the percentage of clusters setting zero fruit more than did the flower removal treatments. Flower removal of 'Cripps' Red' gave a quadratic trend where 50% removal gave a lower percentage of clusters with zero fruit compared to the 25% and 75% removal. More intense thinning led to a higher portion of clusters to set single fruit. The data indicated that only removing flowers and leaving foliage led to increased fruit set. For 'Forelle' and 'Cripps' Red', the yield efficiencies responded in the same way to the thinning treatments with a reduction in yield efficiencies compared to the control. A possible reason for the discrepancy between set and yield results could be because yield was determined on the whole tree, whilst set was recorded on only two branches per tree. The fruit size was improved by all thinning treatments in 'Forelle'. 'Cripps' Red' fruit size was not significantly increased, but fruit size is tended to increase linearly with increased thinning intensity, probably due to an improved leaf to fruit ratio. Color was improved for 'Cripps' Red' by thinning and more so by the flower than the cluster removal. Thinning

treatments improved 'Forelle' return bloom, but had no significant effect in 'Cripps' Red'. The recommendation is the same for 'Forelle' and 'Cripps' Red' for mechanical thinning where the aim should be to remove up to 50% of flowers.

Pome fruit trees flower excessively (Breen et al., 2014; Theron et al., 2011). This flowering behavior often leads to excessive fruit set resulting in lower fruit quality and return bloom (Greene and Costa, 2013). When fruit set is excessive and natural abscission not severe enough, methods of regulating crop load through thinning need to be employed. This is even more critical in cultivars that have intrinsically smaller than average fruit size (Webster, 2002a). Thinning of pome fruit an important practice and is challenging to growers (Bound, 2015).

Current thinning methods consist of chemical and hand thinning for apples (Breen et al., 2014) and pears (Theron, 2011). Chemical thinning effectively adjusts crop load levels, but commercially unreliable results are often obtained due to complex interactions between the environment and the plant physiological status (Breen et al., 2014). It can also often lead to over-thinning or under-thinning, presenting a commercial risk (Bound, 2015). Mechanical thinning of apple and pear trees was evaluated in Papers 1 and 2, as it is seen as a possible new thinning option (Greene and Costa, 2013).

Another method to regulate fruit set and crop load before bloom is through artificial spur extinction (ASE). Some apple cultivars naturally exhibit high bud or spur extinction, and have improved performance in retaining floral buds that bear fruit, i.e. a position bearing a fruit in the current season, will develop a bourse shoot that will again bear a fruit in the following season (Breen et al., 2014; Breen et al., 2015). The ability to naturally terminate weaker non-bearing positions and to channel resources into remaining, fruit bearing positions characterizes cultivars that give regular high yields and are not prone to yield alternation (Lauri et al., 1995). This has led to the development of ASE as a management tool through which the density of floral buds is manually reduced in late winter or early spring (Breen et al., 2014; Breen et al., 2015; van Hooijdonk et al., 2014). The most productive floral buds are kept while weaker buds are removed (van Hooijdonk et al., 2014). Several hours are required to perform ASE per hectare, but generally no further manipulations of reproductive or vegetative sinks are needed (Costa et al., 2013). Thinning of fruit results in a loss of dry matter resources and these resources are saved when ASE is used (Tustin et al., 2012). All ASE work has used apples as a model crop, with no research on pears.

Mechanical thinning with the Darwin 300™ and the BAUM have similarities in response to ASE. Mechanical thinning is done early in spring and should have no negative effect on the remaining floral buds. When using mechanical thinning devices for the first time in an orchard, entire clusters are removed non-selectively (Veal et al., 2011). This is a form of ASE, but not as selective (Damerow and Blanke, 2009; van Hooijdonk et al., 2014). The increased set found in remaining clusters following ASE is due to improved resource allocation to floral spurs early in the season, which increases productivity, fruit size and quality (Breen et al., 2015; Tustin et al., 2011). This should be similar with mechanical thinning at the early stages of fruit development with more assimilates available to fewer sinks (van Hooijdonk et al., 2014). The number of leaves per fruit and the spur leaf area are improved at an early stage, which is important to determine final fruit size (Greene and Costa, 2013). The level of thinning with mechanical devices ranges between seasons and crops and predicting the thinning response is difficult (Greene and Costa, 2013). Therefore, it is important to know to what level thinning should be performed to achieve the optimum response in yield and fruit quality.

The aim of this trial was to determine the response of pome fruit trees to different levels of spur and flower thinning with the purpose of predicting the ideal level of flower cluster or flower removal needed when thinning mechanically.

Materials and methods

PLANT MATERIAL AND SITE DESCRIPTION. In the 2014/2015 season, two trials were conducted in Elgin, South Africa. The first trial was on mature ‘Forelle’ pear trees at Oak Valley Estate (34°10'15.7"S 19°03'35.1"E) and the second on mature ‘Cripps’ Red’ apples trees at Eikenhof farm (34°07'21.6"S 19°03'32.4"E). Both sites have a Mediterranean-type climate. Further details for these orchards are presented in Table 1.

TREATMENTS AND EXPERIMENTAL DESIGN. Treatments were the same for both trials. At full bloom, three cluster removal and three flower removal treatments were applied by hand. Treatments aimed to remove 25%, 50% or 75% flowers or clusters. To achieve these levels, the following was done on entire trees: For 25% removal, one cluster out of every four clusters was removed, for 50%, one cluster out of every second cluster treated, and 75% removal, three clusters out of every four clusters were treated. The cluster selection was random and the position of the clusters on branches was not taken into account. The cluster removal was done by removing the entire flower cluster, which results in the removal of the flowers as well as the vegetative growth emanating from the clusters, while flower removal entailed only removing the floral parts from a cluster. A schematic representation of treatments is presented in Fig. 1. All treatments were hand thinned after physiological fruit drop during commercial hand thinning and a commercial hand thinned control was included in each trial (Table 1). The experimental design was a randomized compete block design with 10 single-tree plot replications.

DATE COLLECTED. Before any treatments were applied, two representative branches in the lower tree canopy were tagged, and the total number of flower clusters counted on the spurs, short and long shoots. After treatments were applied, and physiological fruit drop had taken place, the number of fruit that set in a cluster was determined (from zero to seven) on the tagged branches. The trees were then hand thinned according to standard commercial norms. Hand thinned fruit were weighed and counted for each plot. At commercial harvest/s, all fruit were weighed to determine total yield per plot and was expressed as yield efficiency ($kg \cdot cm^{-2}$ trunk cross-sectional area). A sample of 30 fruit per harvest date was brought to our laboratory where the following fruit quality characteristics were determined per fruit; weight, length, diameter, firmness, fully developed and aborted seed content, blush or color development/extent and ground color. Fruit firmness was determined with a GÜSS texture analyzer (Guss electronic model GS 20, Strand, South Africa) using a 11.1 mm probe for the apples and a 9.0 mm probe for the pears. For 'Forelle' pears, blush development was assessed on a scale from 1 to 6 (1 = most blush, 6 = least blush) using the Unifruco color chart P25. For 'Cripps' Red' apples, color was determined by calculating the percentage of sampled fruit graded as exportable, i.e. at least 60% red color development. Ground color was determined on a scale from 0.5 to 5 (0.5 = most green, 5 = yellow) using the Unifruco color chart for apples and pears. In the following season the return bloom was counted on the tagged branches by recording the number of vegetative and reproductive buds and expressing reproductive buds as a percentage of the total number of buds that sprouted.

STATISTICAL ANALYSIS. Analysis of data was done through ANOVA using the linear model procedure of the program SAS Enterprise guide 5.1 (SAS Institute Incorporated, 100 SAS Campus Drive Cary, North Carolina 27513-2414, USA), and when the F Statistic indicated significance at $P < 0.05$ the LDS test was used. Single degree of freedom, orthogonal, polynomial contrasts were fitted where applicable. A contrast was fitted comparing the control to an average of all treatments, one that compared the average of the cluster removal treatments compared to the average of the flower removal treatments, as well as linear and quadratic contrasts on the levels of cluster and flower removal.

Results

'**FORELLE' PEARS.** The number of hand-thinned fruitlets decreased with cluster thinning from 25 to 50 % but not from 50 to 75% (*P* = 0.0448), but overall the six thinning treatments did not reduce hand thinning requirement comparted to the control (Table 2). Generally, the percentage of clusters that set zero fruit was increased by all treatments relative to the control (*P* = 0.0629) (Table 3). The flower removal treatments resulted in a higher percentage of clusters setting zero fruit compared to the complete cluster removal treatments (*P* = 0.0062) (Table 3). Both cluster and flower removal resulted in a quadratic trend with more positions with zero fruit set after 50% thinning compared to 25 and 75% thinning (*P* = 0.0518 and *P* = 0.0116, respectively) (Table 3). For the cluster thinning treatments, this trend was reversed for positions setting one fruit (*P* = 0.0095) (Table 3). An increasing linear trend was found in the percentage of clusters setting two fruit with more intense flower removal (*P* = 0.0342) (Table 3). The cluster removal treatments caused a significantly higher percentage of clusters to set four fruit compared to the flower removal treatments (*P* = 0.0225), but the percentage of clusters setting four fruit were <5% for all treatments (Table 3). The average fruit set per cluster was just less than two fruit, and fruit set per cluster was slightly higher for the cluster removal treatments compared to the flower removal treatments (*P* = 0.0820) (Table 3). However, average fruit set per cluster did not differ significantly between treatments.

Yield efficiency was significantly decreased by all treatments on average compared to the control (*P* = 0.0118) (Table 4). The greatest reduction compared to the control was 45% for the 75% cluster removal treatment. This latter treatment and 50% flower removal were the only treatments that significantly decreased yield efficiency compared to the control. A linear decrease in yield efficiency was found with increasing cluster removal intensity (*P* = 0.0018). On average, all treatments increased average fruit weight and diameter compared to the control (*P* = 0.0014 and *P* = 0.0020, respectively) (Table 5). Cluster thinning showed a significant quadratic with 25% and 75% thinning, but not 50% thinning significantly increasing fruit weight and diameter compared to the control (*P* = 0.0131and *P* = 0.0243, respectively). Average fruit length and flesh firmness remained unaffected by the treatments (Table 5).

The number of fully developed seeds per fruit was on average reduced by all treatments compared to the control (*P* = 0.0501) (Table 6). More intense cluster removal resulted in fewer fully developed seeds (*P* = 0.0180) and aborted seeds per fruit (*P* = 0.0196) (Table 6). Treatments had no effect on blush development or ground color (Table 6). On average, treatments significantly improved return bloom (*P* = 0.0073) (Table 7). Flower removal gave a significantly better return bloom than cluster removal treatments (*P* = 0.0226) and only flower removal treatments gave significantly higher return bloom compared to the control.

'CRIPPS' RED' APPLES. The number of fruitlets removed during commercial hand thinning decreased linearly with an increase in cluster thinning intensity (Table 8). This resulted in 27% fewer fruitlets needing to be thinned in the 75% cluster removal treatment compared to the control. None of the flower thinning treatments differed significantly from the control. The percentage of clusters setting zero fruit showed a quadratic response to flower thinning where the 50% flower thinning treatment lowered the percentage of clusters setting zero fruit compared the 25% and 75% thinning (*P* = 0.0338) (Table 9). However, none of the treatments differed significantly in the percentage of clusters that set zero fruit. On average, all treatments significantly increased the percentage of clusters setting one fruit compared to the control (*P* = 0.0481). However, 25% cluster and flower thinning did not differ significantly from the control. Both cluster and flower removal treatments showed a linear increase in the percentage of clusters setting one fruit with increased thinning intensity (*P* = 0.0281 and *P* = 0.0131, respectively). The cluster removal treatments caused a linear increase in the percentage of clusters that set two fruit with increasing thinning intensity (*P* = 0.0203). The percentage of clusters setting three fruit was significantly increased by the 75% flower removal treatments, and the flower removal treatments caused a linear increase in the percentage of clusters setting three fruit with increased thinning intensity (*P* = 0.0004). The percentage of clusters setting four fruit increased linearly with increased cluster and flower removal intensity (*P* = 0.0369 and *P* = 0.0701, respectively). The flower removal treatments generally increased the percentage of clusters setting six fruit compared to the cluster removal treatments (*P* = 0.0377) but the percentage of clusters that set six fruit was ≤3% for all treatments. No differences were found in the percentage clusters setting five or seven fruitlets. The 75% cluster and flower removal treatments resulted in the highest fruit set per cluster with an average set of 3.3 fruit per cluster (Table 9). Increasing linear trends were found in the average fruit set per cluster with increasing cluster and flower removal intensity (*P* = 0.0025, and *P* = 0.0011, respectively) (Table 9).

Yield efficiency was not significantly affected at the first harvest date, but an almost significant decreasing linear trend was seen with increasing cluster removal intensity (*P* = 0.0567) (Table 10). At the second harvest date, yield efficiency for all treatments was on average lowered compared to the control (*P* = 0.0315), and the 75% cluster removal treatment reduced yield efficiency by 80% compared to the control (Table 10). A linear reduction in yield efficiency at the second harvest date occurred with increasing cluster removal intensity (*P* = 0.0002). Total yield efficiency was reduced by 28% for the 75% cluster removal treatment, and by 18% for the 75%

flower removal treatment compared to the control (Table 10). These two treatments differed significantly from the control. Cluster removal treatments decreased total yield efficiency linearly with increasing removal intensity (*P* = 0.0002). An increase in average fruit weight was found with increased flower removal intensity (*P* = 0.0112) (Table 11). This trend was also reflected in the average fruit length (*P* = 0.0574) and diameter (*P* = 0.0501) (Table 11). On average, thinning treatments increased the average fruit firmness compared to the control (*P* = 0.0018) (Table 11). The cluster thinning resulted in significantly softer fruit than flower thinning (*P* <.0001). Fruit firmness showed an increasing linear trend with increased cluster thinning intensity (*P* = 0.0501). Fruit of the 50% and 75% flower thinning treatments were significantly firmer than control fruit and also compared to fruit of the 25% flower thinning treatment, thus giving rise to thinning quadratic response to thinning intensity (*P* = 0.0036).

On average, all treatments reduced the number of fully developed seeds (*P* = 0.0041) and aborted seeds (*P* = 0.0398) per fruit compared to the control (Table 12). On average, all treatments also resulted in a higher percentage of red fruit compared to the control (*P* = 0.0136) (Table 12). Cluster removal treatments on average had a lower percentage well colored fruit than the flower removal treatments (*P* = 0.0270) (Table 12). Color development was less at 50% compared to 75% flower removal, resulting in a quadratic trend (*P* = 0.0024) (Table 12). The ground color was on average significantly yellower for fruit from cluster removal treatments compared to flower removal treatments (*P* = 0.0460) (Table 12). Quadratic responses were identified for both cluster and flower removal (Table 12). Fruit from the 25% cluster removal treatment were yellower than fruit of the 50% and 75% cluster removal treatments (*P* = 0.0035). In the case of flower removal, fruit were yellower at 50% compared to 25% and 75% flower removal (*P* = 0.0001). The percentage return bloom was not significantly influenced by any treatments, although a trend of a linear increase in return bloom was observed with the cluster removals (*P* = 0.0609) (Table 13).

Discussion

In 'Forelle', 25% cluster removal required more thinning than the 50% and 75% (*P* = 0.0448), but no trend was found where only the flowers were removed from the clusters (Table 2). An increase in the percentage 'Forelle' clusters setting zero fruit was found with all thinning treatments compared to the control (*P* = 0.0629) (Table 3). Removing clusters lowered the percentage of remaining clusters setting zero fruit compared to flower removal; thus removing whole clusters caused fewer clusters failing to set any fruit (*P* = 0.0062) (Table 3). A similar trend was found for cluster and flower removal where the 50% treatment resulted in a greater percentage of remaining clusters to set zero fruit than did the 25% and the 75% removal treatments (*P* = 0.0518 and *P* = 0.0116, respectively) (Table 3). Most trees set one or two fruit per cluster, as is also reflected in the average fruit set in a cluster of just less than two. The cluster thinning, however, resulted in significantly more clusters setting four fruit than the flower thinning treatments, although actual increases were small (*P* = 0.0225). As mentioned before, the average fruit set per cluster was around two for 'Forelle', and a trend was seen that removing clusters increased the average fruit set per remaining cluster compared to flower removal, although the real increases was negligible (*P* = 0.0820) (Table 3).

In the case of 'Cripps' Red', the hand thinning requirement was linearly reduced the more intense the cluster thinning (*P* = 0.0022), but no effect was found with flower thinning as was also the case in 'Forelle' (Table 8). The 'Cripps' Red' thinning requirement was not reduced overall compared to the control as was also the case in 'Forelle' (Table 8). In 'Cripps' Red' set was more than in 'Forelle', and the 50% flower thinning treatment gave the lowest percentage clusters with zero fruit (*P* = 0.0338) (Table 9). The more intense the thinning (75% cluster and 50% and 75% flower removal), the more clusters set single fruit (Table 9). A linear increase in clusters setting two fruit was found with increasing cluster removal while a linear decrease in clusters setting three fruit was found with flower removal (Table 9). High set per cluster (six) occurred more following flower removal than whole cluster removal although actual increase was small (*P* = 0.0377) (Table 9).

Fruit set is expected to decrease with more severe thinning when calculated as percentage of the original cluster number (Hehnen et al., 2012; Tustin et al., 2012). Fruit set is positively influenced by inflorescence quality and particularly by the number of leaves and leaf surface area in an inflorescence (Lauri et al., 1999; Lauri et al 1996). In our two trials, fruit set was reduced only by cluster removal and not by flower removal. Therefore it appears that leaving the foliage and only removing flowers increased the ability of the remaining, intact inflorescences to set fruit. Fruit set is linked to the sink strength of flowers, the photosynthetic ability of the leaves in supplying assimilated to the flowers/fruitlets, and to increased light penetration which is advantageous for fruit set (Lauri et al., 2004; Lauri et al., 1996; McArtney et al., 1996). In ASE trials on apples, set was correlated to branch floral density, whereby a reduction of floral bud density lowered the number of clusters failing to set fruit and increased the fruit set in remaining clusters to two or more fruit (Breen et al., 2014; Breen et al., 2015; Tustin et al., 2012). This response is a result of increased carbohydrate availability early in the season to the remaining buds (Breen et al., 2015). We did observe this trend in 'Forelle' (*P* = 0.0062) in the number of clusters that failed to set, but strangely in ‘Forelle’ we found fewer clusters setting zero fruit when whole clusters were removed than when only the flowers were removed. In the case of ’Cripps’ Red’, the response was also unexpected considering the usual response to ASE as no treatment significantly lowered the percentage of clusters setting zero fruit (Tustin et al., 2012). Breen et al, (2015) found minor differences in the number of fruit set within buds of apples between ASE and flower removal treatments which was contrary to expectation. We, however, in contrast to ASE, did not select the higher quality inflorescences to remain unthinned and simulated unselective thinning as would be the case with machine thinning.

Floral density was used as the measurement unit to evaluate the required number of inflorescences left on trees after ASE, and measuring this in our trial after treatment application would have further enabled comparisons (Breen et al., 2014; van Hooijdonk et al., 2014). Disparities with ASE work could also be due to differences in tree architecture, as apple trees in the areas of Australia and New Zealand where the ASE research was carried out are more spurred-up than the trees in South Africa, which tend to produce fruits on short shoots rather than spurs (W.J. Steyn, personal communication). This would have been the case more so in the less spurred-up ‘Cripps’ Red’ orchard than in the ‘Forelle’ orchard. Flower density and quality is lower with vigorous rootstocks, and the rootstocks used in our trials were both vigorous, viz., BP1 for ’Forelle’ and M793 for ’Cripps’ Red’ (North et al., 2012; Voigt, 2014; Wünsche and Ferguson, 2005). Trees in Australia and New Zealand are grown on much more dwarfing M9 rootstock (Breen et al., 2015). In the 25% cluster and flower removal treatments on ‘Cripps’ Red’, fewer than 20% of clusters set more than two fruit. As only clusters where more than two fruit set were hand thinned, the hand thinning requirement was very low. Another possible reason for the results deviating from the expected could be due to inconsistent treatment application where the thinning instructions were not followed closely. In some cases, the number of clusters setting fruit was higher than the number of inflorescences that was supposed to have been left on the branch which was seen more in the 75% removal treatments, indicating that the thinning was inconsistent (data not presented). However, one has to caution that the set data was recorded on two tagged scaffold branches in the lower tree canopy, while the thinning was done throughout the whole tree canopy. In addition, we do not know how many additional clusters opened after thinning. Thinning was conducted during full bloom, and due to insufficient winter chilling and delayed foliation, more, but weaker cluster might have opened later during the bloom window (Theron, 2013). It was easier to apply treatments to the ‘Forelle’ trees, which are trained to a Palmette system, compared to the more complex central leader ‘Cripps’ Red’ trees. We should have counted the number of clusters left after applying thinning treatments to have a more accurate indication of the severity of thinning.

On average, all treatments tended to reduce yield efficiency in 'Forelle' and 'Cripps' Red' compared to the control, and more severe cluster removal led to lower yield efficiencies in both trials. A linear reductions in yield due to more severe thinning is expected (Kon et al., 2013). In 'Forelle', the 75% cluster removal excessively reduced yield, which is not the aim of thinning. This indicates that one should aim for a less severe thinning intensity when using mechanical thinning. The discrepancy between fruit set and yield data could be due to the fact that yield was determined on the whole tree while set was determined only on two lower canopy scaffold branches.

Effective thinning should result in improved fruit size and quality and is favorable if the balance between yield and fruit quality can be optimized (Link, 2000). Generally, 'Forelle' fruit size (weight and diameter) was increased compared to the control, and a trend was seen where the removal of 50% of clusters reduced all fruit size parameters relative to the 25% and 75% removal (P = 0.0131, P = 0.0645 and P = 0.0243, respectively) (Table 5). In 'Cripps' Red', there was no significant increase in fruit size by treatments, but linear trends in fruit size improvement were seen for all fruit size parameters (P = 0.0112, P = 0.0574 and P = 0.0501, respectively) (Table 11). These trends are expected in the light of the yield efficiencies found as lower crop loads result in increased fruit size for pears (Webster, 2002b), and apples (Greene and Costa, 2013). A higher number of 'Forelle' clusters failed to set fruit, which could have resulted in the increase in fruit size due to bigger leaf area and available assimilates per fruit (McArtney et al., 1996). The increase in fruit size in 'Cripps' Red' was linear with increased flower thinning severity, also indicating a response to improved leaf to fruit ratio (Dennis, 2000). Differences in fruit firmness were absent in 'Forelle' and small and of no horticultural significance in 'Cripps' Red'. The differences in developed and aborted seed content in 'Forelle' fruit were small and again were of no horticultural significance (Table 6). In 'Cripps' Red', the number of fully developed and aborted seeds per fruit was significantly reduced by treatments compared to the control (P = 0.0041 and P = 0.0398, respectively), but again these differences were small and of no horticultural significance (Table 12).

Generally, one would have expected an improvement in red color with a reduction in yield provided vegetative growth was not stimulated (Sinatsch et al., 2010). No effect was found in 'Forelle' but in 'Cripps' Red' the percentage of fruit with 60% color development was significantly higher for thinning treatments compared to the control (P = 0.0136) (Table 12). Cluster removal led to fewer fruit developing enough red color than did flower removal treatments (P = 0.0270) indicating the importance of leaves and carbohydrates in red color development (Link, 2000). A trend was found where the 50% flower removal treatment lowered the red color development whereas the 75% and 25% flower removal treatments increased the color development significantly

(*P* = 0.0024, respectively) (Table 12). Color development in apples is a function of cool temperatures and high light (Saure, 1990). This effects on color development could have been due to stimulated vegetative growth caused by the removal of 50% of flowers compared to 25% removal, resulting in less light penetration into the tree canopy and onto fruit; however, vegetative growth was not measured (Lauri, et al., 2004). The 75% flower removal probably improved leaf to fruit ratio (Palmer et al., 1997). Earlier onset of anthocyanin synthesis due to advanced maturation as seen in ground color development could have contributed to the color effects seen (Steyn et al., 2005; Wünsche et al., 2000).

Return bloom in 'Forelle' showed that the thinning and therefore reduction in yield did improve return bloom (*P* = 0.0073) (Table 7). The improvement in return bloom is usually found when blossom or fruitlet thinning is done early, due to the early removal of flower induction inhibiting hormones such as gibberellins (Tromp, 2000). Flower removal improved return bloom more than cluster removal in 'Forelle' (*P* = 0.0226) (Table 7), and this shows that the higher ratio of leaves to fruit present during the previous summer improved flower induction and led to improved return bloom (Hoad, 1984). Return bloom data for 'Cripps' Red' did not show the same response as return bloom was not significantly affected. However there was an indication that the heavier cluster removal treatments resulted in increases in return bloom (*P* = 0.0609).

Conclusion

The level of thinning that gave the best results with acceptable yields, was generally the removal of up to 50% of flowers or clusters. The best return bloom in 'Forelle' was also obtained with 50% flower removal. The removal of whole clusters, including leaves and bourse shoots, reduced return bloom in 'Forelle' compared to when only flowers were removed from the clusters. This indicated that a level of between 25% and 50% flower removal should be aimed for when mechanically thinning, and that knocking off spurs and clusters completely should be avoided. For 'Cripps' Red', 75% thinning was too severe and over thinned trees. As with 'Forelle', the 50% removal was the best as no significant loss in yield or fruit quality occurred. Return bloom was not significantly affected in 'Cripps' Red'. Cluster removal will probably cause more long term damage than flower removal as possible bearing positions are removed. Therefore the same recommendation is made for mechanical thinning of 'Cripps' Red' as 'Forelle' with the aim of removing up to 50% of flowers.

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Table 1. Orchard details of plant material, age, rootstock, spacing, previous yield, phenological stages and dates of actions performed for cluster and flower removal trials (2014/2015).

	Oak Valley	Eikenhof
Cultivar	'Forelle'	'Cripps' Red'
Year Planted	1997	1999
Rootstock	BP1	M793
Spacing	4.0 m x 1.2 m	4.0 m x 1.5 m
Trees per Ha	2083	1667
Training System	Palmette	Central Leader
Cross cultivar	'Abate Fetel'	'Cripps' Pink'
Yield 2010/2011 $t{\cdot}ha^{-1}$	55	54
Yield 2011/2012 $t{\cdot}ha^{-1}$	43	94
Yield 2012/2013 $t{\cdot}ha^{-1}$	50	93
Yield 2013/2014 $t{\cdot}ha^{-1}$	58	107
Full Bloom	12 September 2014	30 September 2014
Flower thinning	15 September 2014	30 September 2014
Hand thinned	17 October 2014	11 November 2014
Harvest Date/s	25 February 2015	First : 4 May 2015
		Second : 12 May 2015
Return Bloom	16 September 2015	6 October 2015

Table 2. Effect of thinning on total weight and number of fruitlets thinned of 'Forelle' pears at Oak Valley, Elgin (2014/2015).

Treatments	Average number of fruitlets hand thinned per tree	
Control (hand thinned)	37	ab
25% Cluster Removal	49	a
50% Cluster Removal	28	b
75% Cluster Removal	28	b
25% Flower Removal	39	ab
50% Flower Removal	29	b
75% Flower Removal	32	b
Significance Level	*0.0065*	
Control vs Treatment	*0.5208*	
Cluster vs Flower Removal	*0.7538*	
Cluster Linear	*0.0007*	
Cluster Quadratic	*0.0448*	
Flower Linear	*0.2655*	
Flower Quadratic	*0.2267*	
Treatment LSD	*12*	

Table 3. Effect of thinning treatments on the percentage of fruit set in clusters from 0 to 5 fruit per cluster and average number of fruit per cluster on tagged branches of 'Forelle' pears at Oak Valley, Elgin (2014/2015).

Treatments	Percentage of clusters setting the specified number of fruit per clusters [z]						Average number of fruit set per cluster on tagged branches [y]
	0 fruitlets	1 fruitlet	2 fruitlets	3 fruitlets	4 fruitlets	5 fruitlets	
Control (hand thinned)	28.3 cd	32.5 ns	26.2 ns	9.9 ns	2.6 ns	0.5 ns	1.9 ns
25% Cluster Removal	31.7 bcd	29.3	22.2	11.2	4.9	0.8	2.0
50% Cluster Removal	40.5 bc	17.8	28.2	10.1	3.5	0.0	1.9
75% Cluster Removal	25.6 d	31.9	26.5	12.4	2.9	0.8	1.9
25% Flower Removal	44.1 ab	29.3	17.4	7.0	1.8	0.4	1.7
50% Flower Removal	54.4 a	21.5	15.0	8.1	1.0	0.0	1.8
75% Flower Removal	33.4 bcd	25.4	29.6	11.5	0.0	0.0	1.8
Significance Level	*0.0016*	*0.0806*	*0.0853*	*0.7957*	*0.3072*	*0.6941*	*0.6082*
Control vs Treatment	*0.0629*	*0.1191*	*0.4728*	*0.9631*	*0.8646*	*0.7771*	*0.9246*
Cluster vs Flower Removal	*0.0062*	*0.7842*	*0.1310*	*0.2896*	*0.0225*	*0.2766*	*0.0820*
Cluster Linear	*0.3789*	*0.6401*	*0.4431*	*0.7579*	*0.3307*	*0.9674*	*0.5243*
Cluster Quadratic	*0.0518*	*0.0095*	*0.4254*	*0.6025*	*0.8233*	*0.1553*	*0.8801*
Flower Linear	*0.1250*	*0.4791*	*0.0342*	*0.2401*	*0.3916*	*0.5537*	*0.5175*
Flower Quadratic	*0.0116*	*0.2214*	*0.0838*	*0.7213*	*0.9292*	*0.7320*	*0.4732*
Treatment LSD	*13.8*	-	-	-	-	-	-

[z] (Number of clusters left after thinning – Number of clusters setting specified number of fruit per cluster after physiological drop) / Number of clusters after thinning *100

[y] Number of fruit set after natural fruit drop / number of clusters setting after thinning and natural fruit drop

ns = Not significant at $P < 0.05$

Table 4. Effect of thinning on yield efficiency and estimated yield of 'Forelle' pears at Oak Valley, Elgin (2014/2015).

Treatments	Yield efficiency per tree ($kg \cdot cm^{-2}$)		Estimated yield ($ton \cdot ha^{-1}$)
Control (hand thinned)	0.58	a	72
25% Cluster Removal	0.53	ab	66
50% Cluster Removal	0.50	ab	62
75% Cluster Removal	0.33	c	43
25% Flower Removal	0.47	ab	59
50% Flower Removal	0.41	bc	58
75% Flower Removal	0.51	ab	58
Significance Level	*0.0039*		
Control vs Treatment	*0.0118*		
Cluster vs Flower Removal	*0.7190*		
Cluster Linear	*0.0018*		
Cluster Quadratic	*0.2117*		
Flower Linear	*0.5211*		
Flower Quadratic	*0.1372*		
Treatment LSD	*0.13*		

Table 5. Effect of thinning on average fruit size, length, diameter and firmness of 'Forelle' pears at Oak Valley, Elgin (2014/2015).

Treatments	Average fruit weight (g)		Average fruit length (mm)		Average fruit diameter (mm)		Average fruit firmness (kg)	
Control (hand thinned)	138.3	c	83.4	ns	61.6	c	5.9	ns
25% Cluster Removal	153.1	ab	86.5		63.5	b	5.9	
50% Cluster Removal	145.3	bc	83.3		62.7	bc	5.9	
75% Cluster Removal	159.6	a	84.2		65.0	a	6.0	
25% Flower Removal	147.5	bc	83.8		62.7	bc	5.9	
50% Flower Removal	150.4	ab	83.8		63.4	b	5.9	
75% Flower Removal	149.9	ab	84.7		63.2	b	5.9	
Significance Level	*0.0047*		*0.1548*		*0.0030*		*0.5909*	
Control vs Treatment	*0.0014*		*0.3065*		*0.0020*		*0.4889*	
Cluster vs Flower Removal	*0.2345*		*0.3999*		*0.1606*		*0.7433*	
Cluster Linear	*0.1954*		*0.0589*		*0.0458*		*0.1226*	
Cluster Quadratic	*0.0131*		*0.0642*		*0.0243*		*0.7120*	
Flower Linear	*0.6296*		*0.4594*		*0.5471*		*0.3848*	
Flower Quadratic	*0.6842*		*0.6659*		*0.5050*		*0.4040*	
Treatment LSD	*9.9*		*-*		*1.5*		*-*	

ns = Not significant at $P < 0.05$

Table 6. Effect of thinning on average number of fully developed, and aborted seeds per fruit and blush development and ground color of 'Forelle' pears at Oak Valley, Elgin (2014/2015).

Treatments	Average number fully developed seeds per fruit	Average number aborted seeds per fruit	Average blush development color [z]	Average ground color [y]
Control (hand thinned)	1.2 ns	9.4 ns	3.5 ns	2.8 ns
25% Cluster Removal	1.1	9.4	3.3	2.6
50% Cluster Removal	0.9	9.3	3.2	2.6
75% Cluster Removal	0.7	8.8	2.9	2.7
25% Flower Removal	0.7	9.2	3.4	2.6
50% Flower Removal	0.6	9.0	3.3	2.6
75% Flower Removal	0.5	8.9	3.2	2.6
Significance Level	*0.0662*	*0.1110*	*0.5751*	*0.6769*
Control vs Treatment	*0.0501*	*0.1230*	*0.2596*	*0.0857*
Cluster vs Flower Removal	*0.6876*	*0.5048*	*0.3492*	*0.7256*
Cluster Linear	*0.0180*	*0.0196*	*0.1917*	*0.5351*
Cluster Quadratic	*0.4356*	*0.4481*	*0.6433*	*0.9716*
Flower Linear	*0.1731*	*0.2191*	*0.4298*	*0.5290*
Flower Quadratic	*0.4851*	*0.7125*	*0.9435*	*0.8194*
Treatment LSD	-	-	-	-

[z] Blush development assessed using the Unifruco color chart P25 on a scale from 1 to 6 (1 = most blush, 6 = least blush)

[y] Ground color analyzed from Unifruco apple and pear chart on a scale from 0.5 to 5 (0.5 = most green, 5 = yellow)

ns = Not significant at $P < 0.05$

Table 7. Effect of thinning on percentage return bloom on tagged branches of 'Forelle' pears at Oak Valley, Elgin (2014/2015).

Treatments	Percentage return bloom on tagged branches
Control (hand thinned)	22.3 c
25% Cluster Removal	27.2 bc
50% Cluster Removal	27.6 bc
75% Cluster Removal	29.3 abc
25% Flower Removal	31.7 ab
50% Flower Removal	37.0 a
75% Flower Removal	31.3 ab
Significance Level	*0.0230*
Control vs Treatment	*0.0073*
Cluster vs Flower Removal	*0.0226*
Cluster Linear	*0.6029*
Cluster Quadratic	*0.8473*
Flower Linear	*0.9146*
Flower Quadratic	*0.1134*
Treatment LSD	*7.9*

Table 8. Effect of thinning on average weight and number of fruitlets thinned on 'Cripps' Red' apples at Eikenhof, Elgin (2014/2015).

Treatments	Average number of fruitlets hand thinned per tree
Control (hand thinned)	496 ab
25% Cluster Removal	535 a
50% Cluster Removal	432 abc
75% Cluster Removal	362 c
25% Flower Removal	399 bc
50% Flower Removal	460 abc
75% Flower Removal	392 bc
Significance Level	*0.0266*
Control vs Treatment	*0.1144*
Cluster vs Flower Removal	*0.4014*
Cluster Linear	*0.0022*
Cluster Quadratic	*0.7303*
Flower Linear	*0.8923*
Flower Quadratic	*0.1731*
Treatment LSD	*108*

Table 9. Effect of thinning treatments on the percentage of fruit set in clusters from 0 to 5 fruit per cluster and average number of fruit per cluster on tagged branches of 'Cripps' Red' apples at Eikenhof, Elgin (2014/2015).

Treatments	Percentage of clusters setting the specified number of fruit per clusters [z]								Average number of fruit set per cluster on tagged branches [y]
	0 fruitlets	1 fruitlet	2 fruitlets	3 fruitlets	4 fruitlets	5 fruitlets	6 fruitlets	7 fruitlets	
Control (hand thinned)	25.3 ns	25.9 d	24.0 ns	11.2 b	10.8 ns	1.9 ns	1.0 ns	0.0 ns	1.7 b
25% Cluster Removal	31.0	26.8 cd	21.7	13.0 b	4.6	2.8	0.0	0.2	1.5 b
50% Cluster Removal	18.1	31.4 bdc	23.1	15.4 b	10.2	3.2	1.8	0.6	2.3 ab
75% Cluster Removal	25.3	42.6 ab	33.0	16.8 b	12.7	3.1	0.0	0.0	3.3 a
25% Flower Removal	30.6	30.7 bcd	19.9	9.0 b	6.2	2.0	1.7	0.0	1.4 b
50% Flower Removal	13.5	40.1 abc	23.9	17.7 b	12.2	4.6	3.0	0.7	2.4 ab
75% Flower Removal	29.3	48.8 a	26.9	28.8 a	13.2	2.1	2.7	0.0	3.3 a
Significance Level	*0.3330*	*0.0128*	*0.1523*	*0.0136*	*0.1803*	*0.8347*	*0.2873*	*0.6469*	*0.0018*
Control vs Treatment	*0.9156*	*0.0481*	*0.8328*	*0.1623*	*0.7580*	*0.4917*	*0.6343*	*0.5213*	*0.1046*
Cluster vs Flower Removal	*0.9407*	*0.1294*	*0.3784*	*0.2533*	*0.5403*	*0.8936*	*0.0377*	*0.9126*	*0.8866*
Cluster Linear	*0.5116*	*0.0281*	*0.0203*	*0.4620*	*0.0369*	*0.8446*	*1.0000*	*0.6418*	*0.0025*
Cluster Quadratic	*0.1855*	*0.5938*	*0.2959*	*0.9079*	*0.6279*	*0.8862*	*0.1653*	*0.3183*	*0.8365*
Flower Linear	*0.8789*	*0.0131*	*0.1433*	*0.0004*	*0.0701*	*0.9332*	*0.5023*	*1.0000*	*0.0011*
Flower Quadratic	*0.0338*	*0.9594*	*0.9024*	*0.7911*	*0.4449*	*0.1467*	*0.5337*	*0.1169*	*0.8752*
Treatment LSD	-	*14.1*	-	*10.5*	-	-	-	-	*1.1*

[z] (Number of clusters left after thinning – Number of clusters setting specified number of fruit per cluster after physiological drop) / Number of clusters after thinning *100

[y] Number of fruit set after natural fruit drop / number of clusters setting after thinning and natural fruit drop

ns = Not significant at $P < 0.05$

Table 10. Effect of thinning on average yield efficiency per harvest, total yield efficiency and estimated yield of 'Cripps' Red' apples at Eikenhof, Elgin (2014/2015).

Treatments	Average yield efficiency first harvest per tree		Average yield efficiency second harvest per tree		Yield efficiency per tree	Estimated yield
	($kg{\cdot}cm^{-2}$)	% of total harvest	($kg{\cdot}cm^{-2}$)	% of total harvest	($kg{\cdot}cm^{-2}$)	($ton{\cdot}ha^{-1}$)
Control (hand thinned)	0.47 ns	(78)	0.13 a	(22)	0.60 a	100
25% Cluster Removal	0.48	(79)	0.13 a	(21)	0.61 a	103
50% Cluster Removal	0.46	(84)	0.09 a	(16)	0.55 ab	85
75% Cluster Removal	0.40	(93)	0.03 b	(7)	0.43 c	66
25% Flower Removal	0.44	(83)	0.09 a	(17)	0.53 ab	80
50% Flower Removal	0.48	(83)	0.10 a	(17)	0.58 ab	94
75% Flower Removal	0.40	(82)	0.09 a	(18)	0.49 bc	78
Significance Level	*0.2517*		*0.0037*		*0.0039*	
Control vs Treatment	*0.4690*		*0.0315*		*0.0641*	
Cluster vs Flower Removal	*0.8942*		*0.5036*		*0.8103*	
Cluster Linear	*0.0567*		*0.0002*		*0.0002*	
Cluster Quadratic	*0.5596*		*0.7017*		*0.4490*	
Flower Linear	*0.3280*		*0.9825*		*0.3629*	
Flower Quadratic	*0.1244*		*0.6696*		*0.0942*	
Treatment LSD	-		*0.05*		*0.13*	

ns = Not significant at $P < 0.05$

Table 11. Effect of thinning on average fruit weight, length, diameter and firmness on 'Cripps' Red' apples at Eikenhof, Elgin (2014/2015).

Treatments	Average fruit weight (g)		Average fruit length (mm)		Average fruit diameter (mm)		Average fruit firmness (kg)	
Control (hand thinned)	127.2	ns	57.4	ns	57.4	ns	9.2	bc
25% Cluster Removal	125.4		56.6		57.4		9.1	c
50% Cluster Removal	131.1		57.6		57.9		9.2	bc
75% Cluster Removal	128.1		57.0		57.6		9.3	bc
25% Flower Removal	126.9		56.8		57.5		9.3	b
50% Flower Removal	127.9		57.0		57.6		9.8	a
75% Flower Removal	136.4		58.1		58.1		9.8	a
Significance Level	*0.0681*		*0.3298*		*0.1915*		*<.0001*	
Control vs Treatment	*0.4446*		*0.7028*		*0.2982*		*0.0018*	
Cluster vs Flower Removal	*0.2864*		*0.5405*		*0.5762*		*<.0001*	
Cluster Linear	*0.4569*		*0.5955*		*0.4565*		*0.0501*	
Cluster Quadratic	*0.1679*		*0.1873*		*0.1553*		*0.9158*	
Flower Linear	*0.0112*		*0.0574*		*0.0501*		*<.0001*	
Flower Quadratic	*0.2341*		*0.3980*		*0.3209*		*0.0036*	
Treatment LSD	*9.9*		*-*		*-*		*0.2*	

ns = Not significant at $P < 0.05$

Table 12. Effect of thinning on average number of fully developed and aborted seed content and color development and ground color of 'Cripps' Red' apples at Eikenhof, Elgin (2014/2015).

Treatments	Average number fully developed seeds per fruit		Average number aborted seeds per fruit		Average color development [z]		Average ground color [y]	
Control (hand thinned)	5.3	ns	0.4	ns	55.7	d	3.6	cd
25% Cluster Removal	5.0		0.3		56.3	cd	3.6	cd
50% Cluster Removal	4.9		0.4		67.3	bc	3.9	a
75% Cluster Removal	4.9		0.3		65.7	bcd	3.8	ab
25% Flower Removal	5.0		0.2		69.3	ab	3.7	bc
50% Flower Removal	4.9		0.3		63.0	bcd	3.5	d
75% Flower Removal	4.9		0.3		79.7	a	3.8	ab
Significance Level	*0.1329*		*0.1845*		*0.0019*		*<.0001*	
Control vs Treatment	*0.0041*		*0.0398*		*0.0136*		*0.0862*	
Cluster vs Flower Removal	*0.5857*		*0.3622*		*0.0270*		*0.0460*	
Cluster Linear	*0.6650*		*0.8741*		*0.1108*		*0.0095*	
Cluster Quadratic	*0.7503*		*0.1103*		*0.2094*		*0.0035*	
Flower Linear	*0.4436*		*0.2702*		*0.0783*		*0.1840*	
Flower Quadratic	*0.4742*		*0.8788*		*0.0024*		*0.0001*	
Treatment LSD	-		-		*11.5*		*0.2*	

[z] Color development and quantity determined as either enough export color quantity of 60% or not.

[y] Ground color analyzed from Unifruco apple and pear chart on a scale from 0.5 to 5 (0.5 = most green, 5 = yellow)

ns = Not significant at $P < 0.05$

Table 13. Effect of thinning on percentage return bloom on tagged branches of 'Cripps' Red' apples at Eikenhof, Elgin (2014/2015).

Treatments	Percentage return bloom on tagged branches
Control (hand thinned)	48.9 ns
25% Cluster Removal	35.6
50% Cluster Removal	46.8
75% Cluster Removal	45.2
25% Flower Removal	40.6
50% Flower Removal	48.8
75% Flower Removal	49.0
Significance Level	*0.0736*
Control vs Treatment	*0.2414*
Cluster vs Flower Removal	*0.2207*
Cluster Linear	*0.0609*
Cluster Quadratic	*0.1496*
Flower Linear	*0.1028*
Flower Quadratic	*0.3610*
Treatment LSD	-

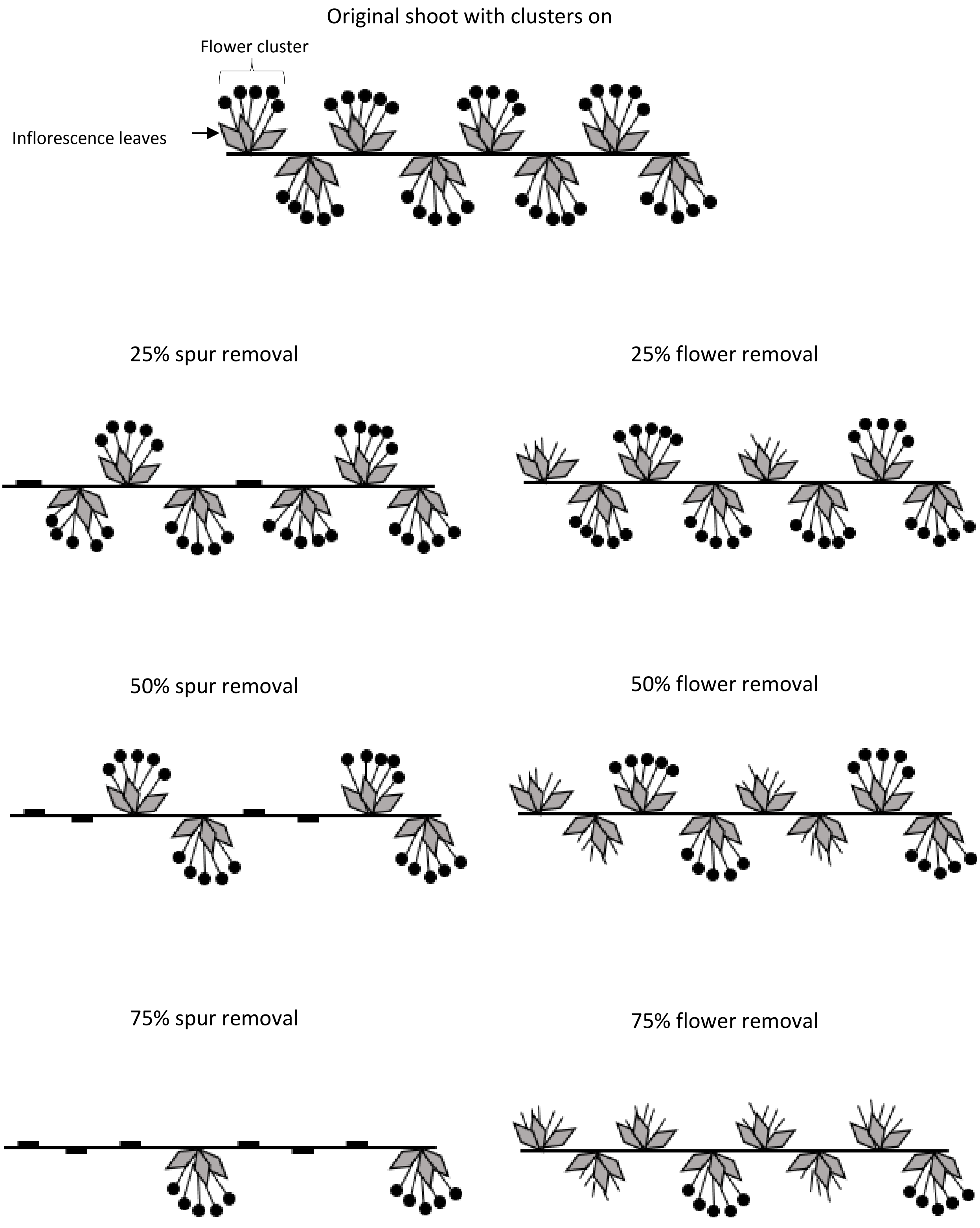

Fig. 1. Scheme of 25%, 50% and 75% spur and hand removal treatments.

General Conclusion

Pome fruit grown under optimal conditions produce more flowers and set more fruit than is needed for an economic harvest. Thinning of fruits or flowers is done to adjust crop loads to levels which improve fruit quality, especially fruit size and increase return bloom without substantial losses in yields. Control of return bloom is advantageous as alternate bearing patterns can be managed. Currently, thinning is done by hand or chemically, or both. Hand thinning requires expensive labor input, which adds substantially to production costs. In addition, labor is scarce and attaining well trained workers can be problematic. However, hand thinning is the only method that can be used when no other thinning options exist, and will ultimately be difficult to replace due to its efficacy and selective nature. Chemical thinning is associated with a different set of problems. Many products are taken off the market due to their negative effects on the environment. Efficacy of chemical thinners are extremely weather dependent, especially the conditions during application and the first three days after application. Thus there is a search for alternative methods of thinning that are environmentally friendly and effective but non-persistent. Mechanical thinning has been identified as a possible solution to these problems.

We obtained variable results using the Darwin 300™ string thinner on Forelle pears (Paper 1). The thinning efficacy was dependent on tractor and rotor speeds. The Darwin 300™ at a tractor speed of 5.2 $km \cdot h^{-1}$ and a rotation rate of 300 rpm consistently gave the best results with a reduced hand thinning requirement, acceptable yields, improved fruit quality, and only a slight negative effect on return bloom, although these effects were not always significant. Orchard training systems and orchard floor conditions were identified as critical factors in determining thinning efficacy, and will need much more attention in the future if tractor-driven mechanical thinning is to be improved. The Bloom Bandit™ hand-held thinning device showed promise as a mechanical bloom thinner of 'Forelle'. This device is used more selectively and adapts thinning needs to individual tree requirements; however, the extra time spent on thinning needs to be taken into consideration if this method of thinning is to be pursued. Using the device together with laborer platforms might prove beneficial. Thinning 'Forelle' with 6-benzyladenine (6-BA) at 100 $\mu l \cdot L^{-1}$ and 150 $\mu l \cdot L^{-1}$ in combination with 5 $\mu l \cdot L^{-1}$ napthaleneacetic acid (NAA) at 8-10 mm fruitlet diameter was effective. Fruit set was reduced without significantly reducing yield while improving fruit quality and return bloom. 1-Aminocyclopropane carboxylic acid (ACC) is an interesting new chemical thinner and effectively thinned 'Forelle' fruitlets, but the rate of 400 $\mu l \cdot L^{-1}$ was too high and over-thinned in our trial. No mechanical or chemical thinning treatment totally eliminated the need for follow-up hand thinning to correct crop loads and remove poorer quality fruit.

Mechanical thinning with the BAUM or Darwin 300™ on apples (Paper 2) proved to be more difficult than on ’Forelle’ pears. Unfortunately, no consistent reductions in fruit set and hand thinning requirement, or increased fruit size, quality or return bloom were obtained. This was probably due to the same reasons, but to a larger extent to those experienced with ‘Forelle’. Apple orchards in South Africa were not designed and trained with mechanization in mind and are therefore not well adapted to the use of the machines. Thinning efficacy depends on tractor speed and it is recommended that faster tractor speeds be used, but in South Africa this is not possible due to the poor orchard floor conditions. When used for the first time in orchards, machines, especially the BAUM, need to “make their path” in the tree canopies and the same angles of the machine arms need to be kept from season to season for the same orchards. Constantly changing the angles will give variable results in orchards. Therefore, orchards first need to be adapted to these machines. With the Darwin 300™ it is important to make sure that there is even contact with the spindles from the top to the bottom of the rotor with the vertical plane of the tree canopy. The rotor should also be kept as close as possible to the tree trunk, as failing to do so will lead to variable thinning efficacies within the canopy as was seen with our trials. The Bloom Bandit™ gave comparable results to chemical thinning on apples when applied for 2 min·tree^{-1}; i.e., reliable reductions in fruit set and hand thinning requirements with improved fruit quality were obtained. However, the Bloom Bandit™ is quite heavy and it can become tiring to use.

Further evaluation of mechanical thinning needs to be undertaken once more suitable orchards are available in South Africa to evaluate the long term feasibility of mechanical thinning on pome fruit. Trials should be conducted over a longer period and should give a more comprehensive and holistic answer for the use of mechanical thinning machines. In addition, mechanical thinning in combination with chemical thinning should also be considered.

Removing up to 50% of flowers did not always give the expected responses, but appears to be an ideal level of thinning for both ‘Forelle’ (Paper 1 and 3), and for ‘Cripps’ Red’ (Paper 3). Thinning flowers from clusters will be better than complete cluster removals. Flower thinning of ‘Forelle’ reduced hand thinning and set, although this reduction was not always enough, as some results were not significant. Yield was reduced to acceptable levels and resulted in increased fruit size. Return bloom was improved by 50% flower removal in the ‘Forelle’ trials. The earlier crop load adjustments and high ratio of leaves to fruit improved flower induction and resulted in good return bloom in the subsequent season. Whole cluster removal, including spur leaves and bourse shoots, reduced return bloom in ‘Forelle’ compared to when only flowers were removed from the clusters. In ‘Cripps’ Red’, 50% cluster removal did not reduce the hand thinning requirement, but resulted in acceptable yield without benefitting fruit size. The most severe thinning intensity of 75% over thinned as indicated by yield reduction without benefitting fruit size. Return bloom was not adversely affected by any of the treatments. The level of flower thinning that should be aimed for with mechanical thinning 'Forelle' should be between 25% and 50%, and for 'Cripps' Red' 50%. Spur and complete cluster removal should be avoided. We did not evaluate partial flower thinning in clusters and this should be part of future research.

To conclude, achieving all the aims of thinning remains challenging. Mechanical thinning could be used in the South African pome fruit industry where the aim should be to remove 50% of flowers. The Bloom Bandit™ needs to be further evaluated on a larger, semi-commercial scale to further develop recommendations for its use. Only under conditions where orchards are suited to the Darwin™ or BAUM should these machines be considered. Suitable orchards will be those where the orchard floor surface is clean and level, and the tree design is adapted to either machine. Adopting mechanical thinning in the future should start with establishing new orchards with mechanization in mind.